Ningaloo Collaboration Cluster: Adaptive Futures for Ningaloo

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Contents

1. SUMMARY OF MAJOR FINDINGS AND THEIR MANAGEMENT IMPLICATIONS

1.1 Objectives

1) To develop modelling tools to support sustainable multiple use management of the Ningaloo-Exmouth system as a whole, with particular focus on the cumulative effects of various human activities on the conservation of the ecological and social values and the sustainable development of the region.

2) To set up a Management Strategy Evaluation (MSE) for the Ningaloo-Exmouth region, aimed at assessing the consequences of different management options across different sectors and making clear the tradeoffs in their performance across a range of management objectives and uncertainties in resource dynamics.

3) To lead decision makers and local stakeholders through the initial steps of the MSE, improve understanding of adaptive management and provide guidelines to facilitate its long-term adoption.

1.2 Outcomes

Our research resulted in four main outcomes:

1) we developed an implementation of InVitro, a state-of-the-art full-system computer model, for the Ningaloo-Exmouth region to capture how both human and natural systems in that area work, including biophysical and ecological components, human activities and uses, economic sectors, possible future development and available management interventions.

2) We employed the concept of MSE to focus the overall research effort and to provide a link between researchers and stakeholders; this included demonstrating to decision makers and local stakeholders the potential of modelling as a decision tool, showcasing initial results, collecting and disseminating both local and scientific information and representing issues of local and management concern in the form of modelling scenarios. We believe this step has been crucial to address initial scepticism on model use and help foster trust and ownership of the modelling effort.

3) We implemented a number of additional, simpler modelling tools to educate non-modellers in model use, to train interested parties to using models, to showcase the MSE approach, to tune different modules of the InVitro model and to provide progressive results to other research projects and interested parties. This activity, together with the use of specifically designed questionnaires, also allowed us to obtain a better understanding of the stakeholder group, their values and beliefs, the existing network of interaction, which is crucial to dissemination of knowledge and information, as well as to collect feedback on our effort and the most appropriate way to communicate with the different industries, departments and the broader community.

4) We analysed a number of InVitro simulations specifically addressing stakeholders and management concerns. This gives a preliminary assessment of likely regional futures under alternative developmental paths and highlights what management options are available to steer the region development towards desired outcomes.

1.3 Non-technical summary

The ultimate aim of people engaged in environmental management research is to provide decision makers, state and local government employers, local stakeholders and regional visitors with knowledge of how the system works (understood both as research results *and* uncertainty) and to help them to use this knowledge in their policies, decisions, practices and daily actions.

In this project's framework, this meant:

1) to generate knowledge (what we know, how well we know it and what we do not know) about the current state of the Ningaloo-Exmouth system, its functioning and likely future pressures;

2) to use this knowledge to generate predictions of possible future regional development via the use of computer modelling, with the understanding that the reliability of such predictions depends both on what we know and what we do not know about the system;

3) to explain what conclusions can be drawn from this knowledge and predictions as well as how reliable these conclusions are;

4) to engage as broad an audience as possible, to make sure that information available among researchers, decision makers, the general public and practitioners is collected, accounted for and disseminated;

5) to highlight the role that each party *can* have in steering future regional development, in order to ensure that decisions are shared rather than imposed upon the region.

The last point is particularly important in the light of the most significant result from our computer modelling: very diverse futures are possible for the Ningaloo-Exmouth region 20 years from now and, fortunately, management interventions are available to steer (at least some components) towards desired directions; among these interventions, fishing regulations, housing plans, marketing and catering for specific tourists type and infrastructure development are likely to provide the largest impact, as discussed in Chapter 6.

In addition to general issues related to sustainability, economic development and quality of life, both decision makers and local communities have specific concerns for the future of the Ningaloo-Exmouth region. Among others, these include fishing and conservation zoning, returning the coastal strip from pastoral leases to State Government management, the listing of region as a World Heritage Area, different regimes of land release for development, the likely impact of construction of new boat launching facilities and bitumen roads as well as tradeoffs in development of multiple small tourist sites vs fewer larger ones. These concerns have guided the design of a number of scenarios for the full-system model InVitro, whose outputs provide indications of possible regional futures and, most important, what management “levers” are available.

We decided to address these issues within a MSE framework which differs from traditional MSE implementations. We have treated ‘building the model’ as the catalyst, rather than the final aim, of the process. In other words, extensive interactions in order to introduce, showcase, discuss and tune the model used within the MSE framework have represented both a requirement and an opportunity to ensure that the model is relevant to businesses, managers and communities and has sufficient trust to be considered for use in choosing among management options. While ‘building the model’ was initially perceived as the final goal of the modelling team, a goal which could be defined at project inception and implemented following the fixed plan, soon ‘building the model’ became an adaptive process both influenced by and influencing stakeholders interaction: the latter would determine the final model structure and the questions it needs to address.

So far, the MSE effort has focussed on three broad areas: stakeholders engagement (including eliciting strategies to test, and the interpretation and communication of results), development of a series of computer models and parameterisation and run of InVitro on the selected scenarios. These three areas are discussed in details in the following chapters.

Chapter 3 discusses the rationale for adoption of MSE approach, how it was implemented, what steps have been takes so far, where we are now and proposes options for ensuring its long-term adoption. We place particular emphasis in trying to map knowledge and uncertainty, by comparing what we knew at the beginning of the project to what we know now and propose what further steps should be taken to monitor what we do not know well and ensure that the knowledge base for decision making keeps growing.

Chapter 4 addresses a core issue in the project: its success depends on whether the models, their results and recommendations are taken up by stakeholders, which in turn depends on engaging them and addressing their concerns. While most parties were aware of this since project inception, what precisely this entailed for the development and acceptance of the ‘model’ (and how much its final success depends on it) has become clear only later on in the project. Despite the late start, by the end of the project, stakeholder engagement alone accounted for roughly 43% of the overall modelling team’s effort and resulted in a number of one-to-one meetings, workshops and seminars. We learnt a lot from this activity, including: a) that stakeholders have very different levels of knowledge and understanding of modelling, what it does and what it can provide, which affects their attitude towards its use in planning and decision making; b) that the network of interactions among stakeholders and among researchers can change as a result of one-to-one meetings, workshops and model use; c) that the style, language and attitude required to showcase models and models results differ considerably depending on the stakeholder types and expectations; d) that communities hold local knowledge that can greatly benefit model development and tuning; similarly, communities and stakeholders may formulate modelling questions not envisaged by modellers and project developers; and e) that the level of community reception depends crucially on the amount of effort *locally* invested – this is true especially when the scientists need to overcome the perception of being ‘outsiders’ to the community and to the problem. How we collected this information, what we did to address these problems and recommendation for future actions are discussed in Chapter 4.

Chapter 5 describes a number of smaller computer models designed to interact with stakeholders, introduce them to modelling, train them on specific skills and feed into InVitro development. Two single-system models focussed on fishery and tourism management, respectively, enabling us to liaise with these two important sectors, collect information, showcase progress and tune these components for their inclusion in InVitro. Two game-like toy-models were developed for educational purposes, to show stakeholders how even apparently (and deceptively) simple decision problems can benefit from modelling support. Finally, two simpler versions of the full-system models were developed to introduce and train stakeholders in using models to address multi-sector management questions. We believe this effort had a considerable positive impact on the project. First, by showing its use in addressing actual, local, everyday problems, it helped in changing the perception of modelling from being merely an abstract, academic activity to a useful source of information on a day-to-day level. This has been essential to build trust and acceptance in the overall MSE approach. Second, it has been pivotal in defining the modelling questions for the final InVitro simulations. Because of the latter, the outcome of the MSE would likely look quite different today, had a multi-model approach not been taken.

Finally, Chapter 6 focuses on the full-system scenario simulations. Our understanding of the Ningaloo-Exmouth system and the predictions around possible development have been obtained via InVitro, a full-system model, whose scientific and technological sophistication allows the simulation of biophysical and ecological processes via analytic methods at system-scale, down to the behaviour of individual agents (like animals or tourists) at the finest scale. Model outcomes, in the form of likely future impacts of specific management actions and development scenarios, are also provided at a wide range of spatial and temporal scales. Chapter 6 describes what scenarios were simulated, presents extensive multi-sector results, introduces to the model visualisation, highlights key uncertainties and guides the reader to interpreting the results.

1.4 Implications for management

The MSE framework is also useful in discussing the implications of different strategies, systems states and development scenarios for robust and sustainable management. As described in Chapter 3, the project has taken three steps into the first MSE iteration: i) learning, ii) evaluating initial planning strategies accounting for stakeholders concerns and iii) assessing their likely impact via computer modelling. Two more steps are needed to complete a first MSE iteration.

The first involves evaluating the trade-offs implied in the modelling results and provide feedback to people active in the system so that they can make decisions about what should be done in the real system. One of the key trade-offs identified in simulations to date are between use of the system and its ecological integrity. Under current management arrangements the cumulative effects of recreational fishing pressure is changing the relative composition and abundance of the fish stocks (which may be helped by changing management regulations) and leading to the degradation of habitat in high use areas. The biggest trade-off in the system however, is between the ecological health of the system and the social and economic objectives; the resident population is particularly vulnerable to issues associated with an aging population and some form of new development (or growth of existing sectors) is required to maintain balanced communities and the provision of services. However, if such growth occurs (it is not guaranteed as it is constrained by available housing and labour) there is not only increased pressure on housing and increased demand for utilities and increased waste handling requirements, but also potentially a significant impact on the local flora and fauna (e.g. potentially a 50% drop in local fish stocks). Targeted growth and modified management regulations can reduce impacts, but only if compliance is high and so the decisions must be “owned” by those with a direct interest in the system. The simulations discussed here (and the ReefTime tool available via the access point at http://www.ningaloo.org.au/www/en/NingalooResearchProgram/ResearchTools.html) provides a means for those decision makers to explore alternative futures.

Because this project was called not in response to a crisis but in an anticipatory approach, a number of options for interventions are available each with their own implications for sectors like fishing, tourism, environmental health and socio-economical development. These are discussed in Chapter 6. Feedback collected in this project (as well as in Chapman 2010, Dzidic et al. 2010, and Chapman 2011) recommends that this planning and implementation step is taken in consultation with local stakeholders to ensure that their voice is heard and that they feel ownership of any decisions. The perception of decisions being imposed from outside could jeopardise the trust in the process and future commitment to implement and follow proposed management directions, affecting compliance with proposed policies.

The second expected step involves monitoring of performance indicators, both for dynamically evaluating the efficacy of management practices versus management objectives, but also for further data collection aimed at reducing key uncertainties. Early modelling results suggest that these uncertainties include: the effects of beach use; predation levels and sea level rise on the long term population health of turtles species breeding in the area; the degree and forms of interactions of large whale sharks with human activities (including but not restricted to wild life and snorkel tours, recreational boating, commercial shipping and extractive activities); and recovery rates of resident lobster species.

Carrying out these two steps would not only establish the foundations for true adaptive management in the region, but also complete the first MSE iteration. The purpose of the MSE is to ensure ’learning by doing’ and (often) the effective use of such learning needs is to be embedded in the management process and to execute a series of MSE iterations. This requires that a structure is in place to ensure that the MSE can continue to be made available. Three minimum conditions need to be fulfilled for this to happen: a) that a entity (local or state government, research institute or university) assumes responsibility for it, b) that expertise is available to run InVitro and some of the other models and to interpret their results and c) that expertise is available to update the model(s) (in terms of input data and additional strategies to assess). Local stakeholders have expressed the desire that facilities to host these activities are made available locally or that at least are co-located.

Tourists will play a crucial role on both the future development and sustainability of the northwest Gascoyne and in particular the Ningaloo ecosystem. Their understanding of the current state of the ecosystem varies considerably, ranging from perceiving the marine environment as pristine, to dismissing it altogether as a wilderness destination. It is reasonable to expect that their attitude towards the environmental richness of the area is also affected by these different perceptions, resulting in possibly vastly different behaviours. Education can address this issue and two recommendations have been made; first, local tourist operators should be kept informed of research developments, which can help to both inform the public and to enhance the service and experience they provide to tourists. Second, a location can be selected and dedicated specifically to the purpose of informing visitors of research findings and implications, possibly close to the park access points or existing information centres (or planned future upgrades or precincts). Attendance in short educational sessions hosted at this location could be made a requirement for access to the park[1].

Our experience with stakeholder engagement and with training and presenting model results has shown that the long-term presence of a researcher in the region can make the difference between a full and an empty house at a public presentation. If this can be taken as indication of interest, perception of relevance, trust or ownership of the research project, then we may expect that such presence, together with regular visits by decision makers and researchers and provision of information, may profoundly affect the reception of future research efforts and resulting policies.

Finally, we all know that the future of the region will depend on human actions as well as on pressures, drivers and events that are beyond our control and beyond our current knowledge. Some of these events could, in principle, be anticipated and prepared for (climate change, cyclones, major economic disruptions, epidemics, etc); others cannot even be imagined. Planning for resilience and adaptation are the only means we currently have to face these challenges. MSE can help address these too, since it mimics the adaptive management process. However, adaptation can occur only provided adaptive management remains truly adaptive, with monitoring, learning (potentially including the use of MSE models) and communication aimed at supporting long-term adoption and that government and social structure is flexible enough to account for the learning and change inherent in this approach.

1.5 Other benefits

This project's outcomes can be divided into two classes. The first class is Ningaloo-specific. It includes, among others: the parameterisation of instances of the InVitro and Ecopath with Ecosim (EwE) modelling frameworks (EwE is a shuttle model focusing on just the ecology of the system); synthesis of input data; a library of model results (available via link at http://www.ningaloo.org.au/www/en/NingalooResearchProgram/ResearchTools.html); the analysis of the stakeholders network, values and beliefs; training (for people interested in the system) on dealing with complex systems; and the initial management recommendations. The second class goes beyond the application to the Ningaloo-Exmouth region and includes tools and general learning that could be extended to other environmental management problems. Among the tools, we list InVitro itself, the toy-models and the material used in stakeholder engagement (modelling exercises and surveys). The learning includes the overall stakeholder engagement process, how to couple multiple model use with InVitro and how to set up, introduce and showcase the MSE approach.

Two components of this research deserve a specific mention, because of their potential value beyond this project. The first is the ability to compare the effects of pressures when sectors are studied in isolation versus the impact when interrelations between sectors and bio-physical

[1] As suggested by local residents and as carried out already at the end of the drive trails in central Australia (mainly in the Northern Territory).

processes are accounted for, which is at the core of a full-system approach. Given that interconnections between processes are considered to be not only signatures, but also contributing causes of many recent ecological and socio-economic problems, this approach promises to be suitable for a wide range of other national and regional problems.

The second component lies not only in providing for adoption of adaptive management, but also in applying adaptive management to the research project itself. This has enabled some important features of the research to arise from interactions between research teams and between researchers and stakeholders, which has resulted in the project taking a form that was impossible to envisage, and to design, at its inception. This was a risky endeavour and a not trivial achievement, given that project success depended on a complex piece of software engineering (InVitro) and on the involvement of so many parties. This experience is ready to be transferred to equally complex projects and is discussed in Chapters 4 and 5.

1.6 Problems encountered

Three types of problems have been encountered and addressed:

1) staff turnover and illness has interrupted the early planned stakeholder engagement, as well as networking among researchers. The effect of this problem has been felt only later on in the project when the effort in mapping interactions among stakeholders and researched highlighted several disconnected hubs (Syme, Dambacher et al. 2009; Dzidic, Syme et al. 2010). As discussed in Chapter 4, the second half of the research has seen a considerable effort in compensating for these problems.

2) Data availability and sharing has not been effortless and, at least in some cases, has depended more on personal interactions and good will than on the project overall infrastructure and communication avenues. This has resulted in delays in model implementation and parameterisation.

3) According to a rough estimate, stakeholder engagement accounted for approximately 43% of the effort of the overall modelling team. This was unexpected but necessary and suggests this activity should be accounted for at project inception.

1.7 Acknowledgements

We would like to acknowledge the assistance of Professor Neil Loneragan from Murdoch University, the pastoralists along the Ningaloo coast (names), the Western Australian Department of Environment and Conservation, with special mention to Kelly Waples and Chris Simpson, Western Australian Department of Fisheries with special mention to Brett Molony, Dan Gaughan and Ross Marriott, Department of Transport Western Australia with special mention to Jo Bruyn, Russ Babcock (CSIRO) for biological data and Wendy Steele (CSIRO) is thanked for her efficient project management.

A very special thank goes to the local residents and the tourism operators, industry representatives, council members, hotel and hospitality owners, pastoral station owners who provided time, information, helpful suggestions and most of all their good will as well as to all the people who took time out of their busy schedules to meet with us and attend our workshops.

2. COMMUNICATION OF PROJECT RESULTS AND DATA

2.1 Publications and planned Publications

2.2 Communications

A list of communication activities related to stakeholder engagement, Ningaloo symposium and modelling demonstrations can be found in Chapter 4, Figure 16.

2.2.1 Presentations

Papers:

We expect that 2-4 papers will result from this work and will be submitted to international journals by the end of 2011.

Fulton, E.A., Boschetti F, Sporcic, M., Jones, T., Little, L.R., Gray, R., Scott, R. and Gorton, R., (in review) A multi-model approach to stakeholder engagement in complex environmental problems. *Environmental Modelling & Software*

Fulton, E.A., Jones, T., Boschetti, F., Chapman, K., Little, L.R., Syme, G., Dzidic, P., Gorton, R., Sporcic M., and de la Mare, W. (in prep) Assessing the impact of stakeholder engagement in Management Strategy Evaluation.

Little, L.R., Thébaud, O., Fulton, E.A. (in review) Evaluation of management strategies in Ningaloo Marine Park, Western Australia

Proceedings:

Fulton, E.A., Gray, R., Sporcic, M., Scott, R., Gorton, R., Hepburn, M., Boschetti, F., and Thomas, L., 2011. Ningaloo from a systems perspective – what has it taught us? Modsim 2011, Perth, Australia

Fulton, E.A., Gray, R., Sporcic, M., Scott, R. and Hepburn, M., 2009. Challenges of crossing scales and drivers in modelling marine systems. Proceedings 18th World IMACS / MODSIM Congress, Cairns, Australia 13-17 July 2009

Fulton, E.A., Sporcic, M. and Gray, R., 2009. Informing Natural Resource Management. Proceedings of Ningaloo Research Symposium, Exmouth, May 2009.

Syme, G., Dambacher, J., Dzidic, P., Fulton E.A. and Boschetti, F., 2009. Integrating research, modelling and decision making: A network and knowledge processing approach for sustainable management of a coral reef. Modsim 2009, Cairns, Australia

Fulton, E.A., Gray, R., Scott, R., and Sporcic, M., 2008. Modelling for Management: News from Ningaloo. Proceedings of Ningaloo Research Symposium, Perth, May 28-29 2008.

Presentations:

Ningaloo from a systems perspective – what has it taught us? – presented at MODSIM 2011, Perth

Management Strategy Evaluation – presented at the WAMSI Conference in Perth, September 2011

Ningaloo – What We Found – presented in public meetings in Coral Bay, Carnarvon and Exmouth, October 2010

Integrating Science for Management – presented at a synthesis workshop in Perth, March 2010

Complex Systems: Issues With Uptake – presented at TechFest 2010, Hobart

Challenges of crossing scales and drivers in modelling marine systems – presented at MODSIM 2009, Cairns

Agent-based models and modelling dynamic ecosystems – presented at 3rd GLOBEC Open Science Meeting, June 2009, Victoria Canada

Modelling the Future – presented to shires of Exmouth and Carnarvon, Coral Bay Progress society (and residents), Carnarvon and Exmouth Tourism Advisory Groups, Gascoyne Development Commission, Department of Environment and Conservation and Department of Fishing, (first edition October 2009, second edition March 2010)

Modellers & Data – iVEC launch August 2008

Gray, R., 2007. Management strategy evaluation using InVitro. Ningaloo Marine Park Symposium, Perth, Australia, July 2007.

2.2.2 Data Accessibility

Meta data description

Virtual library of runs (which will be updated as new simulations are done at request of any prty interested in the system), available via an access point to the ReefTime tool link at http://www.ningaloo.org.au/www/en/NingalooResearchProgram/ResearchTools.html.

Who is the custodian of the data

CSIRO Marine and Atmospheric Research

Raw data and data products description

Time series of values, and maps of the distribution, of the indicators listed in Table 1, which capture the state of the ecological, economic and social state of the situation.

Table 1: Indicators used to track the state of the Ningaloo-InVitro model simulations. Note where the spatial entry says “per area” this is per sub-area within the Gascoyne region (where cape range, the defence lands and each of the towns and pastoral stations is a separate sub-area). Those marked in **bold** are used to summarise the output in this report (for maximum clarity and ease of interpretation, presenting all indicators is too complicated and confusing).

Indicator	Spatial	Notes
Economic		
Gross economic production		
Production per sector[†]	Per area	
Value Add per sector	Per area	
Wages per sector	Per area	
Jobs per sector	Per area	
Unemployment rate	Per town	
Number doing “Home Duties”	Per town	
New job placements per year	Per town	
Number jobs advertised	Per town	
Proportion employed in retail	Per town	
Proportion employed in industry	Per town	
Proportion employed in services	Per town	
Proportion in training/education	Per town	
Social		
Local population	Per town	Both the overall total and the age structure for each gender
Proportion retired	Per town	
Proportion working age	Per town	
Proportion school age children	Per town	Sum of all children used in summaries
Proportion preschool age children	Per town	Sum of all children used in summaries
Births per year	Per town	
Deaths per year	Per town	In each age group
Immigration rate	Per town	Net migration used in summaries
Emigration rate	Per town	Net migration used in summaries
Divorce rate	Per town	
Numbers moving house within town	Per town	
Housing vacancies (availability)	Per town	
Average household income	Per town	
Social perception	Per town	
Zoning (per town)		
Proportion blocks residential	Per block	
Proportion blocks green space	Per block	
Proportion blocks industrial	Per block	
Proportion blocks commercial	Per block	
Proportion blocks public infrastructure	Per block	

Indicator	Spatial	Notes
Proportion blocks under construction	Per block	
Proportion blocks vacant	Per block	
Industrial		
Electricity use per sector	Per area	Includes residential as one "sector"
Water use per sector	Per area	Includes residential as one "sector"
Waste per sector	Per area	Includes residential as one "sector"
Transport - Number trucks on road		
Transport - Number of trucks in maintenance		
Resource sector – total remaining reserves		Per company
Resource sector – total production in the region		Per company
Resource sector – total costs		Per company
Resource sector – total revenue		Per company
Resource sector – total workforce in the region		Per company
Resource sector – total resident workforce		Per company
Tourism – nights per tourism segment* per accommodation type‡	Per area	
Tourism – total tourist expenditure per accommodation type	Per area	
Tourism – total nights per accommodation type	Per area	
Tourism – total number turned away per accommodation type	Per area	
Tourism – total nights per worker accommodation type	Per area	
Tourism – total nights	Per area	Overall and per segment
Tourism – total visitor numbers	Per area	Overall and per segment
Tourism – total spend	Per area	Overall and per segment
Tourism – average nights per visitor	Per area	
Tourism – average expenditure	Per area	
Tourism – average satisfaction	Per area	Overall and per segment
Tourism – total count of tourists doing each activity#	Per area	
Tourism – total spend per activity	Per area	
Tourism – total count of tourists doing each activity per tourism segment	Per area	
Tourism – average group size per segment		
Tourism – average trip length per segment		
Tourism – proportion 4WD ready per segment		
Tourism – average distance travelled per segment		
Tourism – average distance per day per segment		
Tourism –count doing each activity per segment		
Pastoralists – investment in tourism developments	Per station	
Pastoralists – number of fires	Per station	

Indicator	Spatial	Notes
Pastoralists – revenue		
Pastoralists – costs		
Pastoralists – jobs		
Pastoralists – pasture quality		
Pastoralists – sales per livestock type[§]		
Pastoralists – sales of products (e.g. wool, leather)		
Pastoralists – costs per livestock type		
Pastoralists – herd size per livestock type		
Pastoralists – number transported per livestock type		
Pastoralists – number sold per livestock type		
Pastoralists – number bought per livestock type		
Pastoralists – nights per farm stay type[¥]		
Pastoralists – income per farm stay type		
Pastoralists – costs per farm stay type		
Fishery – fishing hours (effort)		Per fishery[◊]
Fishery – catch		Biomass and numbers per species caught. Per fishery.
Fishery – value		Per species caught. Per fishery.
Fishery – number trophy sized fish caught		Per species caught. Per fishery.
Infrastructure		
Ecological		
Biodiversity	Fine scale	
Cover per habitat type	Fine scale	Coral cover used in summaries
Abundance of each species (except microfauna)	Fine scale	Selected key species used in summaries (e.g. whale sharks, turtles, spangled emperor etc)
Biomass of each species	Fine scale	Combined value for fish stocks used in summaries
Age composition per species		
Diet composition per species		

[†] Sectors include: accommodation, tourism, tours, farmstay, farms, fisheries, resource sector, ports, transport, construction, general industry, warehouses, retail, offices, services, hospital, police

* Tourism segments include: nature lovers, recreational fishers, comfortable campers per origin (international, national, same-state)

[‡] Accommodation types include: backpackers, camping, caravan parks, hotels, rental, and other

[#] Tourism activities include: being at the beach, eat out, shore fishing, self owned boat fishing, charter boat fishing, tours, surfing, scuba, shopping, sight seeing, snorkelling, whale shark tours and other

[§] Livestock types include: sheep and cattle (domestic), goats (feral) and kangaroo (wild)

[¥] Farm stay types include: tents, farm house, sheds, dorms, cabins, camping

[◊] Fisheries include: commercial, shore fishing, motor cruisers, small boat, charter boats, dive boats (not really catch in that case, but sightings)

3. MANAGEMENT STRATEGY EVALUATION (MSE) FOR THE NINGALOO-EXMOUTH REGION

3.1 Summary

We introduce the Management Strategy Evaluation (MSE) approach, why it has been used in this project, how we have implemented it, what steps have been taken so far, what steps need to be taken in the future and what actions are necessary for these further steps to occur.

MSE provides a framework to engage stakeholders, decision-makers and researchers in learning how to manage complex regional problems in an adaptive manner, by using computer modelling to evaluate likely future consequences of available strategies for interventions.

An effort of this type faces, among others, two types of dangers. The first is to assume that once 'the model' is available and an environment for interaction between stakeholders and decision makers is provided, the overall MSE team will come together and the process will seamlessly start. Experience teaches otherwise: trust in model use, in the MSE process, in its effectiveness and in its relevance need to be built and fostered. The second danger is to assume that the knowledge collected by and available to each individual party will automatically be accessible to the overall team when needed. Again, experience teaches otherwise: knowledge comes in different forms and is affected by different backgrounds, beliefs, values, aspirations and purposes; also, bottlenecks and disruptions in the interaction communication network may prevent information dissemination. Effective communication, as well as translation of knowledge, also needs to be fostered and actively planned for. The best science, the best advice for management, the best intentions and planning effort, may fail if these two dangers are not accounted and compensated for.

We employed two concepts to address these challenges: i) model building as a catalyst for stakeholder engagement and interaction and ii) mapping and monitoring the knowledge acquired during the project. Both concepts find a natural place within a MSE approach.

The first concept acknowledges that learning needs to occur before the MSE can start and as well as during its natural cycle. In practical terms this means that some parties may not be familiar with modelling and what it can offer regional planning, others may not be familiar with basic system dynamics and how they affect decision making. Other examples include learning what concerns need to be addressed, how to draw conclusions from specific scientific information and model results, how to build trust in the model results, how to evaluate uncertainty, and how to best parameterise the model, etc. 'Building the model', showcasing development steps and initial results, collecting data for model parameterisation, engaging stakeholders in developing modelling scenarios have provided a way to ensure that once 'the model' is ready and the MSE proper can start in earnest, the overall team is ready to participate in the process. We believe this project has made considerable steps along this path.

The second concept acknowledges that only information actually available to scientists can be used in modelling, that only information actually available to managers can be used for decision making and that only information actually available to stakeholders can be used to support policies. Similarly, only awareness of uncertainties and which ones are important can lead to further data collection and information seeking. Mapping available, as well as missing, information is thus crucial for planning, as well as for ensuring that the knowledge base can grow. Below, we provide a simple framework to map this knowledge graphically and to monitor what improvement has been achieved within the project.

These two steps have been necessary to design a number of modelling scenarios and we summarise here the main conclusions which can be draw from model simulations, the full details of which are included in Chapter 6. We conclude by evaluating what step we reached along the MSE implementation to date, how that supports the effective implementation of adaptive management and we formulate some recommendations regarding the infrastructure needed for the on-going support of an MSE approach as part of a fully adaptive management process.

3.2 Introduction

".. the aggregate outcomes of large numbers of individuals interacting .. are typically unintended"

"..how can social interactions be structured so that people are free to choose their own actions while avoiding outcomes that none would have chosen? I call this the classical constitutional conundrum." (Bowles 2006)

"...despite the choice of policy instruments used, a consistent outcome is that resource users behave in a manner that is often unintended by the designers of the management system" (Fulton, Smith et al. 2010)

These statements nicely describe the challenges the Ningaloo-Exmouth region encounters today. The Ningaloo-Exmouth ecosystem can be seen as a common pool resource for which different parties and interests compete. Coordination between these parties is crucial for defining a coherent, sustainable and defensible plan for its development. This ecosystem also holds an immense conservation value to the community, further reinforcing the need for sustainable development. Today it is clear that conservation not only holds moral intrinsic values but also represents the cornerstone of economic and community development (Ostrom 1990). Managing conservation versus development represents a social dilemma in which ecological, economical and social factors need to be accounted for by viewing the region as a unified system.

The approach followed in this research is based on the belief that problems of this kind require a number of coordinated efforts, which include:

1) the assessment of the current state of the system and the challenges it undergoes;

2) the understanding of the system functioning and its main drivers;

3) a consensus among stakeholders on the need for coordinated management and their involvement in defining what kind of future is desired;

4) a way to evaluate, under uncertainty, what futures are achievable, which are more or less likely and the trade-offs they involve;

5) an agreed plan of how to proceed, how to choose and operationalize objectives, implement management actions and monitor their effectiveness.

We expanded and refined a whole of system computer model (InVitro) and implemented it for the Ningaloo-Exmouth region to carry out the task at point 4. This represents a considerable scientific and technological effort in itself, whose value extends past the time constraint and geographical extent of this project. However, the core research contribution lies in seeing the model not as the final deliverable of the project, but rather as the catalyst of the overall process which includes all 5 points above. What this has meant in practical terms is that “building the model” has focussed the data collection needed for the assessment of system state and the understanding of the system functioning (points 1 and 2); “showing the model” capabilities and development and finalising the list of questions to ask have been, among others, one of the avenues employed for stakeholder engagement (point 3); and “interpreting the model results” will provide insights and information for decision support, policy-making and other governance initiatives (point 5). Using InVitro through a Management Strategy Evaluation (MSE) approach has offered the conceptual framework for the coordination of the 5 activities listed above.

Acceptance of an MSE approach requires providing sensible answers to two reasonable questions: a) is there any point in trying to predict when the future is known to be so uncertain? (Bezold ; Coates, Durance et al. ; Durance and Godet ; Miles ; Valaskakis) b) how can a computer model capture the complexity of a real system well enough to carry out a useful prediction (Boschetti, Grigg et al. 2010)? Both questions are meaningful and deserve honest and serious attention from any scientific team: their careful appraisal can only improve work in sustainable development. However, both questions acquire a different flavour when we realise that a prediction is implicit and inevitable in any plan formulation and that a model (whether numerical or mental, conscious or unconscious) is equally necessary to carry out this prediction. The question then shifts from *whether* a model and a prediction are needed to *what* model can provide a *most reliable and informative* prediction aimed at effective planning.

Our belief that a numerical model, rather than a mental model, is best suited to this task is motivated by the technical and scientific arguments discussed in the following sections. Besides these, a numerical model offers another crucial advantage in the way that it lays bare assumptions on system function and can engage the community in discussion, focussing their attention on the problem at hand using a common frame of reference. A numerical model requires making explicit our knowledge, our values, our beliefs and the uncertainty of how some parts of the system work, in the form of numerical parameters and targets. While assigning numbers to these parameters will not remove the associated uncertainty, it will provide for an open discussion, for an assessment of such uncertainty and for checking the consistency of their implications; these actions can iteratively help to better define both knowledge and expectations and to clarify beliefs and values which otherwise may remain hidden. Once made, these choices are coded in the model and can, in principle at least, be checked by different parties today as well as in future works; they are a record of what is modelled, why, under what conditions specific model outputs are obtained and how these results feed into decision-making; this represents an inheritance to future projects, providing the possibility for checks and re-evaluations which would be much harder to carry out for mental models.

3.2.1 Management Strategy Evaluation (MSE)

In a nutshell, MSE formalises the interplay of the essential ingredients needed for adaptive management. That is to: i) identify goals, ii) develop a set of strategies to achieve them, iii) define means of monitoring system responses under those strategies so that progress can be tracked (this is likely to require the prediction of how each strategy will unfold in the future so that potential indicators of appropriate scales can be chosen) and iv) develop a means of transparent reporting and evaluation that allows for updating of strategies with learning. It involves assessing the consequences of different management options and making clear the tradeoffs in their performance across a range of management objectives and uncertainties in resource dynamics (de la Mare 1996; de la Mare 1998; Butterworth, Cowan et al. 1998; Cochrane, Butterworth et al. 1998; Butterworth and Punt 1999; Sainsbury, Punt et al. 2000). It finds its origin in a “learning by doing” or “detect and correct” approach formalised as ‘adaptive management’ in the 1970s and 1980s (Holling 1978; Walters 1986), which was initially applied to single use management (like fisheries and forestry (Jones 2005)) and more recently to multiple use management (McDonald, Fulton et al. 2006; McDonald, Little et al. 2008) .

The approach moves away from the idea of equilibrium and optimal outcomes inherited from traditional economics and decision-making theory and embraces the dynamic nature of social-ecological systems, viewing management as adaptation to shifts in systems (whether due to climate change, changing social attitudes or other factors). This is particularly suited to complex and intermingled systems like the Ningaloo-Exmouth region.

Adaptive management promotes updating a management plan via an action-response-learning cycle based on system responses and experience from previous actions. Anything preventing or delaying the closure of the cycle derails the process (Elzinga, Salzer et al. 1998; Lee 1999); in the context of this project this includes both ‘technical’ and ‘communication’ challenges. On the technical side, unavailability of data on the systems feedback prevents assessing management performance; in certain cases data are actually missing or are not collected; other times, processes may have long time delays or very slow dynamics whose effect becomes apparent only too late for compensative action (climate change being a perfect example). In these cases collecting better data today does not necessarily reveal what is likely to come. In other words, *adaptation may not suffice* and preventive actions, which require *prediction*, are needed. This is where numerical modelling can come into play. In other words, MSE complements adaptation to current responses (as in ‘adaptive management’) with *anticipatory* testing of multiple strategies; these strategies include not only the management plan itself, but also the monitoring program and the associated risks. Modelling is crucial to the anticipatory assessment (that is, to the prediction) of the strategies’ likely outcome. It aims to emulate environmental, social and economic conditions associated with the state of the system as it evolves in response to natural and human forcing. The same testing cannot be done in the real world, because we have only one system, a limited time to make decisions and because ethics (and the fear of litigation) typically prevents testing on real people and real ecosystems[2].

On the communication side, if the monitoring bodies do not engage with decision-makers or if information is not presented in a way that decision-makers can interpret and understand, they will fail to properly evaluate and update their planning as required by the adaptive management concept. This problem is common and particularly disheartening given the effort and funds put into monitoring and research. MSE cannot solve, but can help address this problem via focussing the attention of all parties on the definition and assessment of the planning and monitoring process. Communication becomes paramount to the design of the alternative strategies, assessment of their trade-offs and the choice of a way forward.

Figure 1 summarises the MSE process. The red shapes contain the items from a typical ‘adaptive management’ process; these are the steps which need to be taken with broad community engagement. The large yellow panel shows the contribution from modelling, consisting in the ‘virtual’ testing of a number of tentative strategies and providing as output an assessment (a prediction reliable within the limits of knowledge uncertainty) of likely outcomes and trade-offs.

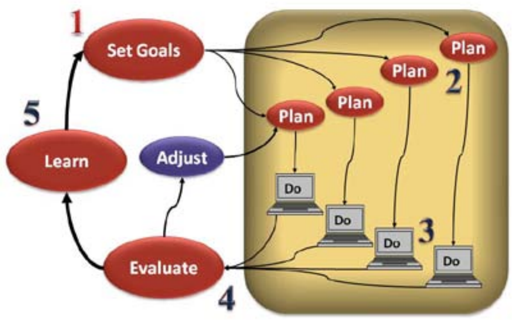


Figure 1. The MSE approach.

The comparison of alternative management strategies employs performance measures derived from management objectives and needs to account for uncertainty at all levels: in the dynamics of the system being managed, in the monitoring program and in the implementation of management measures. Robustness of a strategy can then be weighed versus the performances, as well as versus investments aimed at resolving key uncertainties.

3.3 Knowledge generation in MSE

In (Syme, Dambacher et al. 2009), the authors warn of the challenges implied in large projects involving many parties and organisations with different expertise, backgrounds and expectations. With specific reference to the Ningaloo project, one challenge is represented by

[2] There are exceptions, where significant information has been gained from implementing a specific form of management to see the outcome and reduce system uncertainty (e.g. Effects of Line Fishing experiment on the Great Barrier Reef (Mapstone et al. 2004) or the experimental zoning and monitoring of some areas of the Northwest Shelf trawl fishery (Sainsbury 1991)). This form of management is known as active adaptive management. The potential system (and political) risks associated with its implementation mean it is not used as frequently from passive adaptive management, where learning comes only from standard monitoring sources (potentially augmented by tools such as MSE).

ensuring effective communication among parties by preventing bottlenecks and silos in the communication network (Dzidic, Syme et al. 2010). A second challenge is represented by different expectations of what the project should produce and how the knowledge generated will be represented; common stereotyping suggests that managers expect policy recommendations leading to impact assessment, natural scientists focus on scientific knowledge in terms of publications and social scientists emphasise the 'journey rather than the destination', enriching the social capital. These different expectations are closely related to a third challenge, represented by existence of different types (Joshi, Saonee et al. 2007) and dimensions (Cross, Parker et al. 2001) of knowledge, which can further complicate communication; this is particularly true when the final output of the research is perceived to be a computer model which processes and generated information in numerical form.

In the literature on adaptive management and effective management of natural resources, MSE is put forward as an effective tool for addressing each of these challenges, by focussing the different parties on a common effort (Allan and Stankey 2009; Brugnach 2010), by facilitating engagement (Allan and Stankey 2009; Brugnach 2010), by facilitating evaluation of likely and desired scenarios (Lindenmayer and Likens 2009; Wintle, Runge et al. 2010) and by providing a repository of knowledge and a synthesis tool. Outside the computer model itself, representing or even condensing these different types of information and their implications in a common framework is very difficult. Here we describe one such approach whose pragmatic aim is to ease the evaluation of project deliverables by comparing the knowledge available at the beginning to the one available at the end of the project; probably more important, it can help highlight the next steps in improving and assessing the impact of such knowledge.

In a famous press interview in 2002, the former US Defence Secretary Donald Rumsfeld popularised the concept of 'unknown unknowns', that is of a classification of knowledge and uncertainty into types like 'things we know that we know', 'things we know that we do not know' and 'things we do not know that we do not know'. This classification was already established in engineering and military sciences, which emphasise the risks implicit in the 'unknown unknowns', and in the field of logics (Fagin and Halpern 1987; Samet 1990; Modica and Rustichini 1994; Modica and Rustichini 1999) which studies the decision-making and modelling implications of these classes of knowledge. Here we represent these ideas graphically in a knowledge-awareness plot, that is a 2D plane in which one axis maps knowledge (from total uncertainty to certainty) and the second axis maps awareness. The advantage of using a 2D plot rather than 4 fixed classes is that it provides for representing degrees of knowledge and of awareness.

Figure 2 tries to capture the state of knowledge and awareness of the MSE team at the beginning of the project. The top-right quadrant includes what we knew and we were aware of. For example, we knew we had a working version of the full-system model InVitro that had provided a successful analysis in a previous, similar, project (Gray, Fulton et al. 2006; Little, Fulton et al. 2006) and we knew that this version needed further development and porting to the Ningaloo-Exmouth region. We also knew that not all stakeholders would be open, ready or receptive to the idea of MSE and that some engagement was needed in this direction. We also had some idea of what system behaviours the model had to capture, some data about it and some knowledge of how to interact with some members of the broader project team across the Ningaloo collaborative cluster, although we were also aware that much more information on these items needed to be collected (this is why these 3 items are located halfway between the uncertain and certain quadrant).

We also knew that much needed to be learnt; this relates to both the standard process of scientific enquiry (data collection for biophysical and social processes and model building) as well as understanding of the planning and scenario building for the MSE process. In other words, what scenarios represent stakeholders concerns, how to measure their progress, what management strategies were available and acceptable. Importantly, the main aims of the project (represented as blue boxes in the figure) belong to this quadrant.

Of course, the quadrant of unknown unknowns could not be filled at the project beginning but, in retrospection, we have realised some of its items: we did not know that using multiple models (see below) would be particularly useful at engaging stakeholders during the project and we were only partly aware of the importance of engaging stakeholders at a variety of scales (while we had extensive previous experience working on request with management bodies we were not as familiar with working across quite as wide a range of regulatory, industry and social groups).

If we expand our vision of the MSE team beyond the core modelling group to the entire ensemble of participating groups (comprising researchers, decision makers and the public), some of whom had never interacted before, then in retrospect we also realise that there was much knowledge in the overall team the individuals were not aware of. This comprises the bottom right quadrant – which includes information on status of the fishery and other industries in the region, human behaviour, stakeholders' types, other scientific information, local knowledge in stakeholder groups, etc. Given this snapshot of the status of knowledge in the MSE team at the beginning of the project, the purpose of our activities can be interpreted as moving items within the knowledge-awareness plot. We discuss this in the next section.

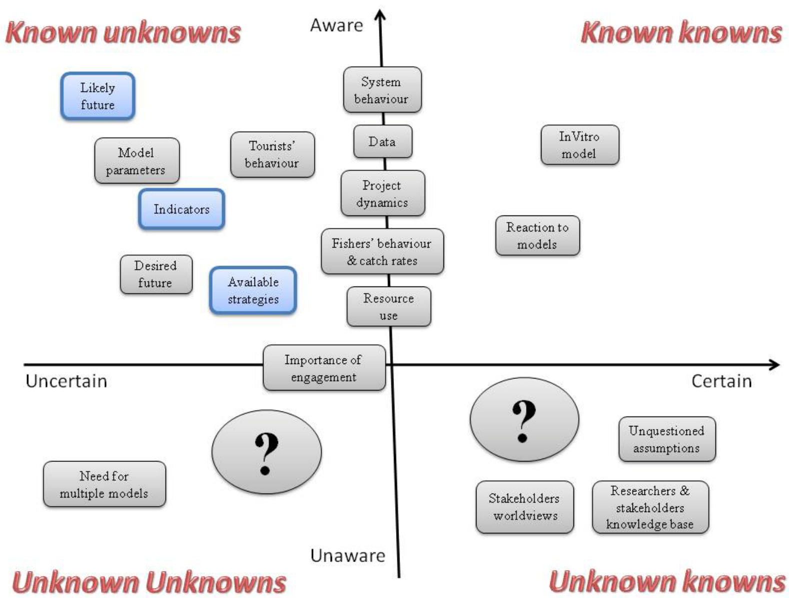


Figure 2. The knowledge-awareness plot at the beginning of the project.

3.4 MSE implementation

The MSE implementation, as carried out in this project, has involved 4 broad activities: a) stakeholders engagement (described in details in Chapter 4), b) development of a suite of ‘simpler’ computer models to facilitate engagement, provide intermediate or progressive(?) results and feed into the final full-system model (see Chapter 6), c) implementation of the full-system InVitro model and d) assessment of the likely outcome of a number of future scenarios for the region – particularly those of stakeholder concern (see Chapter 6). Here we focus on how these steps fed into exchanging and generating knowledge within the MSE.

Stakeholder engagement has been crucial for determining a) who the stakeholders are, what beliefs and values they hold and what drives their behaviours and preferences, b) for collecting local information and c) for understanding aspirations and expectations in order to define the modelling questions. It has also helped disseminating information since, while the team, as a whole, may have all the information needed for the overall project, this information may not reach the specific researcher or manager who needs it because of lack of full connection within the stakeholder network. As a result of effort, by the end of the project several groups displayed interest in MSE and got involved in some initial training and interactive exercises that has highlighted issues of concern, that can in turn be addressed by modelling. The acquisition of this knowledge is represented as blue arrows in Figure 3. These clarify the contribution of stakeholder engagement in the definition of system knowledge and project aim.

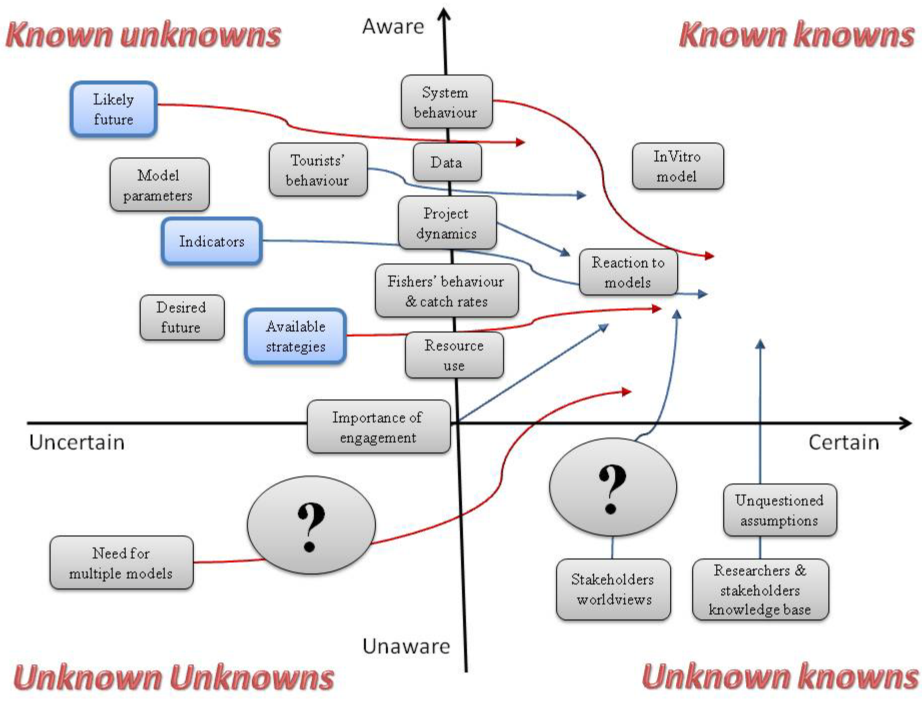


Figure 3. Schematic representation of how stakeholder engagement and use of different types of modelling influence the knowledge base during the project. Blue arrows refer to knowledge acquired mostly during stakeholders engagement, red arrows refer to knowledge acquired mostly during model use.

Of course, stakeholders have very different levels of knowledge and understanding of modelling, what it does and what it can provide. Consequently, a considerable effort is needed to ensure that all parties develop an informed opinion on the matter, which is essential for encouraging model use in planning and decision making. To fulfil these roles within a MSE project we developed five broad classes of models: conceptual models, toy-models, single-system models, shuttle-models and full-system models (see Chapter 5). These actions are depicted as red arrow in Figure 3; they show how the stakeholders understanding of modelling and system functioning improved and how the use of single system, and shuttle models allowed for collection of information on overall system behaviour, which fed into the full-system modal InVitro.

3.4.1 Modelling results

Here we summarise the results of some model runs, which provide likely future outcome of different possible future developments. Please refer to Chapter 6 for a more detailed analysis of a large set of model outputs as well as a full description of how the model runs have been carried out[3].

As discussed in (Chapman 2010; Dzidic et al. 2010; Chapman 2011) the majority of the local population feels they are recipients of pressures and drivers for development originating outside the region. These drivers include trends in population growth, possible growth in resource exploration and extraction across northwest Australia, increase in tourism and consequent infrastructure development. A more specific concern regards the facilities that will be provided for tourism and the resulting change in tourism patterns that may occur. The questions that are most often asked relate to the impact of these alternative development paths on locally scarce resources (like water and electricity), on the environment status (currently the core driver for tourism) and on standards of living, in terms of employment opportunities and housing availability and affordability. These issues have been highlighted via stakeholder engagement and use of simpler computer models and have been incorporated in the model runs in order to obtain information on likely future developments.

A starting point for any analysis of future development is to compare the current state of the region to its likely future, should current trends continue unaltered (e.g. developments already underway). In statistical parlance, this resembles the analysis of the null-hypothesis should the system continue as it is via inertia. Figure 4 shows a radial-plot in which each spoke represents the relative change in a variable of interest. These variables are a subset or the entire list are a broadly representative of broad classes of objectives of interest in the system: economic (local employment and gross economy across sectors), tourism (visitation, expenditure in the region and snorkelling, which is currently one of the most popular non-fishing tourist activities), recreational fishery variables (stocks of trophy fish, catches and effort), environmental (coral, turtles and whale sharks), local resources (water and electricity use), and social conditions (number of residents, housing availability and the local perception of the state of the system). The darker line in Figure 4 shows the current status of the region as a reference point sitting at zero (no change). The darker line shows the likely status of the region in the year 2035. For each variable, the value is the percentage increase or decrease compared to the current status.

[3] These and a growing list of runs are also available via the ReefTime visualization package for the Ningaloo-Exmouth region. Contact the authors for access to this virtual library.

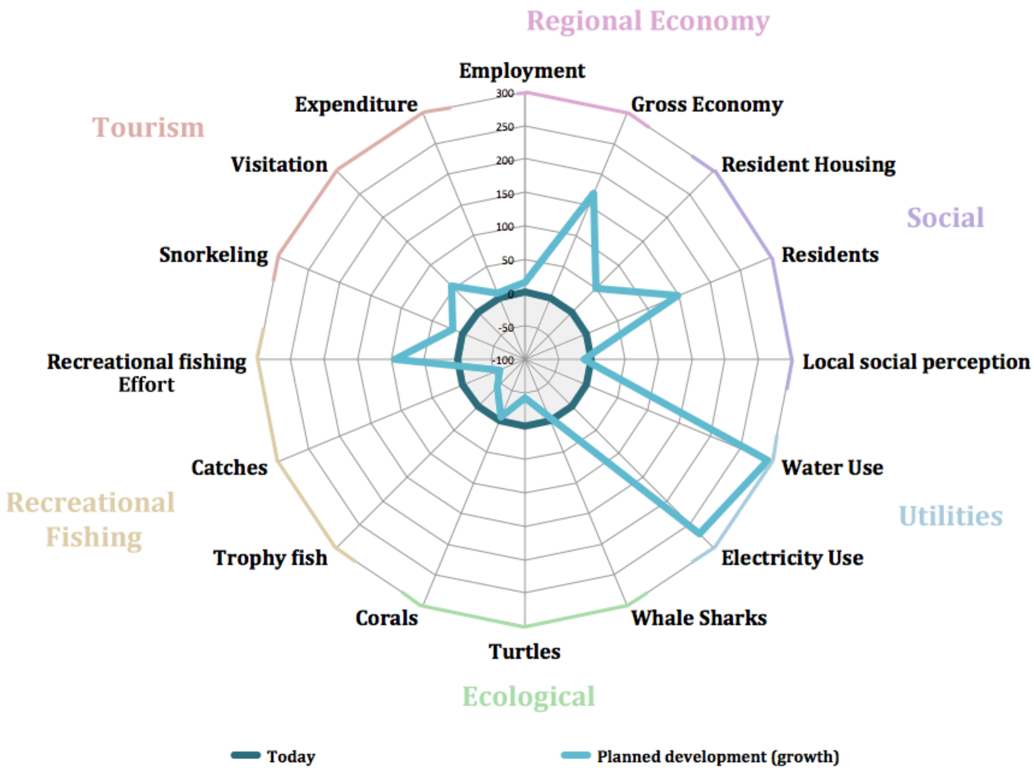


Figure 4. Comparison of the current state of Exmouth area (dark line) versus its likely future state in 2035 given planned development (lighter line).

Figure 4 refers specifically to likely outcomes in Exmouth and the immediately surrounding area on the peninsula. A more precise analysis of model results are given in Chapter 6, where outcomes for the overall region are discussed (results for other regions can be accessed on line via the ReefTime tool). Despite being only a subset of the long list of indicators tracked in each simulation, some clear patterns are already noticeable. The future is likely to bring more tourists, residents and more investment from the growth of the resource sector, which results in more employment, more infrastructure development, more recreational activities (fishing and snorkelling), and more pressure on local resources (water and electricity) with noticeable impacts on the environment, fish stocks and catches.

The strength of simulations is being able to explore alternative futures. For instance we can compare alternatives like: a) slower (or lack of) growth in the resource sector; b) adoption of modified recreational fish bag limits (i.e. a ‘wilderness fishing’ approach), limiting catches to a small number of fish that are intended for fairly rapid consumption; c) a change in the type of visitors and tourists, with emphasis on ecolodges and attracting wealthier tourists, most likely interested in leisure activities rather than committed to intensive fishing; d) land release allowing the construction of 2000 more houses in Exmouth; and e) building additional infrastructure (such as the paving of roads and construction or upgrading of boat ramps). The outcome of these alternative scenarios can be seen in Figure 5, where each variable shows percentage increase and decrease by 2035 relative to the current regional state. The model output in

Figure 5 can be summarised as follows:

1) Decreasing pressure (lack of growth in resource sector) and increasing pressure (construction of 2000 further houses easing constraints on development imposed by a lack of housing) result in opposite impacts on employment. In the latter, there is a considerable increase in economic activities, population and infrastructure and a much steeper drop in fish stocks and catches (lightest blue line) than for an undeveloped system (black dashed line).

2) Decisions aimed at targeting fishing can have a large impact on this activity, as seen by the difference in stock level and catches between promoting 'wilderness fishing' experiences versus facilitating current fishing activities by building a new boat ramp (dark blue and second lightest blue lines).

3) Regional development is also very sensitive to the mix of visitors and resulting change in tourism activity patterns. Wealthier tourists tend to spend more locally, engage in leisure activities like snorkelling and fish less, which result in increased tourism expenditure and reduced pressure per capita on fish stocks; although if this push for a changed visitor mix is achieved via extra ecolodge developments the absolute increase in the number of tourists can still see the absolute effort applied increase, if instead advertising and remediation of existing sites is done instead then the environmental state benefits; however as industrial growth continues recreational fishing pressure from workers in the resource sectors can overwhelm some of the gains made targetting ecotourism.

Finally,

4) Figure 5 suggests that across alternative futures show there is little variation in terms of impact on the habitat and iconic species. This observation may be deceptive though, since sensitivity to change may be greater for some organisms. For example, it is known that even a small reduction in whale shark survivorship (by as little as a few percent) and visitation can have a considerable impact in the likelihood of tour-based encounters and as a result on the viability of wild life tour industry. This and related issues are further discussed in Chapter 6. Moreover, the small levels of variation seen in the results for corals, turtles and whale sharks are due to processes at different scales. The reduction in habitat quality at high use sites could be quite marked with little effect on a regionwide indicator (this is why there is only a small change in habitat regardless of the scenario considered in Figure 5). In the case of whale sharks their state is highly dependent on shipping in the region, which is at a scale beyond just what is happening immediately around Exmouth (though obviously an increase in that region could cause localised increases in mortality of sharks in that region). The results for turtles is highly dependent on whether fox baiting is continued and the level of sea-level rise (and whether nesting beaches are washed out); if sea-level rise is small and baiting is maintained then turtle biomasses can remain about the level of today.

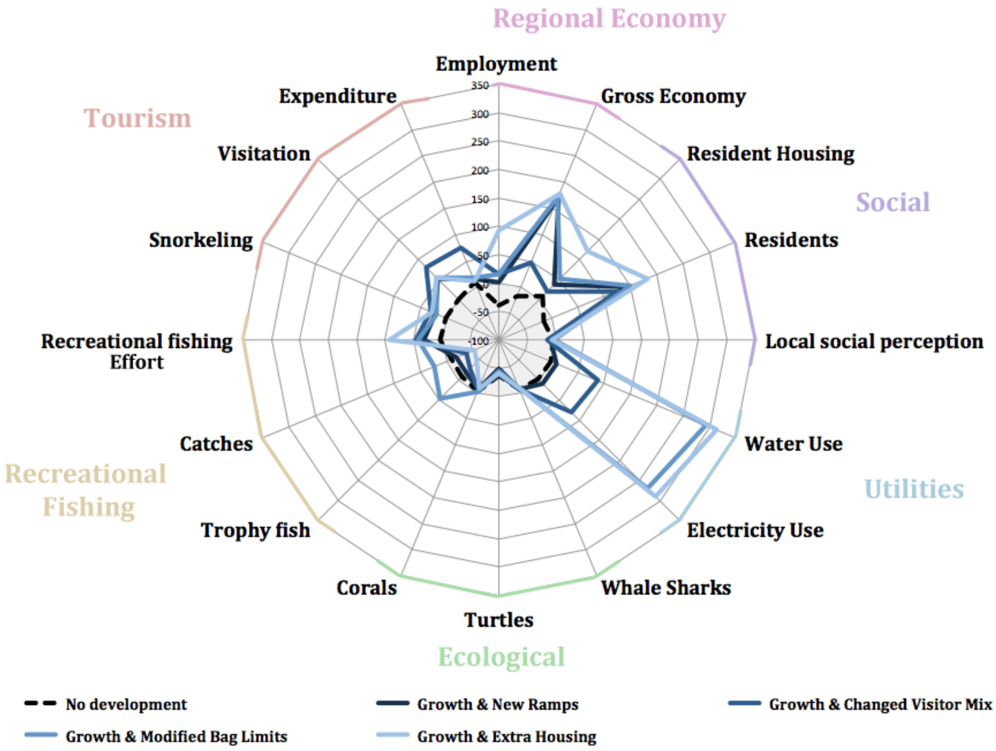


Figure 5. Comparison of alternative futures, based on available departures from the continuous moderate growth discussed in Figure 4.

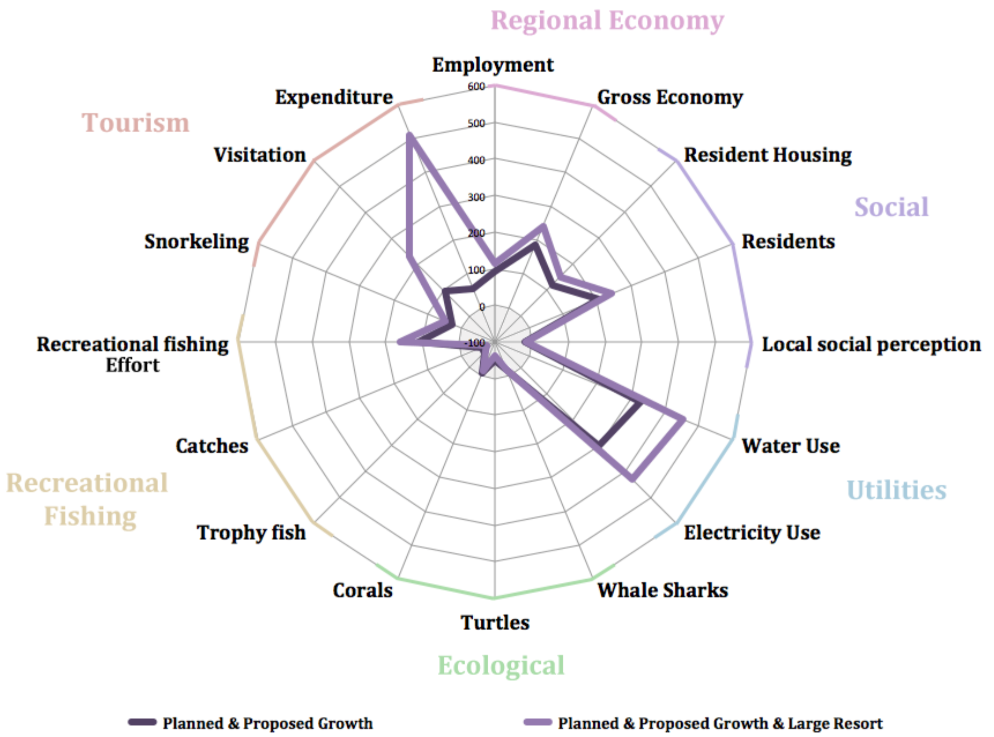


Figure 6. Impact of larger regional growth compared to the continuous moderate growth discussed in Figure 4.

We conclude this brief analysis by exploring the consequence of larger economic and population growth. Figure 6 shows the impact of full regional growth, with all planned and proposed developments (and a 4% population growth to feed it) happening across the Pilbara and Gascoyne. As currently outlined in Australia-CHEVRON (2008) this involves resource sector development and associated port and industrial development. The figure also shows the situation with full growth and the additional construction of a large (2000 bed) resort. The full growth nearly trebles the both the pressure on local resources and doubles the level of economic activities and the local resident population. These increases skyrocket with the addition of a large resort, with impacts and tourism expenditure increasing by roughly 450-500%. Along with this increased activity comes a doubling in fishing pressure and 60% drops in catches and 50% declines in target fish stocks if current management practices remain in place.

3.5 Implications for science and management

This work can feed into decision making and regional management via several different paths.

First, it provides an improved description of the current state of the Ningaloo-Exmouth system. This is the result not only of large bio-physical, ecological and social data collection across the Ningaloo collaborative cluster, but also of model building. Developing conceptual models, engaging local experts and implementing the full-system model InVitro provides an invaluable way to understand how a system works, what it is most sensitive to and what avenues for interventions are available.

Second, we have a much better idea of the network of interactions between local, state and government stakeholders, their drivers, motivation and aspirations and which will influence and need to be accounted for in the decision-making process. As discussed above, this has already been incorporated in the modelling exercises by designing the modelled scenarios based on stakeholder concerns. This knowledge is also extremely important for designing the consultation and implementation process in order to achieve and maintain ownership of the decision making process (Park 1999; Roux, Rogers et al. 2006; Lomas 2007; Sarewitz 2010).

Third, the models are available for future use and interest in maintaining, updating and further consulting them has already been expressed by stakeholders groups in the region. Carrying out these activities will likely be seen as a measure of commitment to take this work into the future.

Fourth, training workshops, model showcases and the stakeholder engagement at large have built a background for the acceptance and implementation of the overall MSE, within which the modelling exercise takes place.

Finally, a considerable range of model outputs are already available as discussed above and described in Chapter 6 (and are available in the ReefTime virtual library). These have been designed to address local immediate concerns and to explore the most obvious future regional paths. These results can help not only start the decision making process but also provide a platform for defining more specific scenarios of interest to explore via future modelling. The results discussed above highlight not only that future impacts are very sensitive to developmental paths, but that they are also sensitive to available intervention options, which should encourage an anticipatory and active approach. The future, at least partly, seems to be under stakeholders' and decision makers' control, they can have considerable influence on how Ningaloo will look like in 20 or 30 years.

3.6 Discussion: Where are we now?

".. ecologists and conservation biologists frequently face results that directly contradict their general expectations"

" .. most management strategies, sooner or later, will not work as planned " (Doak, Estes et al. 2008)

We opened this Chapter with statements highlighting how interactions between people with different expectations inevitably lead to uncertain outcomes. We close it with statements that similarly underline the uncertainty inherent in management interventions in ecosystems. Managing the Ningaloo-Exmouth region involves both people and ecosystems and consequently, no matter how good a devised plan is, allowances for unexpected outcomes need to be included. (Wintle, Runge et al. 2010) recommends that long-term monitoring for unexpected events should be a part of any ecological management effort and several authors recommend adaptive management as the our best approach to prepare for unknown, but likely, threats (Doak, Estes et al. 2008; Allan and Stankey 2009; Denny, Hunt et al. 2009; Lindenmayer, Likens et al. 2009; Lindenmayer and Likens 2009; Fulton, Smith et al. 2010). We subscribe to this view and discuss here how the MSE approach can best benefit of the knowledge acquired and our current understating on uncertainty about processes in this region.

The adaptive management-MSE framework in Figure 1 is based on three main assumptions: a) the model is already available, b) the stakeholders have already accepted the use of an MSE model and c) the model form is independent from the modelling questions. None of these assumptions held at the project inception: the chosen model (InVitro) has undergone a complete redesign and porting from a previous project (Gray, Fulton et al. 2006) and completing its implementation has occupied the modelling team for a considerable part of the project. While some stakeholders were familiar with model use in general, others were not, some were sceptical and none had used InVitro before; as we soon discovered, modelling was for most an abstract activity, requiring a prolonged familiarisation to fully comprehend its precise role in the project and to be able to formulate realistic modelling questions (see also Chapter 4). Finally, in order to provide a useful contribution to decision-making, InVitro implementation needs to reflect both our system understanding as well as the main stakeholders concerns, neither of them were clearly defined at project inception.

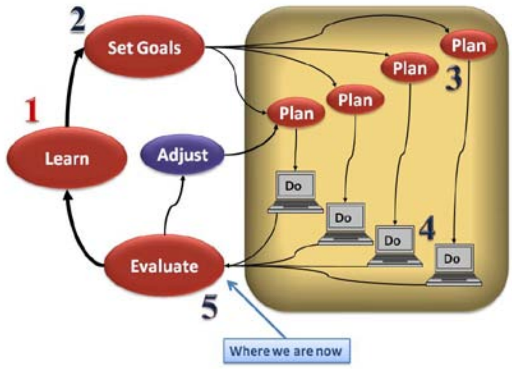


Figure 7. Actual MSE steps as taken in this project and the stage reached.

As a result, the approach we used in the project differs from the ideal MSE framework. Figure 1 suggests a process that starts from setting management goals (as in the top box) and proceeds via a regular series of steps. We needed to start from the 'learn' box on the left and carry out a number of activities in parallel: a) develop a number of smaller computer models to initiate some stakeholders to modelling and to complex dynamical problems and showcase intermediary results, b) engage stakeholders to allow for collection of information on the system, build trust in their use, and ensure their concerns were addressed and c) develop the final version of InVitro, collect input data, parameterise it and run the needed scenarios. Figure 7 summarises the steps as have been taken in the project and where we are at within the greater adaptive management-MSE cycle.

We also try to capture a snapshot of where we are at in the knowledge-awareness plot, as in Figure 8. Our better understanding of the current state of the Ningaloo-Exmouth region and its dynamics is represented by the items in the top-right quadrant (the known knowns). This represents the information included in this Report, as well as what went into InVitro parameterisation and was obtained from its output. As immortalised by Socrates' famous statement, better knowledge also implies a better understanding of the top-left quadrant (the known unknowns); fortunately, it also implies a better understanding of how to address them via well designed monitoring programs, more data collection and modelling of those process whose uncertainty has the largest impact, including, among others, sea level rise and other climate change effects, beach use and predation levels in the turtles breeding areas, the degree and forms of interactions of large whale sharks with human activities and recovery rates of resident lobster species.

Of course, knowledge is not a black and white state: we may be totally ignorant of something but we are never fully knowledgeable of a complex problem. This is why a plot like Figure 8 which accounts for a graded knowledge level is more informative that a crisp distinction between known and unknown. In practical terms, this leads to asking when we know enough (Lewandowsky 2010). Or, in our project, what form of decisions are likely to be useful given our current state of ignorance? Or, within Figure 8, where should the vertical axis be located? Stereotypical judgements often lead to humour; scientists always claim not to known enough: for them the vertical axis lies far on the right hand side of Figure 8 and more research is always needed for decision making. Managers always claim to know enough, for them the axis lies far to the left. Well established experimental work in cognitive science suggests that such polarisation does exist, not necessarily between scientists and managers, but between people with different attitudes towards uncertainty (Sorrentino and Roney 2000). Some people strive in uncertainty (Stanovich 1999), others need certainty, preferring to take firm decisions even when little knowledge is available in order to achieve ‘closure’ on a problem (Jost, Glaser et al. 2003); both will likely be unaware of this and will find arguments to rationalise their attitudes. Being aware of this, as well as the role that people with specific attitudes have in the project, is important in order not to be trapped into apparently rational argumentation which in fact derive from ideological differences.

To a certain extent, the acquired knowledge helps also address, albeit to a limited extent, the bottom-right quadrant, the unknown knowns; it is so because now we have a better understanding of stakeholder and researcher network and a tighter network which may help make explicit and widely available pieces of information and know-how already available within the large team. Of course, some work to ensure that the network links are maintained and benefitted from will be needed and this is an item which decision making should not overlook.

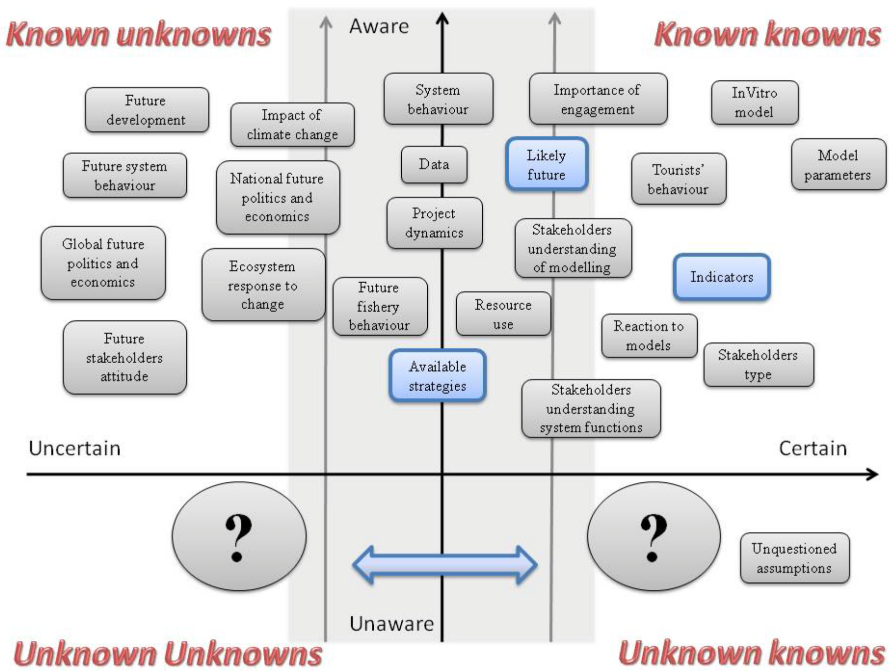


Figure 8. Snapshot of the current state of knowledge in the project.

Included in the unknown-knowns quadrant are also the tacit assumptions we hold about how certain processes work as well as about the beliefs and values we assume other people hold. When such assumptions differ between different parties, they may be elicited by interactions and conversations, allowing them to move to the top-right quadrant. In psychology and social science this is at times referred to as framing. Within environmental management, (Brugnach, Dewulf et al. 2010) suggest that this should be accounted for explicitly as a form of uncertainty in decision making, at the same level as unpredictability and incomplete knowledge.

When such assumptions are held by all parties, it is more likely that they will never be discussed and may remain unconscious for a long time. To account for this possibility, we included a box for unquestioned assumptions in the bottom right quadrant of Figure 8. An example of such assumptions emerged out of serendipity during a stakeholder casual conversation in Coral Bay: underlying the current discussion about what level of limitation should be imposed on recreational fishing in the Ningaloo-Exmouth region, lays the assumption that killing fish is acceptable. It is likely that a similar recreational activity involving killing kangaroos or other land animals would encounter considerable public opinion hostility. It is also likely that many other assumptions of this type remain undiscussed with the potential of preventing the discovery of alternative management paths.

Finally, as widely discussed in the media following Rumsfeld's famous interview and well known in the engineering and military establishment, by far the toughest challenges come from the bottom-left quadrant of the knowledge-awareness plot, the famous unknown unknowns. Within the scope of the Ningaloo-Exmouth region, these include not only external pressures which cannot be envisaged today (wars, political upheavals, natural or man-made disasters and other unexpected circumstances), but also what complexity science warns us most about: the 'emergent' processes whose outcome (supposedly) cannot be envisaged even from knowing the inner working of the system. Naturally, by definition, nothing can be done to anticipate or prepare for this. But the adaptive management (and MSE) approach at least provides a flexible framework for addressing the issue (Brugnach, Dewulf et al. 2008) and by explicitly including monitoring (Wintle, Runge et al. 2010). When items move from quadrant to another, they can be included into modelling and decision-making processes, into data collection and monitoring, or accounted for/guarded against by engagement and adaptation, as described in Figure 9. This realisation further highlights the importance of seeing adaptive management and the use of MSE as a long-term, continuing process, rather than a one off activity to address a short-term decision making need (Contamin and Ellison 2009).

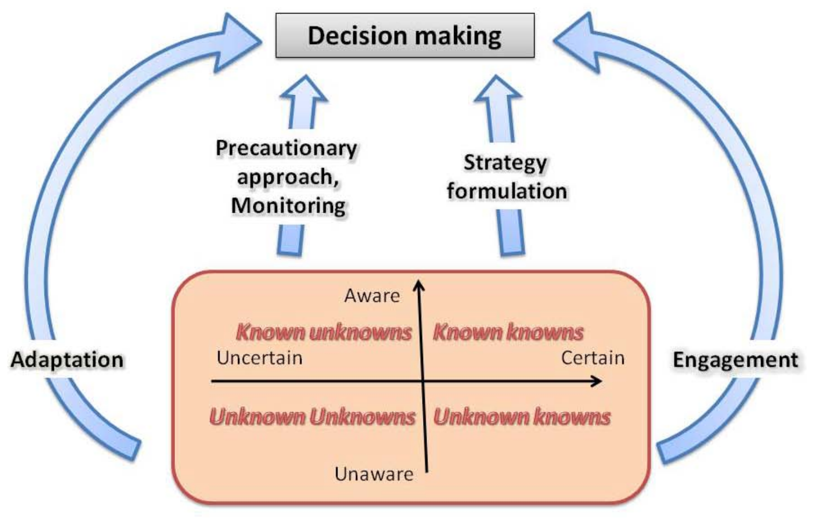


Figure 9. How different types of knowledge and uncertainty fit within the MSE approach

4. MODELLING AS STAKEHOLDERS ENGAGEMENT

4.1 Summary

A key determinant of success in large modelling efforts addressing socio-ecological issues lies on whether the models, their results and recommendations are taken up by stakeholders; evidence suggests that such uptake in turns depends on addressing stakeholders' concerns as well as on engaging them in the project. This observation has guided our approach and has resulted in treating 'building the model' as the catalyst, rather than the final aim, of the process. In other words, extensive interactions in order to introduce, showcase, discuss and tune the model used within the MSE framework have represented both a requirement and an opportunity to ensure that the model is relevant to businesses, managers and communities and has sufficient trust to be considered for ongoing use.

The current Ningaloo Management Plan also explicitly promotes community ownership, communication and understanding of research results, management implications and decision making process. While no researcher involved in the MSE would disagree with the general importance of stakeholders engagement, what precisely this entailed for the development and acceptance of the 'model' (and how much its final success depends on it) has become clear only later on in the project. This has resulted in a considerable effort to engage decision makers as well as the local community in the second half of the project, via one-to-one meetings, workshops and seminars in order to showcase and improve the model, collect local knowledge, explain modelling philosophy and approaches and highlight their strength, limitation and potential role in decision making.

Despite the late start, by the end of the project, stakeholder engagement alone accounted for roughly 43% of the overall modelling team's effort. Our experience may be summarised as follows:

1) Stakeholders have very different levels of knowledge and understanding of modelling, what it does and what it can provide; this affects their attitude towards its use in planning and decision making. A considerable effort in education is needed to allow all parties to develop an informed opinion on the matter; while not all parties will necessarily endorse model use, this education component is nevertheless essential for an open process and community acceptance of model results.

2) In addition to the main model used within the MSE framework, other 'smaller' models are useful particularly for carrying out the previous step. This adds to the modelling effort both in terms of development time and required expertise, but, if properly planned, can contribute to both the final full-system model and stakeholder engagement.

3) The network of interactions among stakeholders and among researchers can change as a result of one-to-one meetings, workshops and model use; while the project organisational structure may not be flexible enough to quickly reflect the change, the model development may need to adapt and account for it.

4) The style, language and attitude required to showcase models and models results differ considerably depending on the stakeholder types and expectations. Not all scientists (and not all modellers in particular) are well prepared for this. Training for public presentations, coordinating team presentations and rehearsing for effecting delivery is not a standard component of the scientific culture. These factors need to be addressed early in the project to ensure effective engagement and communication of model results.

5) Communities hold local knowledge which can greatly benefit model development and tuning; similarly, communities and stakeholders may formulate modelling questions not envisaged by modellers and project developers. Interactions will considerably enhance the final model provided two-way information exchange is provided for. However, information held and sought by scientists and stakeholders may differ in type: formal vs informal, coded vs embedded, anecdotal vs falsifiable; these differences need to be accounted for from early in the project.

6) The level of community reception depends crucially on the amount of effort *locally* invested; this is true especially when the scientists need to overcome the perception of being ‘outsiders’ to the community and to the problem. Our experience shows that a locally based facilitator may make the difference between an empty and a full house at a public meeting, greatly affecting the reception and perception of the modelling exercise.

The above observations have led us to revise the view of modelling within the Ningaloo MSE. While ‘building the model’ was initially perceived as the final goal of the modelling team, a goal which could be defined at project inception and implemented following the fixed plan, soon ‘building the model’ became an adaptive process both influenced and influencing stakeholders interaction: the latter would determine the final model structure and the questions it needs to address. In other words, *stakeholder engagement shifted from being a component of a technical effort (model building) to being an effort in information collection, processing and dissemination.*

4.2 Introduction

Modern economic, political and social sciences suggest that human behaviour arises from the interaction among people’s aspirations and values, market forces, norms and governance. Modelling appears in this framework mostly as a means to estimate the likely implications of the institutional rules and market incentives under consideration: in other words, as a technological aid to (virtually) test whether available options are likely to generate desired outcomes. It is important to consider some of the assumptions implicit in this view of modelling, including a) people (agents in the models) have identifiable, known and fixed behaviours and values; b) these values do not change as a result of market and institutional changes and c) people’s aspirations and values do not affect market and institutional forces. The list can be much longer. It highlights a limited consideration for feedback loops in the human arena. It suggests that because people’s values and aspirations are fixed, different institutional or market forces will *direct*, but not radically *alter*, their behaviour: it reinforces the ‘modern’ view that a good law makes self-interested citizens act for the good of the community (in the tradition of Bernard Mandeville and Adam Smith), which contrasts the ‘classical’ view according to which good laws make good citizens and a law that does not change people’s behaviour is a bad law (as, for example, in Aristotle, Nicomachean Ethics, 1103b) (Bowles

2006). Also, it suggests a clear and unidirectional causal path *from* market forces and institutions *to* people’s behaviour; at least at the scale of a policy formulation, forces in the opposite direction are given less attention.

Most social scientists and ecologists are uncomfortable with this view: for them systems are malleable, dynamic, adaptive and evolving. Only on very short time scales can these effects be disregarded, but they come into play in medium to long term projects in which different forces, interests and cultural approaches compete. Modellers with a strong theoretical background in computation theory are also uncomfortable, because it is today largely understood that models are (typically) ‘closed systems’ in which no interaction with the environment is possible; consequently they (often) cannot simulate the meaningful adaptation, robustness and innovation and creativity played by real people (Kauffman 2000; Rosen 2001; Wiedermann and Leeuwen 2002; Boschetti and Gray 2007; Boschetti 2010). Cognitive scientists too are wary of ‘ballistic’ approaches to complex problems: approaches where we assume we know all we need to devise a solution and then we ‘shoot’ the solution into the real world without checking or being able to adjust its trajectory (Dorner 1996).

What is common among the sociologist, ecologist, modeller or cognitive scientist’s views is the agreement on the importance of missing information: what prevents a stationary view of a system from encompassing change and adaptation is a lack of information: on current system status, on social dynamics, on human psychology, on unexpected events, etc. It is interesting to note that most economists would also agree on this last point: the role of economic agents’ accessing exhaustive and correct information for optimal economic performance is a pillar of current economy theory. According to this view whether decentralised market forces, centralised governmental intervention or community-based norms are economically optimal depends on which one provides the best dissemination of correct information under different contexts (Bowles 2006).

Taking the latter view on board, the important management question swifts from ‘what are the most robust strategies to obtain specific objectives?’ to ‘how can we ensure all available information can be best used to define objectives and strategies?’ In this alternative view the management objectives are not set a-priori and the MSE model may need to evolve as the objectives change; this brings us to the core question we address in this work: ‘*how can all available information be best used so that objectives and strategies arise spontaneously from the system and adapt to/with it*?’ This leads us to we also ask a) where this information should come from and b) how it can be effectively disseminated.

A large body of literature is dedicated to this topic in organisational theory but this does not necessarily apply to the stakeholders group related to the Ningaloo-Exmouth region, which is considerably more heterogeneous than expected in a typical business or governmental organisation. Our tentative answer to the above questions is that both the stakeholders and the model are essential for revealing, generating and disseminating information. In what follows we describe the steps we took to support this information flow, to test its effectiveness and to assess whether any detectable change in the human network closely related to the project and in the project itself could already be identified as a result of our effort.

4.3 Information flow in stakeholders engagement

Stakeholder engagement can be called for utilitarian, social, ethical or political reasons, as discussed in (Bramwell and Lane 1999; Bramwell and Sharman 1999; Aas, Ladkin et al. 2005) and within the scope of the Ningaloo Research Project in (Dzidic, Syme et al. 2010; Chapman 2011). Here we focus specifically on *information*: information generation and real-world, concrete information processing within a MSE framework – how information can be collected, generated and disseminated via the interaction between stakeholders and scientists, where the interaction is mediated by models.

This requires a shift in how modelling and stakeholder engagement are perceived. At the beginning of a project, modellers and different stakeholder groups may have different expectations from these activities. For example, modellers may see the model as the final outcome of their effort and stakeholder engagement as a step in order to define, for example, what the model should do and how it should look; non-modeller scientists may see the aim of modelling in model results, which can feed into other projects; decision makers may focus on result interpretation and consider stakeholder engagement as a natural consultative process. For each of these parties a model is a) defined early in the project, b) implemented (built and parameterised) during the project and c) fulfilled (via model runs, output generation and interpretation) at project completion, as summarised in Figure 10.

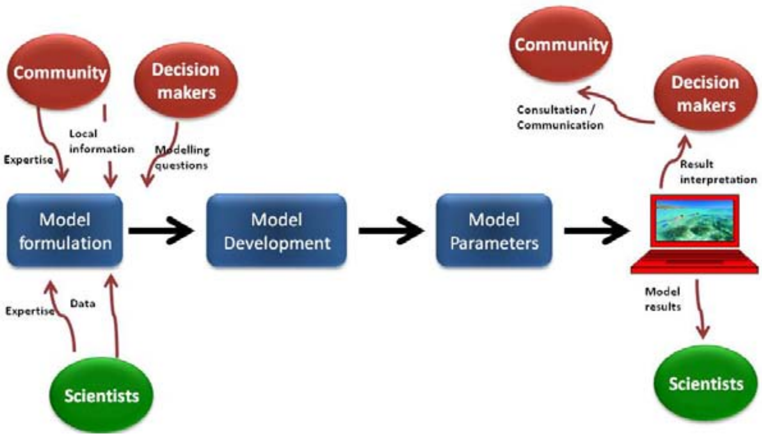


Figure 10. Traditional, sequential model development stages; stakeholder interaction occurs only in the first stage, when information and objectives are collected and in the last stage when model results are delivered.

Other stakeholder groups may have expectations which are both different and diverse: while some groups may be hesitant, sceptical or suspicious of model use in a MSE framework, others may have a more integrated view: they concern themselves with the inclusion of local knowledge and with what happens to the model after project completion (will the model be updated and will new information be included?). For some of these parties model definition and development happen during the overall project as well as after its completion. This view goes to the core of the MSE and the adaptive approach: adaptation is not only fundamental to adaptive management decision making, but also the core of MSE.

This leads to viewing model development and stakeholder engagement as an iterative process in which a) the model shifts in complexity and in focus as the problem is better defined; b) stakeholder engagement increases in depth while the stakeholders improve their appreciation of what modelling can provide and trust in the process and c) modellers better understand how to relate to stakeholders and their concerns. From an information flow perspective, this results in a number of feedback loops between modellers and stakeholders as in Figure 11.

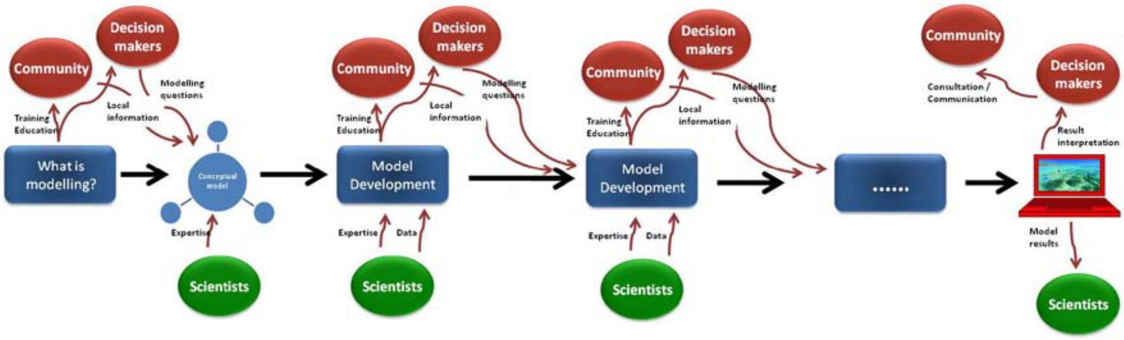


Figure 11. Alternative model development stages; stakeholder interaction occurs throughout the project and information flows into and out of the model at each step.

This also implies that engagement does not need to be a uniform step by step process, in which different stages follow each other in a predetermined way, rather it can be a parallel process in which different stakeholders are engaged separately at the same time as new engagement needs or opportunities arise along the way. Accordingly, it is not necessarily a pre-determined time order of the engagement which is important, as much as allowing for the process to shape itself and evolve according to the project needs.

The importance of information *processing* (in addition to collection and dissemination) is highlighted by recognising the existence of different types (Joshi, Saonee et al. 2007) and dimensions (Cross, Parker et al. 2001) of knowledge. This recognition should not be taken for granted when people with very diverse backgrounds need to communicate and exchange world views. This is of particular significance when the perceived final goal of communication is to ‘build the model’, which may lead to viewing information only in coded form, that is, in terms of numbers and trends that can be fed into and extracted by a model. This directly relates to the dichotomy between ‘classical’ and ‘modern’ view of governance. As discussed in the introduction, coded information helps decision makers understand the ramifications of policies on performance indicators but is less informative about change in people’s attitudes, which may alter the system and thus make or break the policies’ success. Interaction between modellers and stakeholders then helps translate non-coded knowledge (tacit, embodied, etc) into coded ones (essential for modelling purposes) and vice-versa (essential to translating model output into understanding, acceptance and finally behavioural change).

4.4 Engagement goals and actions

When stakeholder engagement is carried out within a MSE framework, a modelling team usually tries to achieve a number of goals, which include determining who the stakeholders are, explaining what models can offer, educating on model use, collecting information, understanding expectations, defining modelling questions and system indicators, learning the most suitable way to communicate information and building trust, ownership and participation. A number of actions need to be taken to reach these goals. Our experience has shown that there is no clear one-to-one correspondence between goals and required actions, which makes planning and carrying out engagement challenging. Some examples are straightforward: in human relations trust and acceptance are not obtained in a one-off effort, but take time to develop. Less obvious is that expectations and modelling questions develop with understanding of the modelling process itself and so do information collection and communication strategies. Modellers learn in the process too, which in turn affects their approach to model building.

The lack of a clear one-to-one correspondence between engagement goals and actions naturally implies an equally unclear relation between actions and engagement stages; very few actions can be planned, performed and ticked off: most need to be repeated and improved during the overall process.

In this section we describe some of the engagement actions we carried out. Their relation to project and engagement stages is described in the next section.

4.4.1 Understanding the stakeholders groups

The stakeholders related to this project were particularly diverse and could be roughly grouped into three classes: a) decision makers from local and state government agencies, b) local community and tourists and c) researchers. The latter should be considered stakeholders of the MSE because several research projects were related to the modelling effort either as data providers or as beneficiaries of the model results.

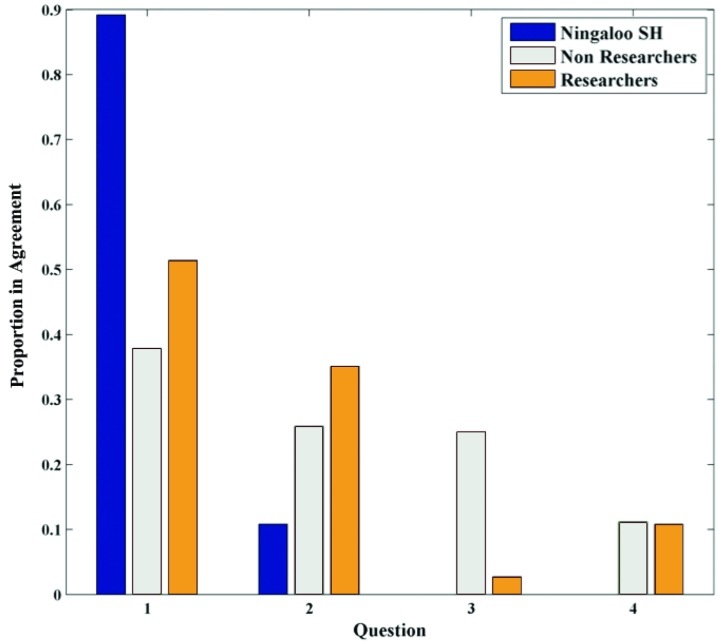
To improve interaction with them it is important to understand a) who the stakeholders are, what beliefs and values they hold and what drives their behaviours and preferences, b) what is the best way to communicate with them and c) how the existing network of interactions could most effectively be utilised to disseminate and collect information. These tasks have been carried out via a number of interviews and questionnaires.

A first type of questionnaire allowed us to evaluate how well the basic concepts of system thinking are understood. This was inspired by recent work highlighting how decision makers' and public misconceptions of accumulation and feedback processes may affect the types of policy they implement and support (Moxnes 1998; Moxnes 2000; Sterman and Sweeney 2002; Sterman and Sweeney 2007; Sterman 2008; Cronin, Gonzalez et al. 2009; Moxnes and Saysel 2009). Our results are described in details in (Boschetti, Fulton et al. 2010; Boschetti, Hardy et al. 2010). Two results are of particular interest. First, our data confirm the estimates reported in the literature: between 65 and 70% of interviewed people show difficulties in understanding basic stocks and flows processes (Sweeney and Sterman 2000; Sweeney and Sterman 2007; Sterman 2008), which, in the context of our application, could result in overfishing (Moxnes 1998) or overexploiting other limited resources, for example. Checking for the occurrence of these cognitive difficulties is important because overexploitation is usually attributed to either greed or lack of environmental and community concern and awareness; policies designed to target cognitive misunderstandings of natural process versus purposeful overexploitation can be considerably different. Similarly, misconception of causal effects due to feedback loops also holds potential implication for suggesting and supporting ineffective policies (Dorner 1996; Sterman 2008). The second interesting result is that performance of scientists, decision makers and the general public on these tasks was not distinguishable (Boschetti, Fulton et al. 2010; Boschetti, Hardy et al. 2010). While apparently surprising, this result also matches data found in the literature on expert knowledge (Camerer, Johnson et al. 1991; Ericsson 1993; Dorner 1996; Tetlock 2005). The main conclusions from these two observations are that a) even in simple decision making tasks models can provide a means of preventing common cognitive fallacies, b) modelling can provide training to develop intuition on system functions and c) these tools are useful to both experts and non experts.

A second type of questionnaire was used to assess the stakeholders' world views, that is, their perceptions of how the world functions and the values they hold. This was motivated by literature showing that people tend to polarise according to specific features which affect not only their decision, but also the way they process and filter novel information (Duckitt, Wagner et al. 2002; Unger 2002; Lewandowsky, Stritzke et al. 2005; Heath and Gifford 2006; Kahan, Braman et al. 2007; Mirisola, Sibley et al. 2007; Duckitt and Sibley 2009). One particularly thorny aspect of this is that people pay attention to information that is in accordance with (reinforces) their world view and tend to ignore anything which challenges it. This means effective communication of research results may need to be tailored accordingly, to stand any chance of getting new information past the inherent filters. People's social and political beliefs impact their attitude towards the environment (O'Riordan and Jordan 1999; Leviston and Walker 2010); these beliefs can be broadly summarised into 4 statements: *1*) 'the environment is fragile and will only be protected if there are large changes in human behaviour and society', *2*) 'the environment can be managed by the government and experts if there are clear rules about what is allowed', *3*) 'the environment can adapt to changes and technology will solve environmental problems eventually and *4*) the environment is unpredictable and we can't control what happens'. The vast majority of the stakeholders we interviewed subscribe to belief *a* (environmental management is a social problem), with a minority subscribing to belief *b* (environmental management is a governance issue). No stakeholder subscribed to belief *c* (environmental management is a technological/economical problem) or to belief *d* (environmental problems are hard or impossible to manage). Unfortunately, we ran this questionnaire only very late in the project, during our workshops and public presentations with local stakeholders in Carnarvon and Exmouth; it is reasonable to believe that these skewed results are a consequence of the voluntary nature of both the participation to our workshops and that a more uniform result would be obtained if a larger proportion of the population was interviewed.

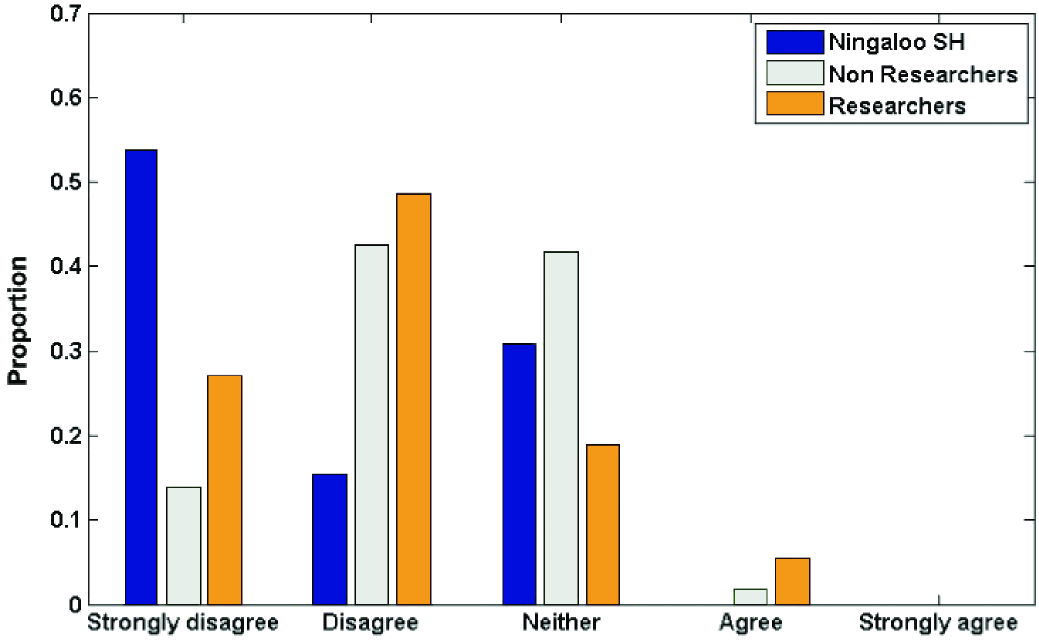
It is interesting to investigate whether these results are peculiar to the region. In order to do so, we ran the same questionaries via an on-line survey targeting two different groups: a) researchers related to environmental studies and b) general public (non researchers) not related to the Ningaloo-Exmouth region; for each group, 37 and 116 people responded to our survey, respectively. An example of the survey can be found at www.surveymonkey.com/s/csiro_worldviews1. The comparison of answers to the above question for the three groups is presented in Figure 12. The distribution of worldviews is much more uniform in the general public, as discussed in (O'Riordan and Jordan 1999); for the researcher group the distribution is somewhere in between the general public and the Ningaloo stakeholders. The difference between each pair of groups is statistically significant. Nevertheless, we observe that the larger the sample the more uniform the distribution of answer is, which leaves the possibility that a more exhaustive sampling of stakeholders in the Ningaloo-Exmouth region could also show more widespread opinions on this topic.

Figure 12. Summary statistics of the answers to the Worldviews questionnaire. For each of the 4 questions (horizontal axis) the bars show the relative (i.e. proportional) agreement within each of the responder groups (so the vertical axis is the proportion of the respondents of that type in agreement with the regional rresponses). Blue bars represent the attendees to the workshops and presentations in Carnarvon and Exmouth; gray bars represent the general public not related to the Ningaloo-Exmouth region; orange bars represent researchers in environmental disciplines.



A third type of questionnaire explored the preferences for how scientific results should be presented. There are indications that this is not just a matter of personal taste but it is also affected by personality types (Dorner 1996; Stanovich 1999; Sorrentino and Roney 2000). Needless to say, matching the style of information delivery with preferences can be crucial for effective reception. Most stakeholders stated they preferred simple, condensed and intuitive presentations, with a minority of them interested in more detailed information. Furthermore they perceive the ability of communicating difficult information in a simple manner as a sign of scientific competency.

A fourth type of questionnaire explored cognitive attitudes (not to be confused with IQ, (Stanovich 1999)), attitudes towards uncertainty and how novel information is processed. This questionnaire is longer and was administered only to the participants of the modelling workshops. Because of the smaller sample size, these results are less reliable. Despite the results being fairly spread out, participants appear to agree on a number of issues, all of which are encouraging, given the management task ahead. Attendees claimed to be a) open minded to processing new information, considering novel possibilities and willing to change their opinion when warranted; b) aware that difficult problems need careful analysis and planning; c) wary of rushed decisions; d) accepting that laws and policies may need to adapt to a changing world; e) concerned about environmental problems not only for their impact on themselves, but mostly on the local and non local communities; f) committed to improving and preventing further environmental pressures and g) strongly believing in science. Whether these results are also due to the selected audience is worthwhile testing with further surveys. However, as for the Worldviews questionnaire in Figure 12, we run a subset of these questions via the on-line survey, as described above (the questions can also be found at www.surveymonkey.com/s/csiro_worldviews1). In this case, the answers between the two groups differed much less than for the previous survey. Only one item gave a statistically significant difference: “Wise people make fast decisions”. Responders from the Ningaloo-Exmouth region seem to be far more wary than others of rushed decision making, followed by



the researcher group and the general public (see Figure 13)

Figure 13. Answers to a question related to the appropriateness of fast decision making. The question was asked to three groups: a) attendees to the workshops and presentations in Carnarvon and Exmouth (Ningaloo SH), b) general public (Non Researchers), not related to the Ningaloo-Exmouth region and c) environmental researchers (Researchers).

Finally, social network analysis (e.g. (Bodin and Norberg 2005; Ernstson, Sorlin et al. 2008)) was used to assess the network of interactions among different groups involved in the project. This task was carried out half-way through the project. Collaboration and information dissemination among the overall research team was the main concern behind this activity. While the team, as a whole, may have all the information needed for the overall project, ensuring that this information reaches the specific researcher or manager who needs it is much less straightforward. Interviews were carried out with 44 individuals from government and non government organisations having distinct continuing roles in the project. Participants were asked to draw an egonet (or egocentric map (Marsden 1990; Wasserman and Faust 1995)) of the parties they expected to interact with and the perceived relationship between them. This provided a provisional map of a) where critical positive interactions occurred, b) where disruptive feedback loops or structural holes may occur and c) which are the key nodes for the transmission and interpretation of particular forms information (Reagans and Zuckerman 2001).

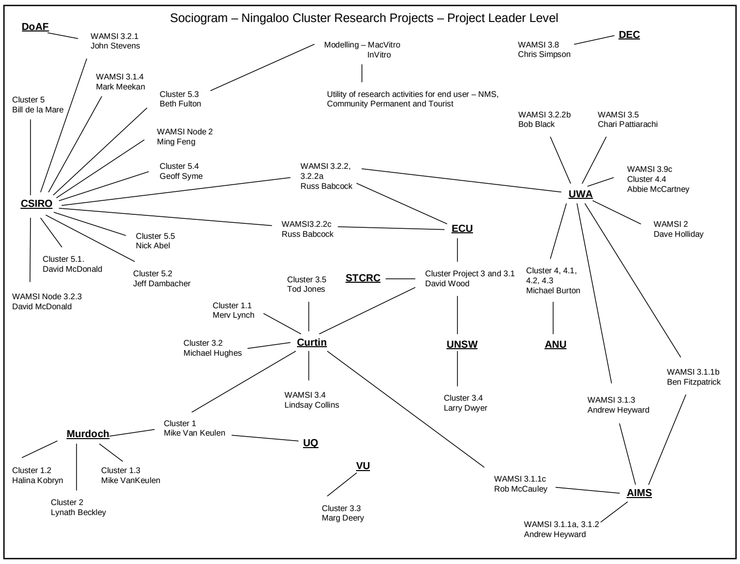


Figure 14 Sociogram of Ningaloo Cluster Research Projects midway through the project.

A full description of the reconstructed social network can be found in (Dzidic, Syme et al. 2010) and is reproduced in Figure 14. It shows a wide variability between project interconnections, with particularly weak inter-group connections, that is between research, management, industry and local stakeholders. This appears to be the outcome of groups having only 1 or 2 connections with other groups. While connections within a group seem to be quite strong, the disruption of the few inter-group connections may isolate an entire group and have a large impact on the overall project connectivity and organic management.

4.4.2 Introducing and building the models

In the MSE framework, a large section of the stakeholder group should interact with modelling: technical staff in public or private organisations may become model users by inheriting the model from scientists, some decision makers will interpret model results to formulate and implement policies and the community will hopefully support and follow polices if they understand how and why they were developed. It is reasonable to believe that familiarising with the model will benefit all these parties and make it more likely that MSE makes an impact.

For this to be possible modellers need to provide a certain level of education in modelling philosophy and process: a computer program simulating an individual stakeholder’s everyday environment and daily actions can be received with suspicion and a certain level of (healthy) scepticism needs to be overcome (‘how can a model account for the complexity of daily life?’, ‘how can a model prediction be believed, when the future is so uncertain?’). It is the modeller’s responsibility to explain why we model, how we do it, how uncertainty is addressed and to what extent the model results are informative.

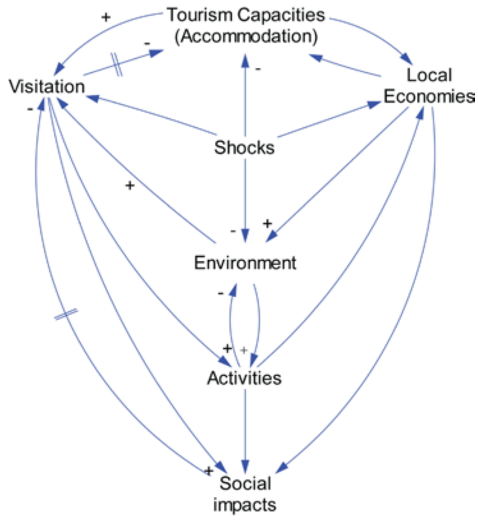


Figure 15. Example of conceptual model, from (Jones, Wood et al. 2010)

We carried out this task via four types of activities: a) seminars and public presentations, b) conceptual model building, c) modelling showcases and d) modelling workshops. While seminar and public presentations are what a modeller is mostly familiar with, since they match the style of scientific communication, delivery style needs to be considerably changed to make it accessible to non technical audience. This has occasionally been difficult and the supervision of a communication officer has been of great help. This was partly due to presentation style and partly due to some stakeholders' lack of familiarity with the topic. Our experience is that repeated workshops are needed for successful reception (we have collected anecdotal evidence of 'flashes of understanding' occurring suddenly at the 3rd or 4th presentation as a result of a slightly different communication styles[4], despite both presenter and attendees thought such understanding had already been reached; whether these flashes relate to information style, serendipity or the effect of repeated deliveries is probably worth exploring).

Conceptual model building is the activity in which the main drivers of a system are highlighted as components of the model; this usually results in a diagram summarising our understanding of how the system works (for an example, see Figure 15). This activity has been carried out via workshops and has been very useful in setting up the model scope, capturing local knowledge, ensuring stakeholder concerns are addressed in the model and providing ownership of the process. It also holds a considerable educational potential (Jones and Wood 2008), since it provides an intuitive way for non technical stakeholders to visualise how real world processes map into a model, and it can offer a more effective training exercise than model use only (Druckman and Ebner 2008).

While not all stakeholders wish to become model users, many of them may want to be familiar with the model development to better understand what it can offer to the final decision making

[4] And in some cases switching presenters was very useful, a new take on the same topic providing a new entry point to the idea. Once the idea made sense then all presentations were understandable. This was not simply a reflection of "good" and "poor" presenters, rather that there are multiple backgrounds and contexts amongst the presenters and listeners and the best matches had to be found between them to facilitate true communication.

process. Moreover, some people needed to build trust in the modellers and modelling process, to see how information was used and how it was possible to learn and increase understanding. This is where regularly showcasing model development and intermediate results is important. This step is also important because of another difference in communication and thinking style between modellers and most stakeholders: modellers necessarily deal with mathematics and computer programming, which requires abstract thinking, something large sectors of the population are not comfortable with (Stanovich 1999). Showcasing model development via practical examples, clearly related not only to the overall project task but also to the concerns of specific stakeholders groups, considerably help the process. We have achieved this by using what we defined as single-component models in (Boschetti, Fulton et al. 2010). These are fairly sophisticated models of a single component of the Ningaloo-Exmouth region, like fishery or tourism. They have also highlighted which aspects of these problems needed be included into the final full-system model and provided intermediate results to better define the model scenarios.

After the conceptual model is turned into computer programs and the stakeholders have seen the models developing through a few stages, modelling workshops allow interested parties to obtain hand-on experience with using the models. In these workshops we used temporary models of intermediate complexity, which we defined as ‘shuttle’ models (Boschetti, Fulton et al. 2010). They allow us to model all crucial components of a system, but are a simplified version of a final full-system model. In the workshops, first we defined a number of exercises for the attendees to follow and reproduce in order to familiarise with the models interface and the result visualisation. We then proposed a more complex task, in which relatively simple scenarios were investigated and reported upon. Following a recommendation in (Dorner 1996), these tasks were carried out by small teams of 2-3 attendees collaborating in front of a single computer. This exposure to the modelling process and to learning had a broader social value as well. It is never possible for every member of the community (or industry or other interested group) to directly reach the modellers or the models. Instead the broader group relies on “role models” or “representatives” on which to proxy their views. For instance, while a specific individual in the community may not have had time to come to a workshop and may not have direct knowledge of the models and whether to trust them, they can look to information coming from some one who has and make their judgements based on the experiences, impressions and decisions of that representative (“I don’t know whether to trust models/modellers, but Mary has looked into it and she says she is confident that they know what they are doing”).

4.4.3 Scenario development

The final aim of the MSE is to assess what futures are desired and possible and to evaluate their likely trade-offs. These futures represent the ‘questions’ we ask the model and the ‘answers’ the model provides give us some indication of the likely trade-offs. Formulating these questions is not easy: a stakeholders group as diverse as the one related to the Ningaloo-Exmouth region can naturally produce a very diverse range of desired futures and opinions on what is acceptable. Also, only a limited number of questions can be asked to complex models for the computation, analysis and communication of the results to be manageable. These issues are discussed in Chapter 6.

Here we focus on an unexpected further difficulty we encountered: the lack of familiarity with modelling (both in term of philosophy and practise) made it difficult for some stakeholder groups to formulate the questions, that is to define what scenarios the model was expected to run. This resulted in paralysis or in asking questions either too general or too specific. Modellers found this issue perplexing and at times frustrating, because of its effect on the project workflow. This is a very practical example of how different backgrounds, assumptions and knowledge have affected communication and it highlights how crucial stakeholder engagement is.

To some modellers it appeared that the model was supposed not only to provide answers, but also to formulate questions, which is logically impossible from a modelling perspective. However, it is indeed what is supposed to happen from an engagement perspective, if we accept that modelling is not what expert outsiders do, rather a process which included experts, stakeholders and the local community. Indeed, a combination of repeated modelling seminars, workshops, showcases and one-to-one meetings eventually did deliver the scenarios for the full-system model, which are described in the glossary in Chapter 6. It is important to notice that, while some workshops were organised specifically to design scenarios, these scenario eventually were developed via a more complex and ad-hoc process, involving phone calls, e-mails as well as workshops designed for different purposes. This is a further example that engagement goals and actions do not necessary coincide precisely.

4.5 Engagement stages

Here we discuss the difference between a) how the modelled team expected the engagement process to develop, b) how it was actually carried out and c) the lessons we can draw for the experience, leading to a possible future improved process.

Figure 10 summarises our expectation on how the stakeholder engagement would develop. The process is clearly divided into four stages: 1) model planning and data collection, 2) model development, 3) model parameterisation and 4) model runs, with dissemination and discussion of the results. Stakeholder engagement in this framework happens early in the project, when information mostly flows into the model process and at the end when it flows towards the decision makers, other research projects and local community.

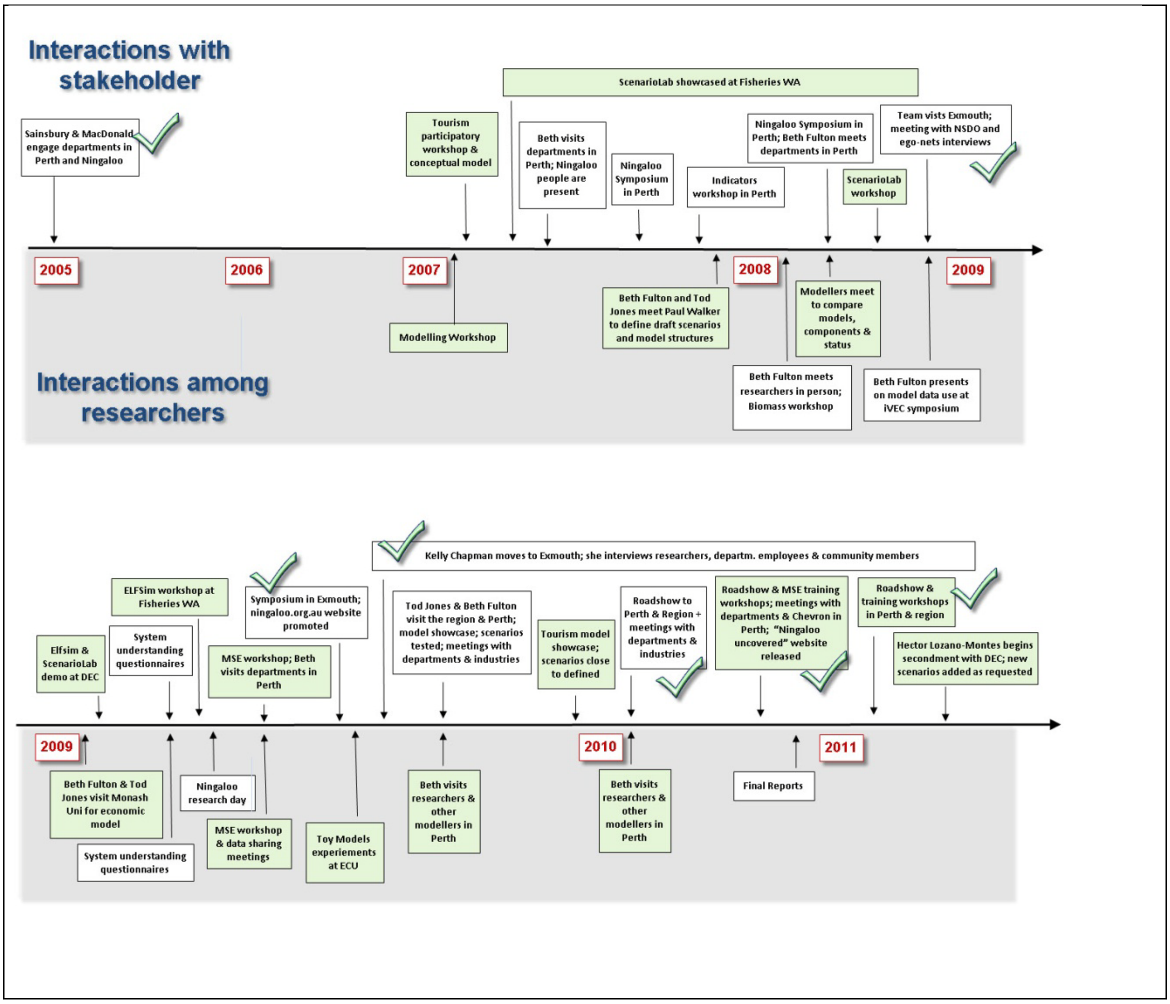


Figure 16. Actual stakeholder engagement process, as carried out during the project. Items above the time line indicate interaction between modellers and stakeholders; items below the time line indicate interaction among modellers and other researchers. Filled boxes indicate actions which directly involved model use or development. Accents indicate interaction which occurred in the Ningaloo-Exmouth region.

In fact, our engagement process followed a different path: Figure 16 summarises the actual engagement actions taken by the modelling team during the project. Early stakeholder engagement was initiated before project commencement by properly designated staff. Unfortunately, staff turnover and illness interrupted this process; two years later the modelling team restarted and carried out the process directly. This has included several one-to-one meetings, workshops with other scientists, local and state government organisations and local communities. In particular, a total of 8 trips were taken to the Ningaloo-Exmouth region by different team members. These interactions between team members and stakeholders allowed for model improvement and acceptance, and also helped develop the questions the model needed to address. Pivotal to community engagement was the extended presence in the region of Kelly Chapman, a PhD student with professional experience in moderating stakeholder interactions whose effort not only filled the gap between local community and the research team perceived as outsider, but also informed the modelling team of the need to ensure local acceptance and ownership of modelling research and how to achieve this.

The actions in Figure 16 resemble a continuous, two-way engagement process as in Figure 11 more closely than a sequential process as in Figure 10. However, a large full-system model, like InVitro, requires a software engineering team to develop, whose workflow resembles Figure 10 more closely than Figure 11; clearly a certain level of flexibility is required by model developers, modellers and engagement team alike, in order to ensure that the model development proceeds smoothly and the engagement both adapts to the stakeholders needs and informs the final model. In this project, this interaction has been carried out mostly via the use of toy, shuttle and single-component models, which are described in detail in Chapter 5. It is likely that a similar approach is beneficial for future projects, allowing for a reasonable compromise between proper long-term software engineering planning and the ad-hoc requirements which comes about when a project adapts to different parties interacting and communicating.

4.6 Impacts: What has changed and what may change

Inspired by an ideal definition of impact (Wolpert and Tumer 1999; Boschetti 2007), the fundamental question we would like to answer is 'how different would the outcome of this project have been so far and will be in the future, had no stakeholder engagement happened?' While answering the question precisely is impossible, even a rough evaluation can be very effective in improving the design of future projects (Wolpert, Tumer et al. 2004; Boschetti and Brede 2008). The above question can be framed within the Integrated Figure of Merit for public good research with multiple stakeholders (Geisler 1996), according to which research (or modelling) outputs can be thought of in terms of four temporal and conceptual classes: a) *immediate* (e.g. publications, other measurable research outcomes and changes which can be detected promptly in the system), b) *intermediate* (e.g. the number of regular model and MSE users), c) *pre-ultimate* (e.g. specific management activities that can be demonstrated to have occurred from the MSE implementation) and d) *ultimate* (the role of this project in achieving overall community benefit).

This chapter is written in coincidence of the immediate stage and consequently pertains only to this type of results. Intermediate and longer–term results can be monitored using an influence diagram, tracing model use through differing levels in the stakeholders network, as described in (Geisler 1996)) or an analytical hierarchy process, as suggested in Syme et al. (2006). In what follows we report on some immediate impacts we detected a) in the stakeholders and researchers networks, b) in the definition of the questions to ask the model and c) in the development of the model itself. We then describe some less tangible impacts we noticed and discuss how to monitor possible future, longer-term impacts.

4.6.1 Networks

Through the course of the work there has been at least a partial evolution of the structure of the network of community and research contacts associated with the broader Ningaloo research program.

Work by Dzidic et al (2011) showed that initially there were some connections between researchers and regulatory bodies, though few with the general community (Figure 17). While we were unable to replicate the survey of the regulatory body or community we did have an opportunity to revisit the research groups. As you can see in Figure 18 an extensive number of new connections were created through the course of the project. This is indicative of the trans-institute interest of the research, but is also due to the growing transdisciplinary nature of the entire programme of research as well as the integrative use of the models (and other methods, like the action research performed by Kelly Chapman at Edith Cowan University) as a means of synthesising information across many fields.

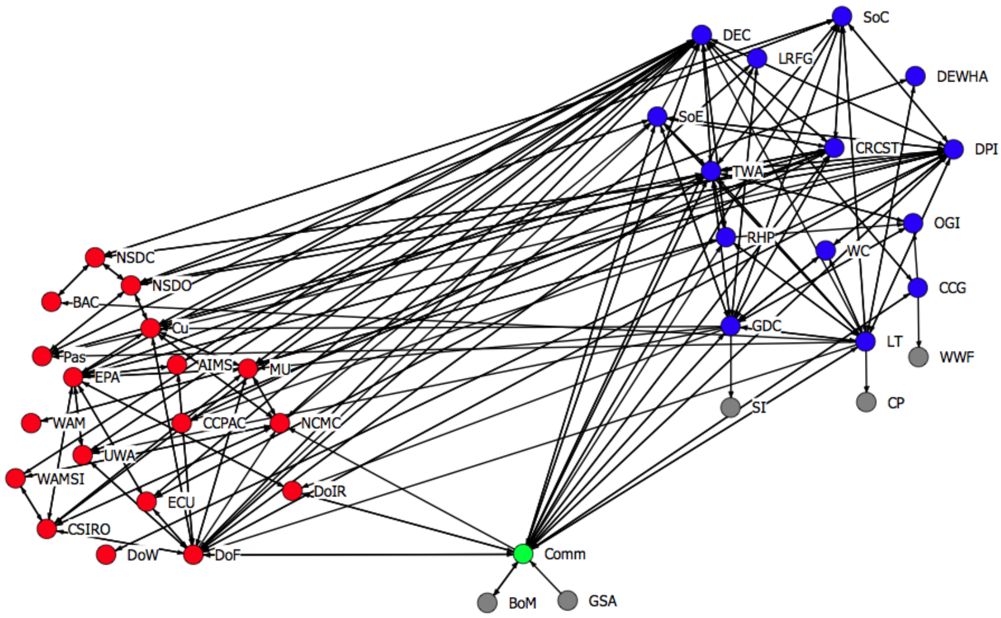


Figure 17: Original sociogram of the connections amongst Ningaloo stakeholder groups (redrawn from Dzidic et al 2011). Red circles indicate research institutes, blue are regulatory bodies and other organisations active in the Ningaloo-Exmouth region, green is the general community and grey are preferal connections.

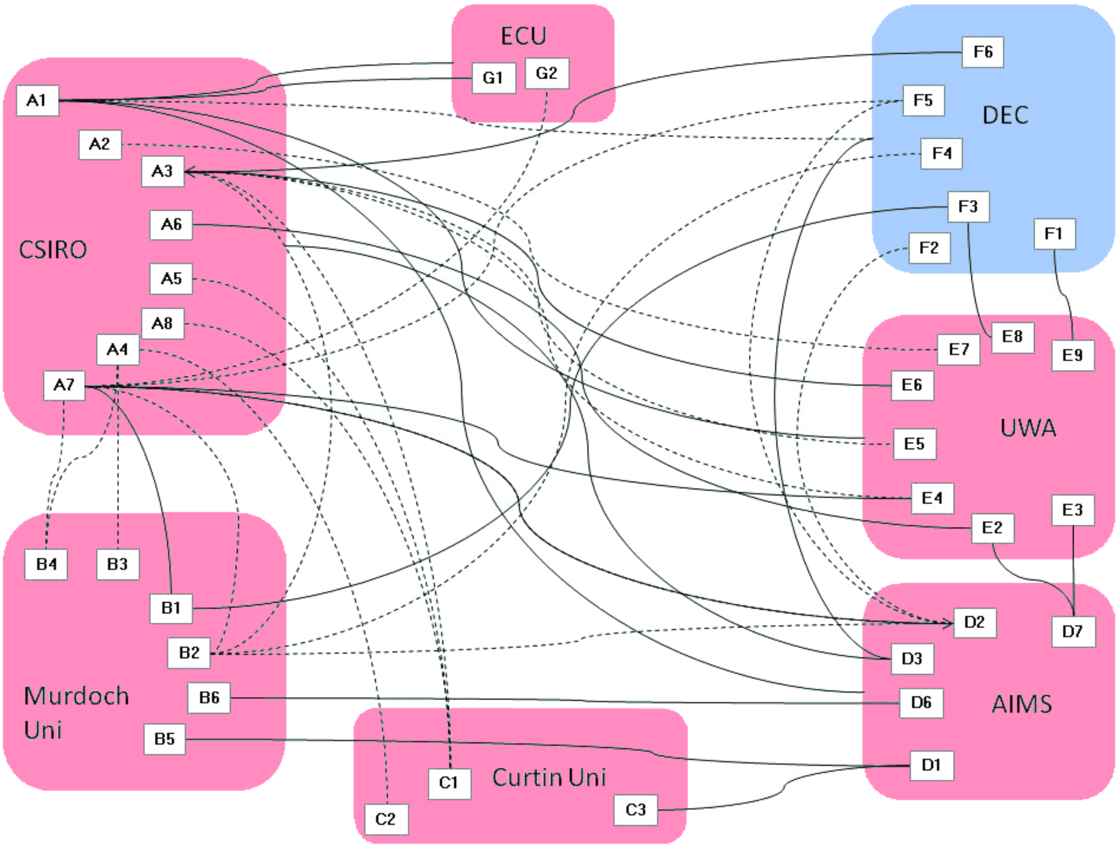


Figure 18: Sociogram for researchers working on Ningaloo research at project completion. Pink boxes refer to different research institutes that were red in Figure 17 and the blue box is an institute marked in blue in Figure 17. Small white boxes refer to individual researchers. Dashed links refer to interactions at researcher level that were included in the project plan. Solid links refer to interactions that were not included in the project plan and were developed adaptively during the project.

4.6.2 Management questions

Conservation, human activity and development in the Ningaloo-Exmouth region need to be consistent with the directions set out in the existing Ningaloo Marine Park management plan (MPRA and CALM 2005), which aim to ensure that *"the marine flora and fauna, habitats, sediment, and water quality … will be in the same or better condition in 2015 than in the year 2005").* Together with broad guidelines, the plan also highlights objectives and performance indicators for different components of the park which can be divided into three broad classes:

1) clearly defined ecological objectives, aimed at ensuring that the general conditions of specific ecosystem components (macroalgal and seagrass, coral reef, coastal biological communities, etc) improves, or at least does not deteriorate;

2) broadly defined ecological objectives, to be specified following research or community input (indigenous heritage, land and seascapes, various recreational activities);

3) various economic and extractive objectives, which need to be defined as part of the process.

It is thus important to evaluate to what extent stakeholder engagement delivered on defining the objectives and indicators for which public consultation was sought. The entire list of final modelling questions can be found in (Fulton 2010); of particular interest is to consider which questions arose specifically out of stakeholders concern.

State government managers in Perth showed specific concerns with a) the implications of development and fishing zoning decisions on infrastructure requirements, b) the implication of returning the coastal strip from pastoral leases to State Government management and c) a rough assessment of the overall carrying capacity of the region.

Regional stakeholders focussed on a longer list that includes both more specific concerns and ones with a longer time span. The list includes:

1) general implication of the region being listed as a World Heritage Area;
2) impact of managing sectors in an individual versus integrated manner;
3) construction of boat ramps at three specific locations;
4) tradeoffs in development of multiple small tourist sites, vs large camps vs large resorts;
5) construction of a bitumen road connecting two tourist locations;
6) tradeoffs in dispersed vs concentrated access with regard to all activities;
7) implication of different regimes of land release for development;
8) impact of system shocks (climate, economic, epidemic etc) and climate shifts;
9) implications of moderate to large population growth.

The final questions we asked the full-system InVitro model can be found in Chapter 6. As can be seen, these have been mostly influenced by the specific concerns collected during the stakeholder interactions, which focus the general issues highlighted by the Ningaloo Marine Park management plan. For instance, the implications of (i) increased (or decreased) costs and ease of access; (ii) changed zoning or bag limits; and (iii) different kinds of development (whether different forms of tourism developments or growth of other sectors).

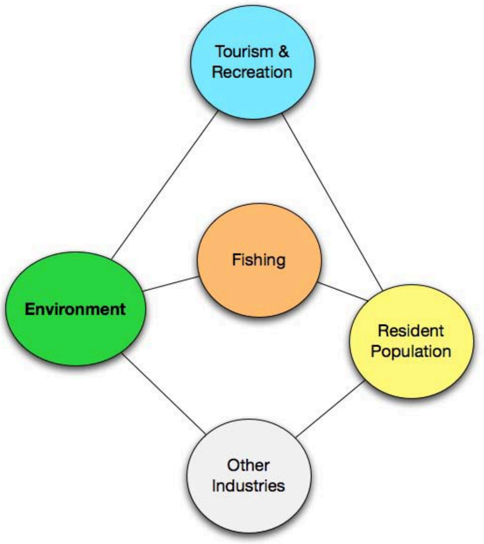
4.6.3 Model development

Stakeholder engagement impacted the model development in two ways. First, it inspired the implementation and use of a set of ‘small’ models (toy-models, single-component models and shuttle-models) as described in Chapter 5. Second, it influenced the structure and parameterisation of the full-system InVitro model, taking it from a simplified form of a version inherited from a previous project (Gray, Fulton et al. 2006) to its final Ningaloo-specific implementation. The technical details of this transformation are beyond the scope of this work, but a rough appreciation can be obtained visually by comparing the model structures at different stages through the project, as summarised in Figure 19, with the components of the full model included specifically after discussion with stakeholders shown in Figure 20.

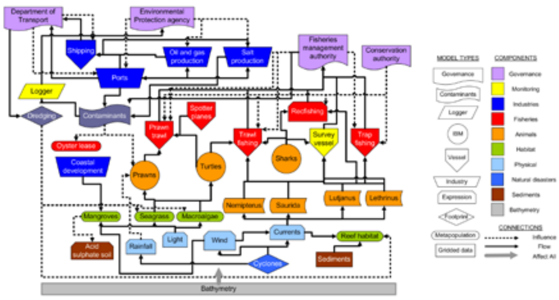
4.6.4 Other less measurable outcomes

Feedback from purposely designed questionnaires and casual conversation suggest that the stakeholders who got involved more closely with the modellers, via presentations and workshops, have acquired a deeper understanding of what models can provide and how they can be used in decision making. This is promising; as discussed in Section 4.4.1, to what extent this is due to the selected feedback we received and to what extent such learning has been achieved in the overall stakeholder group is something worthwhile monitoring in 6 to 12 months from project completion. This information can feed into designing better future training and interaction processes.

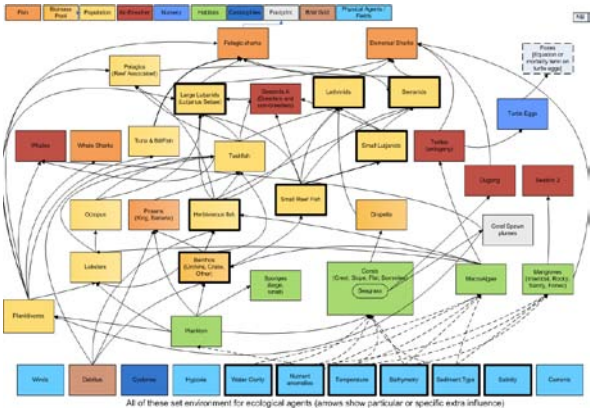
Engagement has also affected some members of the modelling team, some profoundly, especially the ones less experienced with this process. This will reflect, depending on the modeller's role, on more attention to model design in future projects, ensuring user-friendliness in interface and result visualisation, placing more focus on interacting with users early in the project and seeing them as participants, rather than recipients of the modelling effort.



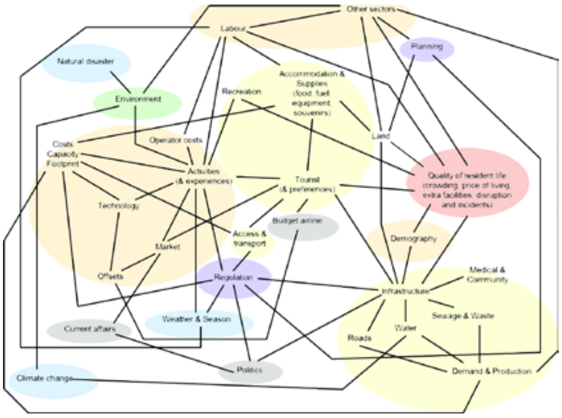
1. Conceptual Model



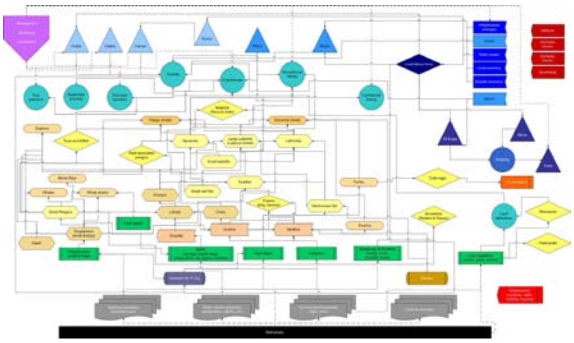
2. Pilbara InVitro model structure used as an implementation starting point



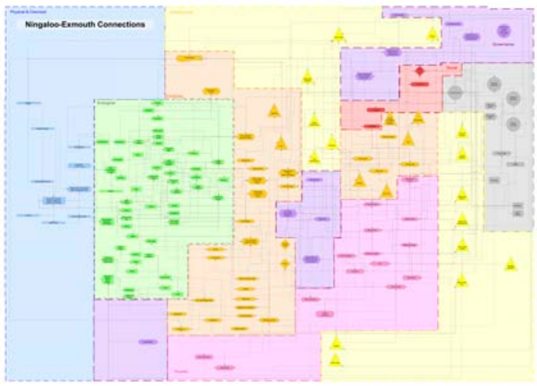
3. Ecological components (after biological advice)



4. Tourism relevant components (after expert and local advice)



5. Initial full system model (focusing on direct connections)



6. Final full system model form

Figure 19. InVitro model structure at different stage through the project; click on the images to view an enlarged version (stored in Appendix A - System Diagrams).

Finally, a considerable role has been played by the media (local and national radio interviews and news and local newspapers) in informing and educating the local community about the project and its initial outcomes. This is not a communication avenue naturally used by scientists and a lot has been learnt in this interaction which will benefit future projects.

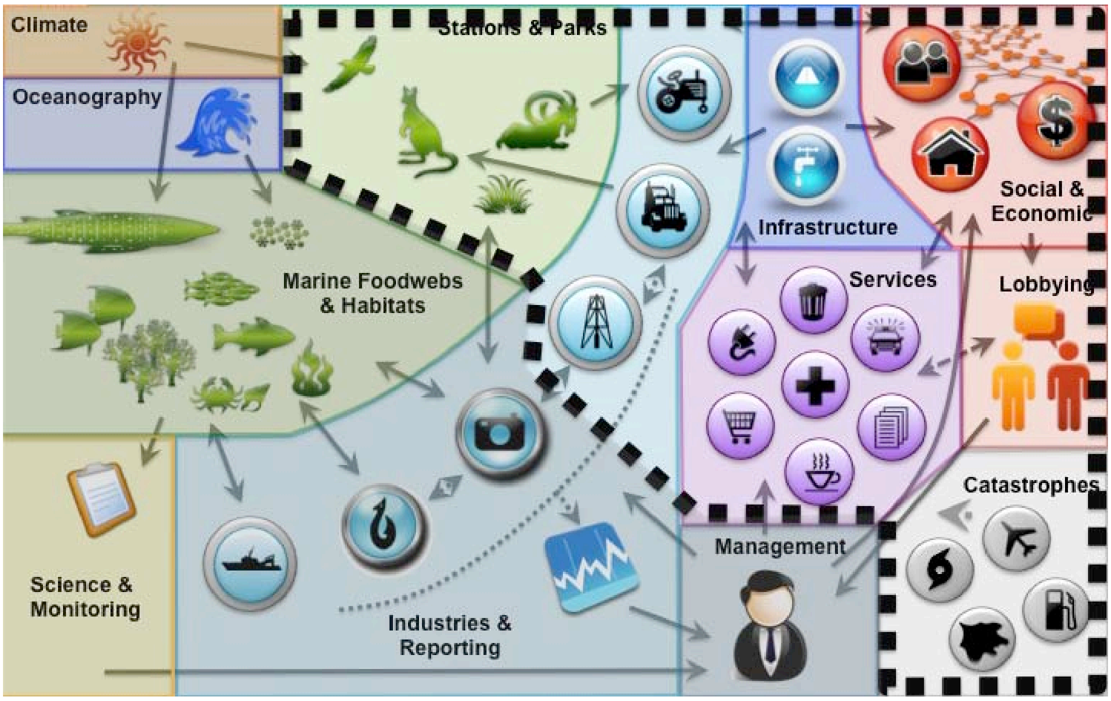


Figure 20: Simplified schematic diagram of the Ningaloo-Exmouth system. The highlighted region edged with a thick dashed line (top right half of the diagram) shows the components included after consultation with stakeholders.

4.6.5 Monitoring future impacts

Before we address this item, it is worth reflecting on why evaluating the impact of stakeholder engagement (and of the overall project) is so difficult. The very same uncertainty, serendipity, change of network relations and ecological, economic and social adaptation which make it so difficult to establish and predict causes and effects will inevitably act upon the system in the future; this *will* generate unexpected dynamics and surprising events, no matter how well we improved system understanding that led to effective management structures. To a certain extent, devising a reliable method to measure project and engagement impact assumes reliance on our ability to predict how local future events would occur, had research and engagement not happened. If we were able to do so, the system would probably be simple enough not to require a large research project in the first place. When devising a solution is impossible (as in all complex problems, that is), the best we can do is to use knowledge and experience to improve on current practises; this applies also to measuring research impacts.

This effort is well worth carrying out. In the short to medium-term all parties need to monitor project outcomes: decision makers and project initiators have an administrative pressure to justify the work; scientists need to demonstrate their relevance outside academia; local stakeholders' effort in trusting and collaborating with the process will likely be reinforced by seeing practical outcomes. But there is also a longer-term purpose in monitoring project impacts. At the core of involving stakeholders in designing a MSE process there is the intent to predict, prepare for and, as far as possible, steer the future. Mankind has tried to do this since the beginning of time, with efforts becoming more rigorous, formal, frequent and larger since WWII (Bezold ; Bootz ; Coates, Durance et al. ; Durance ; Ringland). Unfortunately, much less effort is put into evaluating these projects: which one predicted better? Which ones better steered the future according to the stakeholders' intent? Under what conditions did they work or fail? An effort pertaining to the future must wait for the future in order to be evaluated; not carrying out this evaluation is like performing a lab experiment without bothering to check the results. If projects like these will be initiated in other Australian regions, knowing what worked and what failed in the Ningaloo-Exmouth region will be of immense value.

4.7 Cost of engagement

Despite no staff being specially allocated to stakeholder engagement over the entire project and despite the process has been carried out in an almost ad-hoc manner, at the time of project completion this task had involved a considerable amount of effort. This not only includes organising meetings, workshops and related travelling, but also writing toy and shuttle models and initiating and following a considerable flow of e-mail and phone communication.

According to a rough estimate, stakeholder engagement accounted for approximately 43% of the effort of the overall modelling team, the remaining going to data collection, model development and parameterisation and result visualisation. This only adds to the importance of properly resourcing and facilitating this process at project inception.

The above costs do not include training the modellers on how to successfully run the engagement process, since no such training has been carried out, which leads to the question of who is best suited to interact with stakeholders. With few exceptions, most modelling and science training does not provide for public presentation and communication, a problem that local stakeholders soon realised and pointed out in a series of interviews (Chapman 2010). Trained communicators, and even actors, could overcome this problem. There are several benefits in considering this option (Dray, personal communication): first, professional communicators, and actors in particular, are trained to improvise and make the most of unexpected opportunities which may arise during a workshop; second, they are necessarily seen as independent brokers, being external to the problem as well as to the research; third, as highlighted in Section 4.4.1 stakeholders strongly prefer simple, jargon-free, intuitive presentations, which also reflects on the perception of the science quality. On the other hand, in the same interviews, stakeholders also highlighted the importance of interacting directly with the very scientists who carry out the research, which is crucial to building the trust needed for subsequent model use. This may suggest either forming a mixed team of professional communicators and researchers, or providing researchers with training in stakeholder engagement; planning, coordinating and rehearsing for public presentations (something not common and often not well received in the scientific culture) may also need to be incorporated in future projects.

4.8 Discussion

We conclude with a slightly more general analysis of why stakeholder engagement in a MSE project is important. The greatest challenge in modelling ecological and social system lies in capturing adaptation as well as the chance occurrences which have the potential to steer the system towards unexpected directions; in other words, in complex system science jargon, to model ‘emergence’. While a considerable amount of work and analysis has focussed on this task (Crutchfield 1994; Kauffman 2000; Rosen 2001; Wiedermann and Leeuwen 2002; Kubic 2003; Laughlin 2005; Boschetti and Gray 2007; Ryan 2007; Boschetti, McDonald et al. 2008; Prokopenko, Boschetti et al. 2008), the problem is not technical, rather fundamental since it relates to the impossibility of capturing the behaviour of an open system (reality) within the constraints of a closed system (the model) in which all features have to be determined a-priori and cannot (easily) change as more information becomes available and new behaviours arise. One example clarifies this problem: some stakeholders involved in the engagement process are the very agents in the model; this is true not only for a generic, name-less tourist and for a decision making role subjected to staff turnover, but also for some specific tourist operators, fishers and farmers (the ones with *real* names and surnames) who will influence and will be influenced by the regional development. From a modelling perspective, there is a considerable difference whether the behaviour of these very people is included or not: while our understanding of celestial mechanics will not affect the motion of the planets, our understanding of these actors will affect their actions and as a result the long-term behaviour of the system itself. As someone may change behaviour after having the future read by a palm-reader, a stakeholder may change behaviour after seeing the implications (or lack of) of his/her actions in the simulated world. As discussed above, behavioural change is indeed one of the aims of the project itself. This is a potentially very powerful feedback loop between model and stakeholders. How the stakeholders’ behaviour may change is not easy to predict, since it is the results not only of the model simulation, but also of worldviews, life history and chance occurrences. Once a change occurs, the only way to account for it in our future model is to re-parameterise the model or to rewrite some of its components[5]. Of course this is true also for some ecological process, including change of behaviour of certain species as a result of adaptation to pressures like fishing and climate change. To a certain extent model adaptation has already happened as a result of the workshops carried out: some computer code has been altered, some features have been removed, others added, others tuned; and, as we have seen above, some behavioural change has already occurred in the stakeholder group at large.

Viewed in this perspective, stakeholders engagement, as well as further data collection and MSE-inspired monitoring provide the link between the model and the real world, making the model ‘interactive’ and turning it into an ‘open’ system. Said differently, if these stakeholder interactions did not happen and the model could not adapt to the process, the model would miss the implication of its own existence: it would soon lose its relevance as a model of the system (or at least be a less complete model). These issues are well understood in theoretical computer science and artificial intelligence (Rosen 1985; Wegner 1997; Wiedermann and Leeuwen 2002), and are likely to provide advances in fields like distributed and embedded computing which, together with developments in social sciences, can benefit future MSE implementations.

[5] This is indeed what happens to a human brain when new information and experience become available.

5. MULTIPLE MODELS AND MSE

5.1 Summary

We have developed a state-of-the-art, full-system model (InVitro) to assess the likely outcomes and tradeoffs from different possible future developments of the Ningaloo-Exmouth region. InVitro (Gray, Fulton et al. 2006) includes some of today's best knowledge and technology in modelling biophysical, ecological and social processes and, most important, their interactions.

Because of project constraints, InVitro's implementation and parameterisation occurred at the same time as the regional Management Strategy Evaluation (MSE) development. This resulted in two challenges. First, we needed intermediate results in order to address some decision-makers' concerns, feed into other research projects and tune the model behaviour on specific sectors. Second, some stake-holder groups lacked familiarity with modelling in the broad sense, which prevented both building trust in the model's future use and formulating modelling questions; the latter issue in particular was unexpected and had the potential to affect the project workflow.

To address these challenges, we developed a number of smaller models, which helped both interacting with stakeholders and feeding into InVitro development. Two single-system models focussed on fishery and tourism management, respectively; these enabled us to liaise with these two important sectors, collect information, showcase temporary results and tune these components for their inclusion in InVitro. Two game-like toy-models were developed for educational purposes, to show stakeholders how even apparently (and deceptively) simple decision problems can benefit from modelling support. Finally, two simpler versions of the full-system models were developed to introduce and train stakeholders in using models to address multi-sectors management questions.

We believe this effort had a considerable impact on the project. First, by showing its use in addressing actual, local, everyday problems, it helped change the perception that modelling is merely an abstract, academic activity. This has been essential to build trust and acceptance in the overall MSE approach. Second, it has been pivotal in defining the modelling questions for the final InVitro simulations. Because of the latter, the outcome of the MSE would likely look quite different today, had a multi-model approach not been taken.

In this Chapter we describe these tools and how they have been used to engage stakeholders. We conclude by drawing some conclusions from this experience and highlight how this can feed into possible future projects.

5.2 Introduction

This Chapter focuses on the role of multiple computer models in a large MSE project. MSE is proposed as an effective approach to complex socio-ecological problems which require learning, adaptation and evaluation of difficult trade-offs. Modelling is a crucial component of the approach, allowing for evaluation of the likely outcomes of available interventions before implementing them in the real world. There are other benefits modelling can provide, which relate to engaging different parties involved in a MSE project, including researchers, decision-makers and stakeholders. Here we focus on three specific items:

1) allowing a less biased interpretation of available information;

2) allowing for learning specific skills and attitudes needed when facing complex problems;

3) providing an avenue for communication and collaboration.

Allowing a less biased interpretation of available information is important because people with different worldviews may interpret and draw very different conclusions from the same information (O'Riordan and Jordan 1999; Duckitt, Wagner et al. 2002; Unger 2002; Lewandowsky, Stritzke et al. 2005; Heath and Gifford 2006; Kahan, Braman et al. 2007; Mirisola, Sibley et al. 2007; Duckitt and Sibley 2009; Leviston and Walker 2010). Research on attitudes to climate change, nanotechnology and vaccination, among other issues, show how worldviews affect policy support more than available information, because they filter how such information is processed. Accounting for such biases in a model (by parameterising the model according to different worldviews, (Boschetti 2011)) may be a way to highlight the issue and the potential inconsistencies which may arise from it and to move the discussion from perspectives to mechanisms, in the hope that this may reduce the influence of biases and preconceptions in information interpretation.

Training on specific skills and attitudes needed to face complex problems is important because scientific insights risk being lost unless they are understood by those making and supporting decisions: recent studies have shown that human cognition and psychology affects decision-making at least as much as the complexity of the problem at hand (Moxnes 1998; Sterman and Sweeney 2002; Sterman and Sweeney 2007; Sterman 2008; Moxnes and Saysel 2009). Worse still, these difficulties are not necessarily obvious and may be confused as purposeful decision making (Moxnes 2000). Computer models, resembling flight simulators, can be designed to train individuals to better understand the basic processes of real world significance for decision making, including management of limited resources and unexpected feedbacks. The belief underneath this approach is that managing and predicting complex behaviours can be learned and that models can represent systems in a manner appropriate for learning and training.

Not only cognitive skills, but also cognitive attitudes are crucial to effective decision making in complex problems (Dorner 1996; Stanovich 1999; Sorrentino and Roney 2000): the behavioural attributes and habits we bring into a problem, the way we formulate goals, we interpret outcomes against expectations, we balance emotional responses like humility, curiosity, frustration and blame-shifting have a significant influence on how effectively we deal with complex situations (Dorner 1996). Tangible, constructive means to improve problem-solving in complex settings can be identified and trained via computer models (Dorner 1996; Boschetti, Hardy et al. 2010). Interestingly, some of the most effective cognitive approaches (including tolerating high levels of uncertainty, acknowledging mistakes, searching for counter evidence, self-reflection, etc) can be in direct opposition to behaviours rewarded in political and management roles. More widespread awareness of what makes an effective decision maker, possibly leading to improvements in training programs, may have an immense impact on a wide variety of real world issues.

Finally, the key determinant of success in MSE lies on whether the models, their results and recommendations are taken up by stakeholders; evidence suggests that such uptake in turn depends on addressing stakeholders' concerns as well as on engaging them in the project. Extensive interactions in order to introduce, showcase, discuss and tune the models represent an opportunity to ensure that the models are relevant to businesses, managers and communities, have sufficient trust to be considered for continuing use, receive political legitimacy and provide improved coordination for making decisions (Bramwell and Sharman 1999; Aas et al. 2005). From a community perspective, it can also provide a 'democratising and more inclusive and equitable set of processes than conventional approaches' (Bramwell and Lane 1999, p. 180).

A single model can rarely fulfil so many diverse tasks: a full-system model used to predict the impact of policies accounting for feedback cycles at different scales is unlikely to represent the best tool to train users to understand the effect of simple stock and flows processes; similarly, the latter is unlikely to be effective to convince stakeholders that models can help their community and the time involved in building large models means there is a significant risk of a loss of interest or knowledge of the project (due in part to a turnover in the stakeholders in regulatory bodies and the local population). Here we describe a suite of models we have developed to fulfil the different roles for models within a MSE project. Some of these models can be used to introduce stakeholders and decision makers to the philosophy of modelling; others to showcase what a model can do for the specific issues at stake; others to train users in system dynamics; others to engage the community with model developments; others to facilitate defining strategies to test in the MSE; finally, a full-system model can be used to deliver the final results. Each model will be briefly described; most important, we will discuss how the models have been used at different stages in the project and the main lessons learned.

5.3 Why do we model?

Different modelling teams, and often different modellers and users within the same team, may have very different ideas of what models do and what their output represent (Boschetti, McDonald et al. 2008; Boschetti, Grigg et al. 2010). For example, models may be used to:

- predict the behaviour of a system;
- retrodict (understand what led to an observed situation);
- understand how a system functions;
- understand possible causal relations;
- explore system behaviour;
- build tools for others to use;
- teach how a system functions;
- train specific skills and develop useful learning attitudes;
- communicate formalised knowledge;
- foster communication and collaboration.
- systems design

All the items above have a role at different stages of a successful MSE, as is discussed at length below. Here we focus on a challenge which a modelling team is likely to face: while for natural scientists using a model to synthesise system understanding and predict its behaviour is an obvious procedure (i.e. what science is about), for many stakeholders this is a fairly esoteric, speculative, abstract and unrealistic way to address a problem. This may result in scepticism which may prevent communication and trust. Effort needs to be invested in overcoming this and the following two approaches may be useful.

First, it is important to realise that modelling and predicting is what we all do whenever we plan and implement a daily action; this modelling however happens in our brain, not in a computer. Toy-models (described below) can be useful to show how the two processes (mental and formal modelling) relate and how a computer model can be useful to overcome the mistakes which may occur when dealing with complex or unfamiliar problems.

Second, it is likely that all stakeholders are already familiar with the concept of modelling but not aware of it: we are all in general recipients of model results, for example by interpreting and making decisions on weather bulletins and stock market projections. Showing the analogies between different types of models and involving stakeholders in the process of conceptual model building, followed by regularly showcasing model development and temporary results, can accustom stakeholders to the types of models used in MSE. This continuous work is essential for stakeholder to trust, understand and take ownership of the final model results.

5.4 Types of model used

We group the models we have used into five broad classes: conceptual models, toy-models, single-system models, shuttle-models and full-system models. In conceptual models the main drivers of a system are highlighted for subsequent representation as components of the full-system model; this usually results in a diagram summarising our understanding of how the system works. In toy-models a problem is simplified in such a way that only a handful of components are included. The purpose of these models is mostly educational: we want to understand how each component affects the problem and in order to achieve this, we temporarily renounce a satisfactory understanding of the overall problem. In single-system models we include a fairly detailed representation of a single component of the system (in this case recreational fishing and tourism); these models can be used to introduce stakeholders to modelling, provide temporary results from the study of a single activity of an ecosystem which will feed into the development of the final full-system model or address sector-specific issues. In shuttle-models, we include the *minimum* number of processes we believe are crucial for a basic understanding of the overall problem. We know these models are still too simple for full system description, but they provide a sufficient understanding to enable us to contemplate, build and use the more complex models needed for full problem description. The term ‘shuttle’ refers to taking us from a minimum to a full description of the problem, a journey that is necessary both to developers in model definition and parameterisation and for stakeholders in the interpretation of the final full-system model results. Finally, the full-system model includes all information collected through the project and addresses all scenarios of stakeholder concern, whose definition has been greatly eased by using the ‘simpler’ models.

For example, a conceptual model may identify fishing and tourism as main drivers of a region; a toy-model may describe how catches affect fish stocks; a single-system model may include the effect of gear, regulations and other processes affecting recreational fishing; a shuttle-model may include a simplified representation of the interaction between fishing, tourism, and infrastructure development on the overall health of the local ecosystem; gradually 'taking' us to comprehension of the 'full' model, which may include tourism pressure, fish market values, climate effect, larger food-webs, etc.

The role of conceptual models has been discussed in Chapter 4. Here we focus on the other types of models and how they have been used in the Ningaloo Research Program. Before proceeding, it may be useful to further clarify the relation between the different purposes for using models in a MSE and types of models, as summarised in the Table 2 below.

Table 2: Table of Modelling purposes and appropriate model types.

Modelling Purpose	Model Type
Predict/Retrodict	Single System, Full system
Understand system functioning	Toy models, Shuttle models, Concept models, Full system
Understand causal relations	Concept models, Shuttle models, Toy models, Full system, Single System
Explore system behaviour	Shuttle models, Single System, Full system
Build tools for others to use	Shuttle models, Single System, Toy models
Train specific skills and develop useful learning attitudes;	Shuttle models, Toy models
Foster communication and collaboration.	Toy models, Shuttle models, Concept models

5.4.1 Toy models

Toy-models have been developed mostly for educational purposes, as described in detail in (Boschetti, Fulton et al. 2010; Boschetti, Hardy et al. 2010). We used two types of toy-models: stocks & flows and feedback loop models.

The stocks & flows model (Boschetti, Fulton et al. 2010; Boschetti, Hardy et al. 2010) (see also http://www.per.marine.csiro.au/staff/Fabio.Boschetti/ToyModels/ToyModels.htm) allows us to interactively control the in and out flows into a bathtub, as inspired by (Sweeney and

Sterman 2000)). It was built for use in interactive sessions guided by a facilitator, who specifies the exact aim of the exercise in order to train a user on simple dynamical processes. In general, a user is asked to predict the amount of water in the bathtub as a function of how much water enters and exits at different times. As explained in (Sweeney and Sterman 2000), even well educated people often fail at predicting the behaviour of this apparently simple process. Since all systems depend on a careful balance of resource usage (water, energy, people, CO_2, biological species) understanding these process is crucial to effective management.

The feedback loop model (Casagrandi and Rinaldi 2002; Boschetti, Fulton et al. 2010; Boschetti 2011) (see also http://www.per.marine.csiro.au/staff/Fabio.Boschetti/ToyModels/ToyModels.htm*)* allows us for study of the interaction between three abstract variables: 1) the size of a population exploiting a resource, 2) the way exploitation is carried out and 3) the dynamics of the environment which provides the resource. By specifying the nature of the population and type of resource, this abstract representation can be applied to a range of different problems, including fishery management, water conservation, tourism development and climate change. While a simple three-variable model cannot capture the complexity of a real system, it can help understand the medium and long-term effect of positive and negative feedback loops; it can also help develop an intuition for the role and impact of specific links on system behaviour and where points of intervention may lie. This type of model can thus be seen as a learning tool and a reality check to verify the soundness of assumptions about system behaviour.

5.4.2 Single-system models

Two single-system models have been used: a fishery model (ELFSim) and a tourism destination model.

ELFSim (Little, Punt et al. 2007) is a fishery decision support tool designed to evaluate options for conservation and harvest management, including area closures, minimum catch size and gear selection, in terms of biological and economic performance indicators. It includes three conceptual modules: a) a biological module, which can model both sedentary and mobile target species and incorporates several features of the species of interest, including larval settlement/transport, age-related structure and sub-populations; b) an effort allocation module, which projects historical fishing data into the future and c) a management module, which evaluates the likely outcomes of different management options..

The biological module models several local populations of the same species. Each population is associated with a single reef and has a specified age, sex, and size-structure, which may be linked to other reefs through larval dispersal. The biological model also allows for variability in natural mortality and larval survival among different reefs and at different times, as well as monthly variation in the relationship between fishing effort and fishing mortality. The fishing component accounts for both infringement into closed areas and displacement of effort away from them, enabling to evaluate alternative management options according to expected compliance.

An ELFSim simulation consists of two parts. In the first, the biological module uses information from the physical characteristics of individual reefs to determine the population size and structure on each reef given past fishing. The second part projects the reef populations forward in time according to simulated fishing pressure and provides biological and economic performance indicators thus allowing evaluation of alternative management options.

The tourist destination model (Jones et al. 2011) predicts the economic, social and environmental impacts of different planning decisions, tourism styles and behaviours, changes in tourism numbers and tourism segments and specific events. It aims to explore alternative futures related to infrastructure development, tourism growth, external economic impacts, resource use, perception of a location natural attractiveness, service delivery, energy consumption, waste generation and specific system shocks such as cyclones, pandemics and loss of a significant natural assets (for example coral bleaching and changing patterns of iconic wildlife visitation). This model has been very useful to engage stakeholders in the early stage of the process; it has provided some answers to tourism management questions and has feed into both a shuttle model (EwE) and the final full-system InVitro model.

5.4.3 Shuttle models

Two shuttle-models were also used in this project: ScenarioLab, focussed mostly on fishing and Ecopath with Ecosim (EwE), which includes a larger system view.

ScenarioLab (Boschetti, de La Tour et al. 2008; Boschetti, Fulton et al. 2010) allows for rapid assessment of the effect of decision-making on fishery management by allowing a team of non-expert modellers to compare the outcomes of multiple model simulations via a set of GUIs. As a distinguishing feature, the goal of the management strategies can arise as a result of the interaction between the user and the model, rather than being defined a priori, and can change during the process in response to the accumulated information and insight.

ScenarioLab estimates the expected effect of a number of fishery regulation options available to the management team, which control the number of dispensed fishing licences, the total areas reserved as sanctuary zones, daily catch limits, and minimum and maximum legal lengths for two species of interest. Once these regulations are defined, the model mimics the behaviour of a fishing fleet and its effect on the modelled foodwebs. For each regulation option, the model is run a number of times under different model settings, in order to mimic natural and parameterisation uncertainty.

ScenarioLab has also been used to explore system behaviour at large, that is to gain a rough estimate of what types of behaviour the system we study may display (Boschetti 2010), which can be useful because management decisions need to account for unexpected or counterintuitive system behaviours. This approach requires a large number of model runs, which are computationally too expensive with full-system models but manageable with shuttle-models.

The Ecopath with Ecosim (EwE) (Christensen 2011) modelling approach was originally developed to explore the consequences of fishing, environmental disturbances and human behaviour on the dynamics of marine foodwebs. The approach and software has been under development for over 25 years and combines ecosystem trophic mass balance analysis (Ecopath, released in 1984), with a temporally dynamic modelling capability (Ecosim, released in 1995) for exploring past and future impacts of exploitation and environmental disturbances. In 1998 Ecospace was added to the package, this replicates Ecosim models over a spatial map grid to allow exploration of policies such as marine protected areas, while accounting for spatial dispersal/advection effects. Together the three components form an integrated package that is relatively straightforward to use and has been applied to over 200 locations around the world.

Ningaloo–EwE contains 53 ecological groups, spanning both terrestrial (foxes, marsupials, ospreys, coastal seabirds, goats and sheep) and marine components, ranging from primary producers (e.g. macrophytes, grasses or phytoplankton) to top predators (like demersal or pelagic sharks). EwE was originally written to consider the effects of fisheries but it is possible to include a broader set of human activities, including agriculture, shipping, camping and tourism, which makes EwE a perfect shuttle-model candidate to introduce the use of the full-system InVitro model described below, while it is much easier and faster to parameterise and easier to learn for people who are less experienced with modelling.

5.4.4 Full-system model

The InVitro modelling framework (Gray, Fulton et al. 2006) has been used to study the interrelation among all processes of interest in the full Ningaloo system. It allows for modelling of processes across scales (Figure 21) and components (Figure 22). As it brings together all main system components (biophysical, ecological, socio-economic), it helps highlight tradeoffs between the demands of different economic activities and the requirements for social and ecological sustainability. Importantly, it captures feedback processes that can lead to unexpected changes in the system. The cross-scale capability is achieved using a hybrid framework that combines analytical, equation-based formulations for physical or lower trophic level processes with algorithmic, rule-based formulations for the higher trophic levels and humans, each framework acting at the appropriate time and spatial scale.

InVitro consists of 5 main sub-models: 1) biophysics, which defines the natural environment, 2) socio-economics, which defines human behaviour, 3) industry, which defines large-scale economic drivers and institutions, 4) management, involving the decision making and institutions and 5) monitoring and assessment (Figure 22). This modular design provides flexibility by choosing alternative representations of the each sub-model depending on the specific modelling task as well as a means to handle uncertainty by jointly testing and implementing multiple representations of the same module.

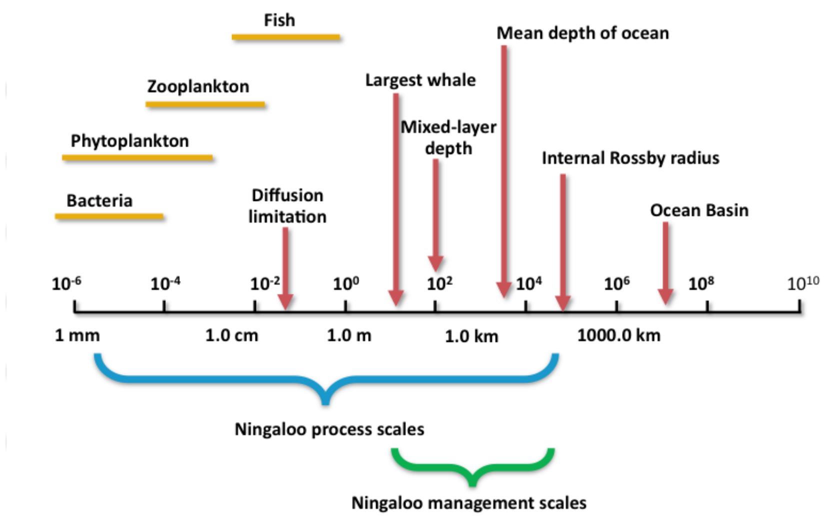


Figure 21: Scales of processes and management jurisdictions to be included in the Ningaloo-InVitro model

The biophysical sub-model includes all the dominant system components of a 60 species foodweb (primary producers, benthic habitats, benthic invertebrate communities, pelagic forage fish, main target species of fin-fish and crustaceans, top predators and species of special interest like turtles) and detailed representation of several physical processes (oceanography, weather, climate, geomorphology, contaminants, etc).

The industry sub-model includes commercial and recreational fisheries, tourism, oil and gas, salt production, coastal development and infrastructure, ports, shipping, regional economics, catchment use, recreation and conservation.

The effects of human activities on the marine environment are represented using a combination of analytical decision models, response functions, specified rules, historical data and scenarios. Uncertainty is included in each of these options and affects which exact activity is carried out and its outcome; this aims to capture natural ambiguity in human and animal behaviour, missing or incorrect information and unpredictable events.

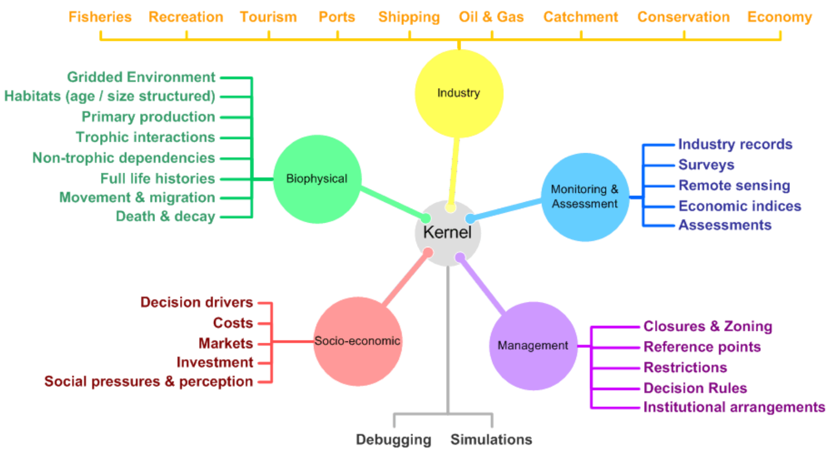


Figure 22: Modular structure of the main components and processes included in the Ningaloo-InVitro model.

5.5 Model use during project development

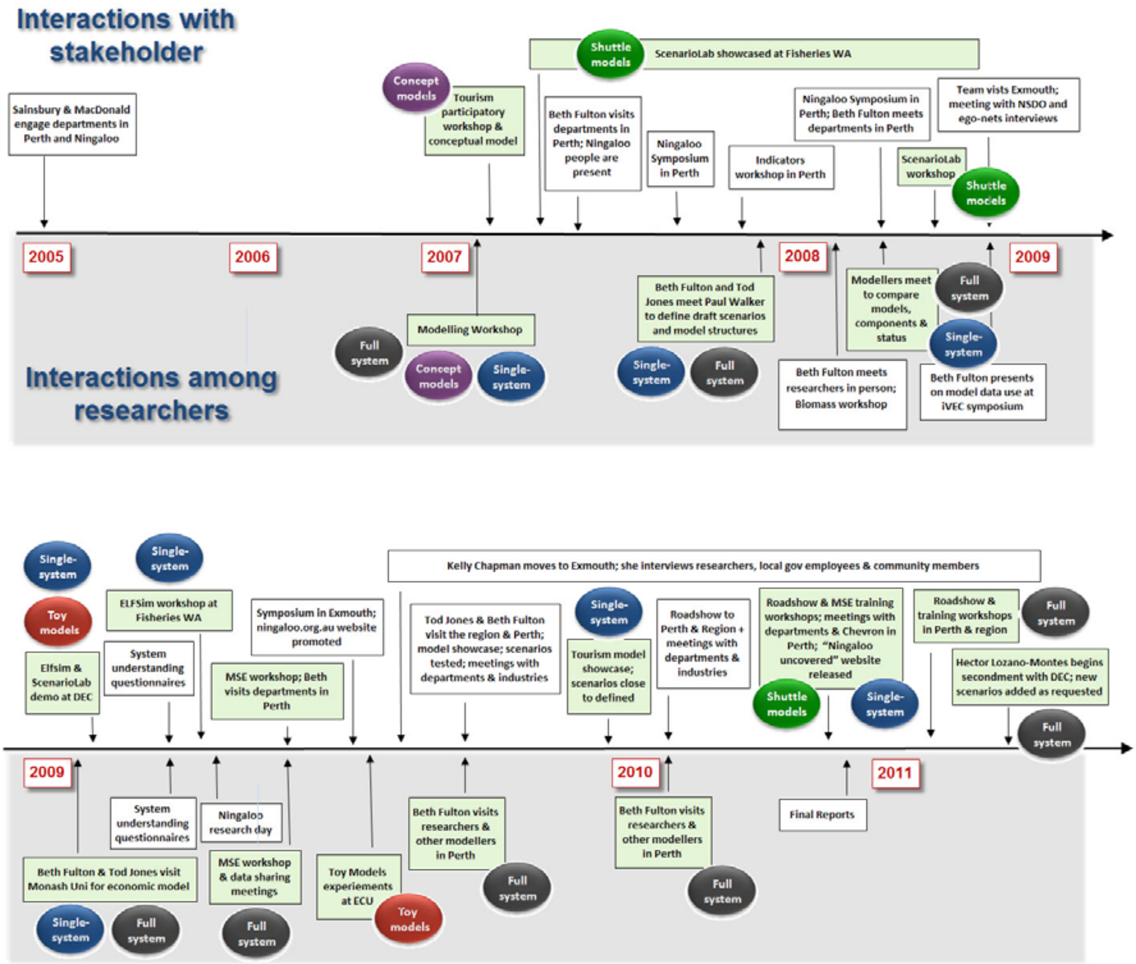


Figure 23. Actual use of different model types during the project.

Figure 23 summarises when and within what context the different models types have been used in relation to stakeholder engagement activities as described in Chapter 4. The relative ad-hoc nature of the models development, which followed opportunities and needs as they arose rather than an organic plan (see Chapter 4), is noticeable from the sparse formal use of conceptual models and the use of toy-models fairly late in the project, rather than at the beginning, when most training is likely needed. It is also likely that shuttle models have been under-utilised. This has been a learning experience for the modelling team, as is discussed in the next session.

5.6 Outcomes

This project's outcomes can be divided into four broad classes, each significant to a different type of audience: a) model results, b) actual models, c) stakeholder learning and education in model use and d) learning for the modellers themselves.

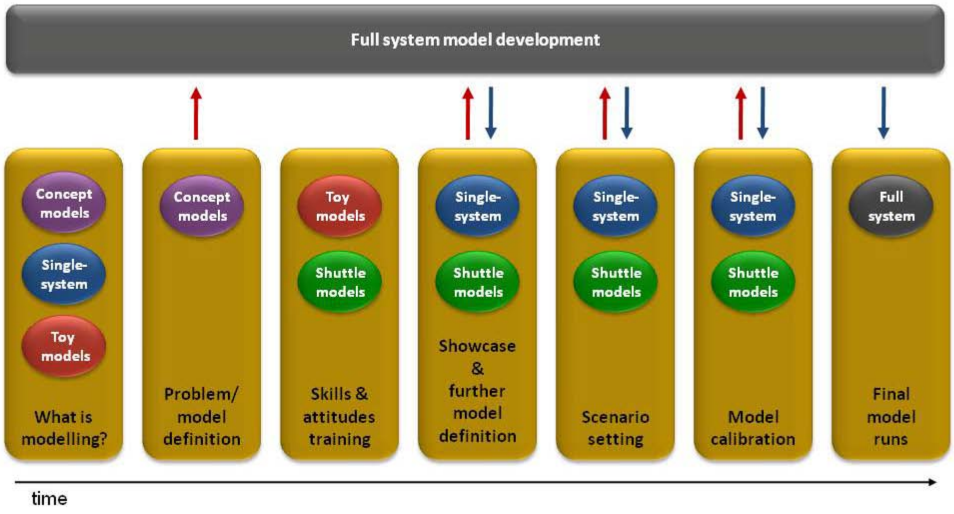


Figure 24. Relation between project and stakeholders engagement phases and use of different model types.

The output from the full-system model (InVitro) and the two single-system models (Ningaloo Tourism Destination model and ELFSim) will be interpreted in collaboration between researchers and decision makers and will feed both into the decision making and consultation processes. These results are discussed in Chapter 6. Some of these results will also be available to the general public via a number of web sites. For example, some toy-models are available at http://www.per.marine.csiro.au/staff/Fabio.Boschetti/ToyModels/ToyModels.htm; shuttle models can be made available upon request (a simple example of a shuttle model is the Ningaloo Tourism Destination Model, developed by Curtin University and detailed in Jones et al 2011, which is accessible at http://www.ningaloouncovered.com/). Single-component models are available on request, while the full-system model is available both as a stand-alone package that can be run by interested users and via the online tool ReefTime (accessible via http://www.ningaloo.org.au/www/en/NingalooResearchProgram/ResearchTools.html), which allows users to explore virtual libraries of runs (that can be augmented on request).

While there is no expectation that all stakeholders will want to actively use the models personally, feedback from purposely designed questionnaires and casual conversation suggest that the stakeholders who got involved more closely with the modellers, via presentations and workshops, have acquired a deeper understanding of what models can provide, and how they can be used in decision making. This is promising; as discussed in Chapter 4, to what extent this is due to the selective feedback we have received, and to what extent such learning has been achieved in the overall stakeholder group is something which is worth monitoring in, say, 6-12 months from project completion. This information can feed into better future training and interaction processes.

Finally, considerable learning has occurred within the modelling group. This relates not only to the engagement process discussed in Chapter 4 and to modelling itself, which always improves with accumulated experience and technology, but specifically to how to employ different types of models within different engagement phases. Figure 24 summarises this learning visually; it includes 7 stages going from the first engagement and model building activity to the final delivery and discussion of the modelling results and for each it shows what types of models that can be useful when tackling such a large and complex problem. Importantly, it also includes the relation to the software-engineering activity of building the full-system model which, as discussed in Chapter 4, requires an organic project plan from project inception. While the exact details of which toy or shuttle model are needed may develop during the project, and a certain level of flexibility will be required, maintaining a relation between these models and the full-system model can be beneficial. For example, a common user interface may allow users to accustom themselves to the different models without re-training and can provide more specific information of the GUI effectiveness for the final model.

5.7 Discussion

Traditionally, MSE includes stakeholder engagement to define project goals, plans, monitoring and learning, while it employs a model to assess the likely outcomes and trade-off from possible alternative plans. As described in Figure 25, our MSE implementation differs in three important features. First, modelling has been used at each stage of the process, to engage stakeholders, facilitate learning, elicit feedback and improve model design. Second, different types of models have been used for different purposes and for different audiences, including conceptual models to capture system functioning, toy-models for training, single-component models to highlight and understand specific drivers in the system, shuttle-models to introduce system complexity and full-system model to deliver the final data. Finally, these models have allowed for the MSE process to be implemented differently. While traditionally MSE begins by identifying goals (as on the left hand side of Figure 25), models can be used to start the MSE process with learning (as on the left hand side of Figure 25). This step can be particularly useful in future projects since, as discussed in Chapter 4, some stakeholder groups in our project found it difficult to formulate MSE questions because of their lack of familiarity with modelling; overcoming this difficulty with a suitable training in the philosophy and use of models can considerably speed up the overall process at later stages. While facilitating people’s ease with models and their understanding of complex systems proved to be one of the most important aspects of the work, without which the modelling would have been of little use, it was not originally clearly defined as the basis for the research. It is important therefore to acknowledge that by the end of the project this engagement accounted for roughly 43% of the overall modelling team’s effort and resulted in a number of one-to-one meetings, workshops and seminars. It is critical that engagement be correctly include and costed into the future (especially as it will be an continuing need, though maybe at a reduced level, if the models are to be supported and maintained). As previous studies have highlighted (Elzinga et al. 1998, Lee 1999), to provide successfully for science-based management outcomes, relevant information must be effectively communicated.

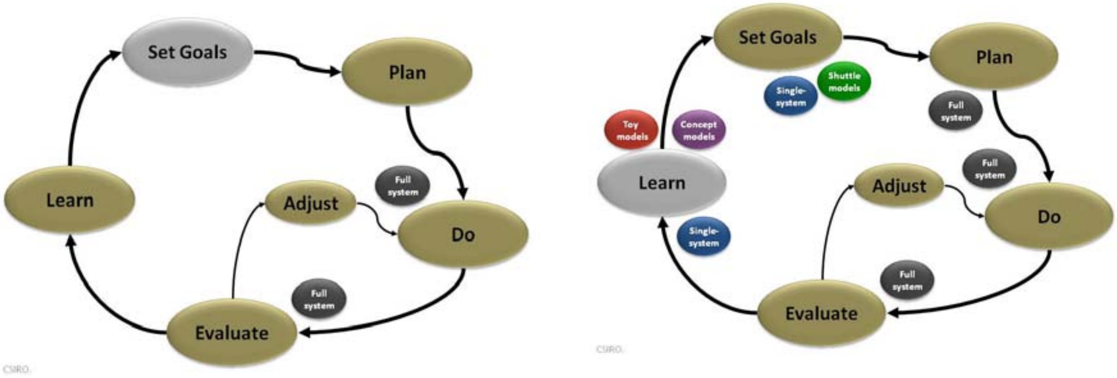


Figure 25. Traditional MSE implementation, in which modelling is used essentially to assess likely impacts of alternative plans (left); the MSE implementation described in this work, in which different types of models are used at each stage of the process (right).

6. MANAGEMENT STRATEGY EVALUATION: APPLICATION TO NINGALOO-EXMOUTH REGION, WESTERN AUSTRALIA

6.1 Summary

In consultation with people interested in the system (e.g. shire officers, tourism operators, officers from DEC or DofWA) a range of scenarios were defined that cover some of the chief development and management questions for the region (as of 2010).

There were a broad range of outcomes from the results of these simulations, but there were a few notable points to emphasise. Environmentally, among the most significant is that turtles are vulnerable to many pressures in the region (chiefly mortality due to foxes and the effects of rising sea level and nest site flooding) and will need continual management, to reduce the pressure on the population if they are to be given a significant chance of long term survival. The natural systems are also under cumulative pressure; human usage placing fish stocks under sufficient pressure to lead to long term declines and system restructuring (under current management arrangements) and significant habitat degradation is noticeable at high use areas. It is possible that these impacts can be ameliorated or reversed if alternative management strategies are put in place (e.g. wilderness fishing can lead to a significant increases in the size of target stocks, but it may be difficult to enforce in practice if a sizeable proportion of recreational fishers come by boat from outside the region and do not make landfall).

With regard to the social and economic state of the system, the region is very vulnerable to an aging population and some form of economic and social development is required for growth and viable long-term (i.e. through to 2100) community with desirable social properties. If 2006 levels of tourism (roughly 200000 per annum in the region) had remained static without other development (e.g. the industrial development of recent years) this would have been insufficient to prevent a shift towards an older population. Growth, or the potential for growth, is not a panacea however, as (i) the realised level of growth is highly constrained by available housing and labour and (ii) there are large utility demands associated with increased development (largely independent of the form of the development, though some forms have higher demands than others) and population sizes. Carefully planned and targeted development can help moderate the demand and achieve effective infrastructure supply without exacerbating potential environmental consequences.

6.2 Introduction

The ultimate aim of sustainability research is to provide a science-based foundation for decision makers (or any one else) involved in the use and management of natural resources. This information needs to provide knowledge both for policy making and day-to-day operations. For integrated coastal zone management, or the management of near shore marine environments, this necessitates synthesising information on many different biophysical, social and economic aspects of the overall system and dealing with scales from sub-metre to hundreds of kilometres.

To do this a "full system" model was implemented using InVitro (see Chapter 5) using data from historical sources and the recent WAMSI and Ningaloo collaboration cluster projects carried out in the region. This provided information on the current system state, system functioning and likely responses to future pressures. The model was then used to generate projections of possible future regional development using a Management Strategy Evaluation (MSE) approach (as detailed in Chapters 3 and 5), which simulates the different steps in the adaptive management cycle and allows for comparative evaluation of alternative management regimes. The results of 95 of those projections are presented here. These simulations (and others that may become available in the future) can be accessed via an online portal (or virtual library) – visit the ReefTime tool link at http://www.ningaloo.org.au/www/en/NingalooResearchProgram/ResearchTools.html. An example of the map view screen of Reef Time can be found in Figure 26.

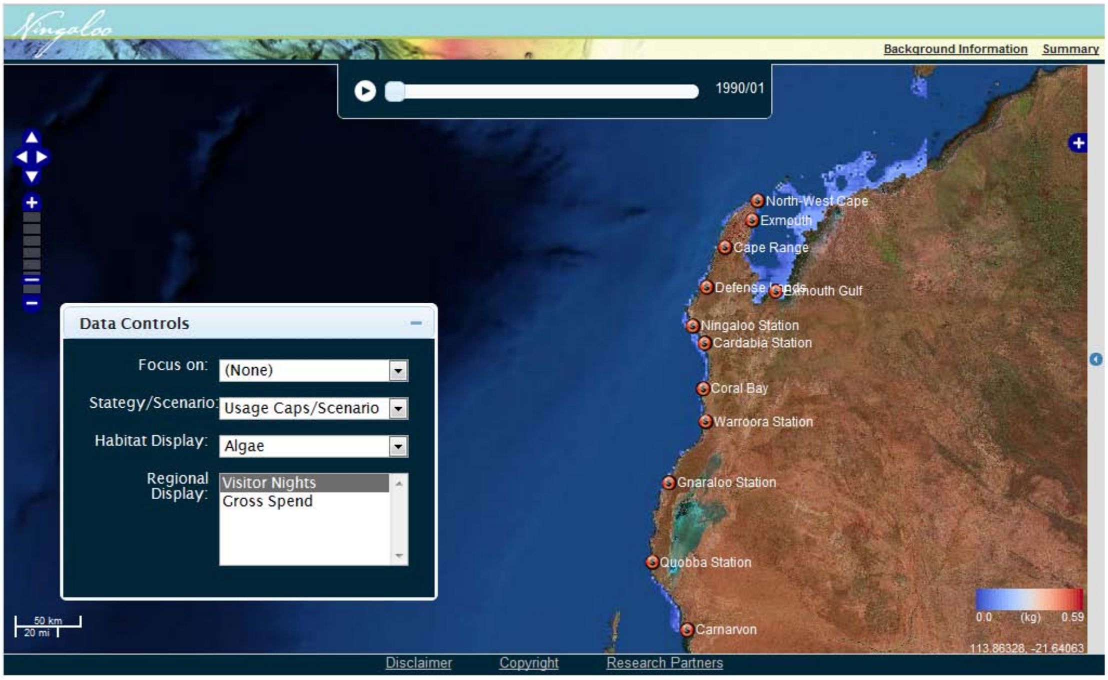


Figure 26: Model domain - showing the starting algal habitat layer and the main human settlement sites or use regions followed in the model.

6.3 Management Strategy Evaluation - Ningaloo

6.3.1 The Ningaloo-Exmouth Region

Ningaloo Reef and Exmouth Gulf lie within the Gascoyne region of Western Australia (the model domain is shown in Figure 26). The area is sparsely populated, with the distribution of townships largely a result of the pattern of development of the pastoralism industry in the late 1800s (when wool from the region was shipped to national and international markets). While this sector still makes up 80% of the land tenure, the economy of today has diversified to include tourism and the resource sector, amongst others. Due to its exceptional beauty, the region is the focus of high tourism visitation (based primarily around a 300km fringing coral reef and land attractions in places like Cape Range National Park (CRNP)). More recently, increasing industrial development in the broader north-western area of Australia (including the neighbouring Pilbara region) is largely based around mining and oil and gas extraction. The close geographic association of these developments, the diversity of local activities (e.g. farming, tourism) and iconic natural sites (e.g. Ningaloo Reef, which was listed as a World Heritage Area (WHA) in 2011, and other reserves, such as CRNP) is raising new sustainability challenges.

6.3.2 The Ningaloo-InVitro Model

The Ningaloo-Exmouth region is a system defined by the importance of extremes of scale – from the finest of reef scale interactions (metres or less) to regional ocean current systems and human use patterns, and onto global influences (e.g. fuel prices, industrial demand and the tourism market). This creates significant modelling challenges, regardless of the kind of model used. The problem is complicated further by the mismatch between jurisdictional boundaries of management authorities and system breakpoints (e.g. marine species assemblages show a clear break west and east of the northern tip of North West Cape). While there is some degree of spatial segregation of human activities (with reef associated industries to one side, extractive activities in the Gulf on the other, and agriculture and other land-based activities in between), this segregation is not immutable. Currently, some aspects of the ecological breakpoint are still reflected in management plans (e.g. the placement of marine reserves), but this is not true of all sectors (e.g. there is increasing oil and gas development within 20-50km of the Ningaloo Reef Marine Park boundaries) and the resident human population considers the region as an integrated whole.

Previous chapters of this report (and associated reports such as Jones *et al*. 2011 and Little *et al*. 2011) deal with the many models used to consider aspects of the system. However, only the Ningaloo-InVitro model spans the entire system (see section 5.4.4), while also capturing the important details of the dynamics of its constituent parts. Uncertainty is included for each part of the system, helping determine whether some decisions are robust about which activities are carried out and their possible outcomes. Moreover, uncertainty is captured via alternative parameterisations of the most uncertain biological, environmental, social and economic components; with all parameterisations based on data from a broad range of sources, including the data collected by members of the Ningaloo research program (which ran 2005-2010), data from government departments (federal and state, including the Western Australian Department of Fisheries, Department of Environment and Conservation, Department of Transport, Department of Planning, Department of Lands), annual reports by industry members, and from the shires of Carnarvon and Exmouth. Where gaps remained, data were drawn from neighbouring systems (e.g. the Pilbara) or other environments with similar properties or structures (e.g. Great Barrier Reef).

6.3.3 Scenarios and Strategies Considered

Extensive interaction with groups interested in the Ningaloo-Exmouth region was used to elicit information on objectives for the region and to define a wide range of management strategies and contextual scenarios that could describe alternative futures for the region. Close to 100 simulations are included in the results presented here (more will be made available through the online portal, see the link given at the end of the introduction). In particular there were key questions addressing the effects of a range of developments (from the existing Ningaloo Regional Coastal Strategy, to hypothetical developments based on new camp sites, a large resort, the paving of the Gnaraloo road and resident developments driven by the growth of the oil and gas industry in the region) and management strategies (including extended spatial management, alternative fishing regulations and increased education and enforcement). A glossary of the environmental scenarios and management strategies covered in each of the scenario options and simulations is listed in Table 3 in Appendix B, with a summary of the results of each of the simulations given in Figure 39 also in Appendix B. Note that each of the simulations runs from 2000 to 2035, with the period 2000-2010 covering a historical burn-in and then 2010-2035 a projection under the scenario-strategy being evaluated.

While hundreds of indicators could be used to summarise the outcome of these projections, a relatively short, but still comprehensive set was chosen. The selection spans the social, economic and ecological indicators suggested by groups interested in the system, while also being easily interpretable by a broad audience (see Figure 39 for the list of indicators).

To help simplify interpretation a multivariate cluster analysis and principle components analysis was performed (using the R software) to see if the outcomes of the simulations clustered. Six major types of outcome are apparent in the results of the multivariate analyses (Figure 27a) and we also included the “climate change” scenarios, as they have significant ecological impacts beyond those seen in the other cases. A summary of the general form of each of these general classes of results is shown side-by-side in Figure 27b, using traffic light like icons coloured based on the direction and magnitude of change, and using radial-plots in Figure 27c-j (so that the reader can readily get some sense of how “evenly” the change is vs the multiple objectives in the system). In the radial-plots, if the indicator value has moved towards the outside of the circle then the value has increased by 2035, if it has contracted toward the centre of the circle then it has decreased.

6.4 Simulation Outcomes

Summary of general classes of results

While there was variation in the specific details across each of the simulations that fell within a general class of result, for each general class there were some common signifying features[6]:

Base case: little if any population growth, stagnation of the economy of the region, rising unemployment and an aging population; the visitor mix slides more toward recreational fishing, seeing a further decline in stocks and the state of the natural system, though there is some reduction in demand for services and infrastructure.

Reduced growth: in gross terms similar in trend to the base case, but more extreme so that there is a contraction in the state of the system away from nearly all objectives (environmental, social or economic).

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[6] Note that in all cases discussed here turtle populations tend to fall unless fox baiting is maintained (or expanded).

Changed management, but no developments: almost irrespective of the form of alternative spatial management used (or if there is increased education), the changes typically mitigate some of the environmental impacts (e.g. protecting habitats), but have little overall effect on the system.

Ecolodges and reduced growth: the development of Ecolodges, even as there is reduced growth in the rest of the economy, sees a significant per capita increase in spend and stronger environmental outcomes – due to the different visitor profile attracted; unfortunately this does not prevent strong competition for local housing (as there is insufficient development to see widespread land release, but there is sufficient tourism to see a strong labour market for that sector, meaning in-migration of workers and competition for existing dwellings).

Introduction of modified bag limits: the introduction of modified bag limits (in line with the wilderness fishing concept) provides significant protection for fish stocks, which increase relative to 2006-2010 levels; the stocks rebuild to a point where the probability of catching trophy fish per trip significantly increases; and the recreational fishers attracted to the region help maintain the local economy (though they do compete with residents for the local houses).

Large developments (resorts or resource sector): major expansion of the resource sector, tourism or other industry leading to a major increase in the economy, road transport, resident population and demand on services and infrastructure; all, unfortunately, at the cost of the environment.

Large developments and the introduction of modified bag limits: as for the large development case, but with less of an impact on fish stocks (to the point they remain at the levels of 2006-2010 or even increase).

Changed climate: a contraction in agriculture and some other aspects of the local economy (e.g. a contraction of the peak tourism season through the cooler months and a drop off in tourism segments unwilling to pay for air conditioned accommodation), slower growth in the population and a decline in available services; the ecological impacts are strongest however, with the habitats becoming more vulnerable (due to the combined effects of storms and acidification) and turtle nesting beaches heavily impacted by sea level rise.

Summary of extremes from the particular results

Looking across the different projections there are some system properties (indicators) that are fairly consistent regardless of the context or strategy under consideration. For instance, the proportion of the population in older age groups consistently increases relative to today. In contrast, large and potentially vulnerable megafauna like whale sharks and turtles decrease (to differing extents depending on the management strategy in place).

Thinking of the objectives in the extreme; the greatest increase in the gross economy is when the system undergoes a considerable change, with high industrial growth, large resort development, additional urban residential developments and novel management arrangements (reduced bag limits). Interestingly the lowest state of the economic growth occurs with high industrial growth without expansion in infrastructure, services, housing and tourism developments. In that case any potential benefits of the industrial expansion are either channelled out of the region or prevented altogether by flying labourers in and out, bypassing the local economy.

The most positive social outcomes (in terms of life style) occurs when there is sufficient initial development (or the promise of it) to deliver infrastructure, but access failures (either via regulations that cap local populations and visitor numbers or roads and other infrastructure such as boat-ramps are not constructed), or the absence of industrial development, sees the population growth remain low; so the locals receive all the “life style” benefits while avoiding the substantial effects due to crowding, growing utility demands or environmental degradation[7]. The poorest social outcome is occurs when there is infrastructure development together with population and tourism growth in the region; in this case increased crowding, rising demand (and costs) for utilities, residential housing pressure and degraded environmental status sour the lifestyle.

The most positive ecological outcomes (in terms of biodiversity, habitat, iconic species and fish stocks) coincides with no extra development of the region; the population and tourist numbers remain at the current level and there are no new management interactions (particularly modified bag limits). Any form of heavy use of Ningaloo with current management arrangements leads to a degradation of the system. With the effects of climate change, many of the highly values features of the ecosystem are detrimentally impacted, almost irrespective of the form of management in place. For example, coral habitats are impacted by acidification and changed storm state (either frequency or intensity) even if coral bleaching[8] does not become a common occurrence. Even with fox

baiting the loss of turtle nesting beaches to inundation as sea level rises sees populations fall significantly. Although fish stocks can be conserved under modified management arrangements (e.g. modified bag limits), an absolute increase in recreational fishing pressure (as a result of industrial development in the region) in conjunction with climate impacts can overwhelm any changes to management arrangements unless they are stringently applied.

[7] Note that what is judged as a benefit or an undesirable aspect is based on the output of a survey by Jones *et al.* 2011, which had residents indicate what were objectives for the region socially and what they would rate as “desirable” and “undesirable” states of the social system.

[8] Healthy corals are colourful because of symbiotic microalgae (zooxanthellae) living within the coral’s tissue. When stressed the coral expels the zooxanthellae, leaving the white skeleton visible through the transparent tissue. If the stress abates the bleached coral can recover its stock of zooxanthellae, regaining its colour and health. However, if the stressful conditions prevail and the coral does not recover there is a significant chance of coral mortality.

Figure 27: Summary of the main types of results from the simulations: (a) principal components analysis showing the major classes of results

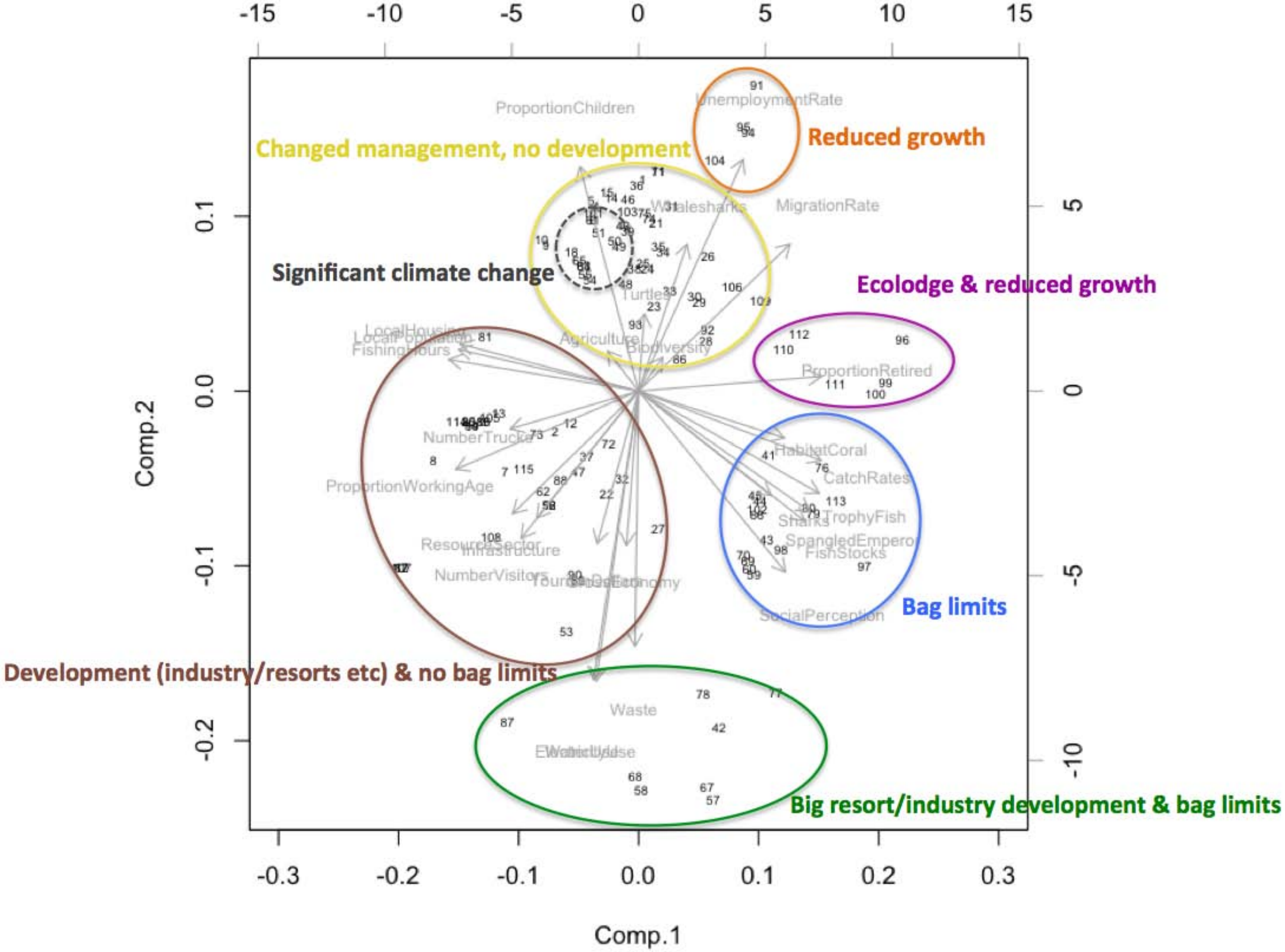
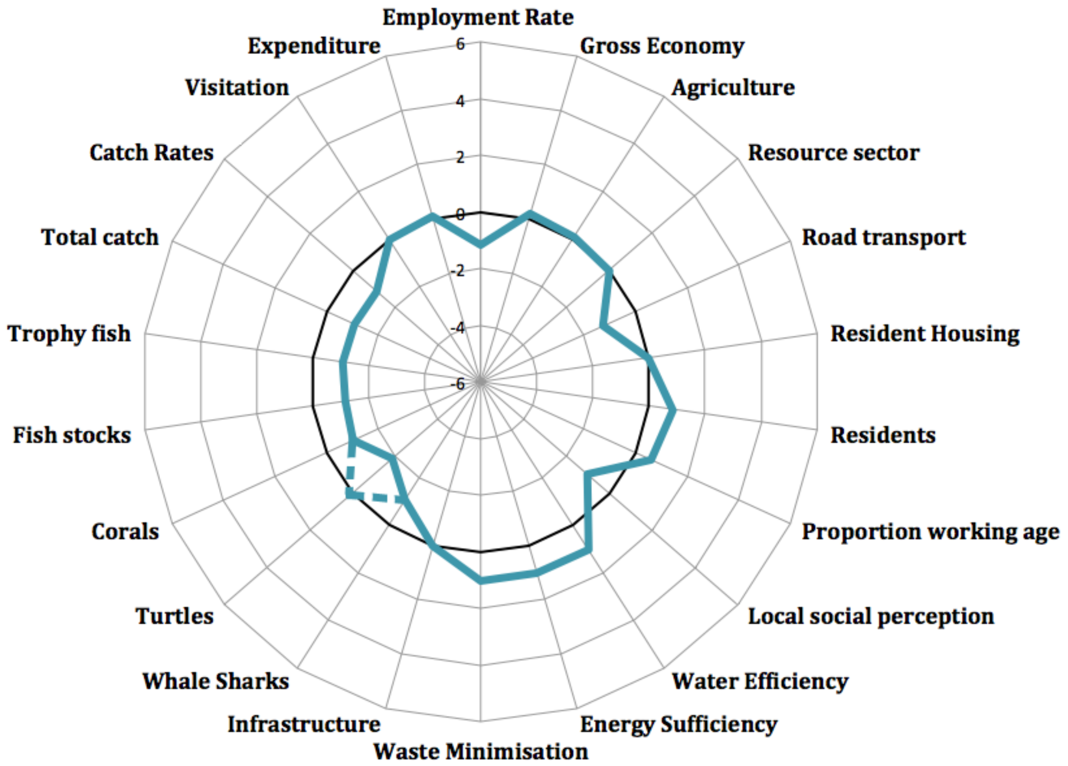


Figure 27: (b) a comparative summary of the different class of results – the icons are colour coded to represent the direction of change seen in the general form of the outputs for each class of outcome vs objectives identified for the region by regulatory bodies, operators in the region or residents (note that specific details of individual simulations could differ form this general picture and interested readers should refer to the barplots in Figure 40 in Appendix B). The colour of the indicator shows how it has changed compared to 2010 – red (downward arrow) means the indicator is worse (versus stated objectives) than 2010, green (upward arrow) means the indicator has improved and orange (dash) means no significant change. The two entries for turtles are with (dashes) and without (red arrows) fox baiting programs (for some scenarios there is a decline regardless).

	Base Case	Climate Change	Reduced Growth	Changed Management	Ecolodges	Modified Bag Limits	Large Developments	Large Developments & Modified Bag Limits
Employment Rate	▼	▼	▼	▼	–	–	▲	▲
Gross Economy	–	–	▼	–	–	▲	▲	▲
Agriculture	–	▼	–	–	▼	–	–	–
Resource sector	–	–	–	–	–	–	▲	▲
Road transport	▼	▼	▼	–	▲	–	▲	▲
Resident Housing	–	▼	▼	–	▼	▼	▲	▲
Residents	▲	▲	–	▲	–	▲	▲	▲
Proportion working age	▲	▲	▲	▲	▲	▲	▲	▲
Local social perception	▼	▼	▼	▼	▼	–	▼	▼
Water Efficiency	▲	▼	▲	▲	▲	▲	▼	▼
Energy Sufficiency	▲	–	▲	▲	▲	▼	▼	▼
Waste Minimisation	▲	▲	▲	▲	–	▼	▼	▼
Infrastructure	–	–	▼	–	–	–	▲	▲
Whale Sharks	▼	▼	▼	▼	▼	▼	▼	▼
Turtles	▼ –	▼	▼ –	▼ –	▼ –	▼ –	▼	▼
Corals	▼	▼	▼	–	▲	–	▼	▼
Fish stocks	▼	▼	▼	–	▲	▲	▼	▲
Trophy fish	▼	▼	–	–	▲	▲	▼	▲
Total catch	▼	▼	▼	▼	–	▲	▼	–
Catch Rates	▼	▼	–	▼	▲	▲	▼	▼
Visitation	–	▼	▼	–	▼	–	▲	▲
Expenditure	–	–	–	–	▲	–	▲	▲

Figure 27: (c) summary of results for the base case (i.e. 2006 levels of tourism, and static activity levels for other industries, without other developments); the black circle indicates the zero mark (i.e. no change), with values further out that than zero mark being better outcomes and inwards worse. The size of the bar represents the increase (or decrease if negative) in the property vs its state in 2010 – the change is the magnitude of change (so +2 means double the original level whereas -2 is half the original level)[9]. For turtles the solid line indicates the case without fix baiting and the dashed line indicates the value with fox baiting maintained, note in some cases it makes little difference.



[9] This scale was used so that change could be considered symmetrically. Zero indicating no change and with equal magnitude of change possible wither increase or decrease. If a simple ration or percent change is used then it is possible to get very large increases in one indicator (e.g. 1000% increase), which dwarfed the possible declines in another (it is not possible to decline more than 100% as then that system feature is completely gone).

Figure 27: (d) summary of results when there is reduced growth; the black circle indicates the zero mark (i.e. no change)

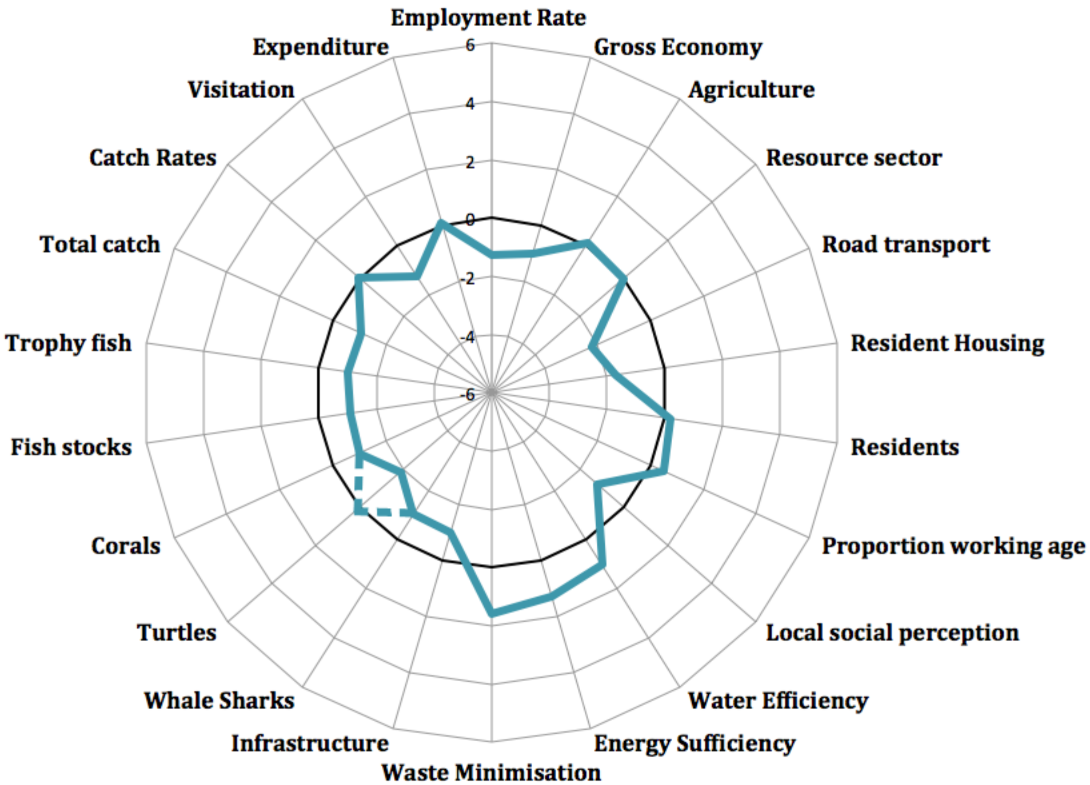


Figure 27: (e) summary of results when there is changed management, but no developments; the black circle indicates the zero mark (i.e. no change)

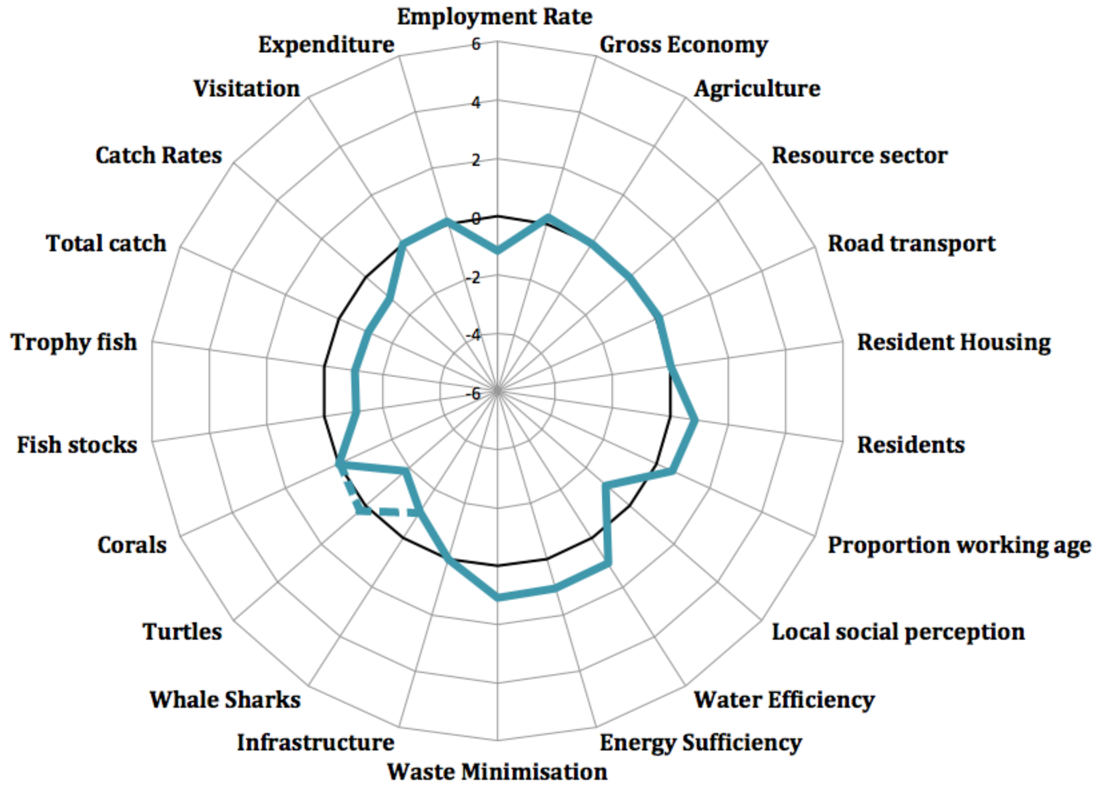


Figure 27: (f) summary of results when there are ecolodges and reduced growth; the black circle indicates the zero mark (i.e. no change)

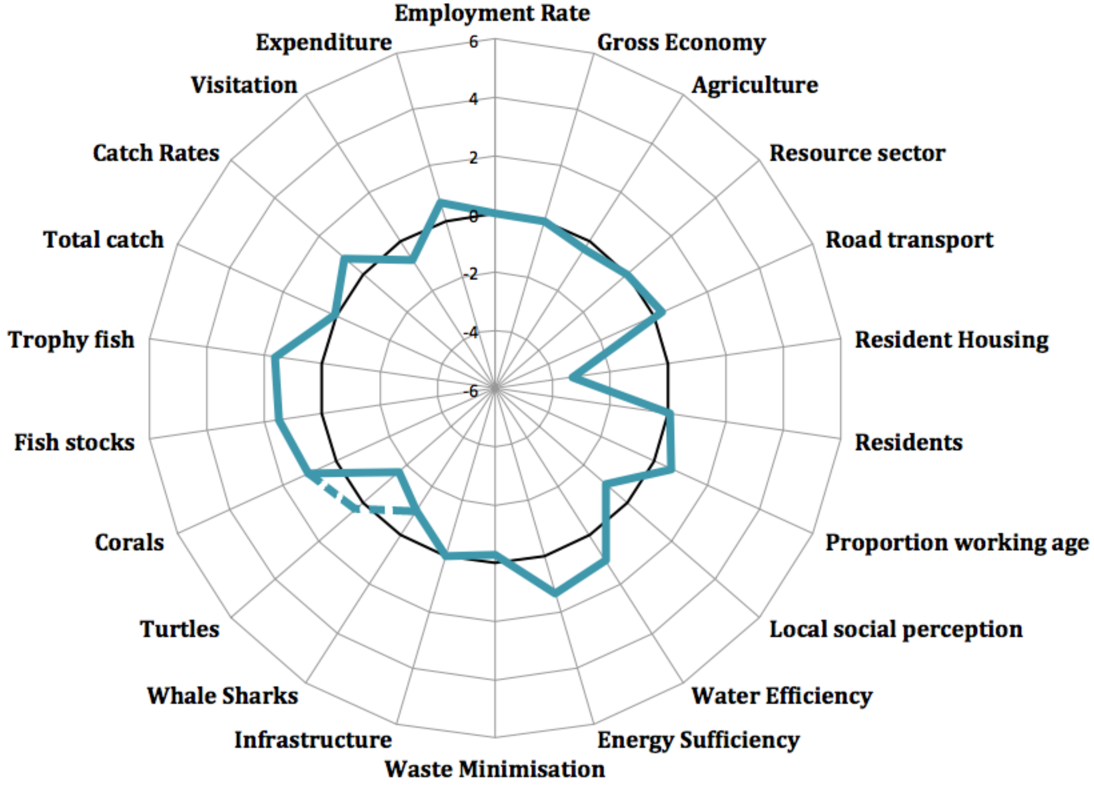


Figure 27: (g) summary of results when bag limits are modified; the black circle indicates the zero mark (i.e. no change)

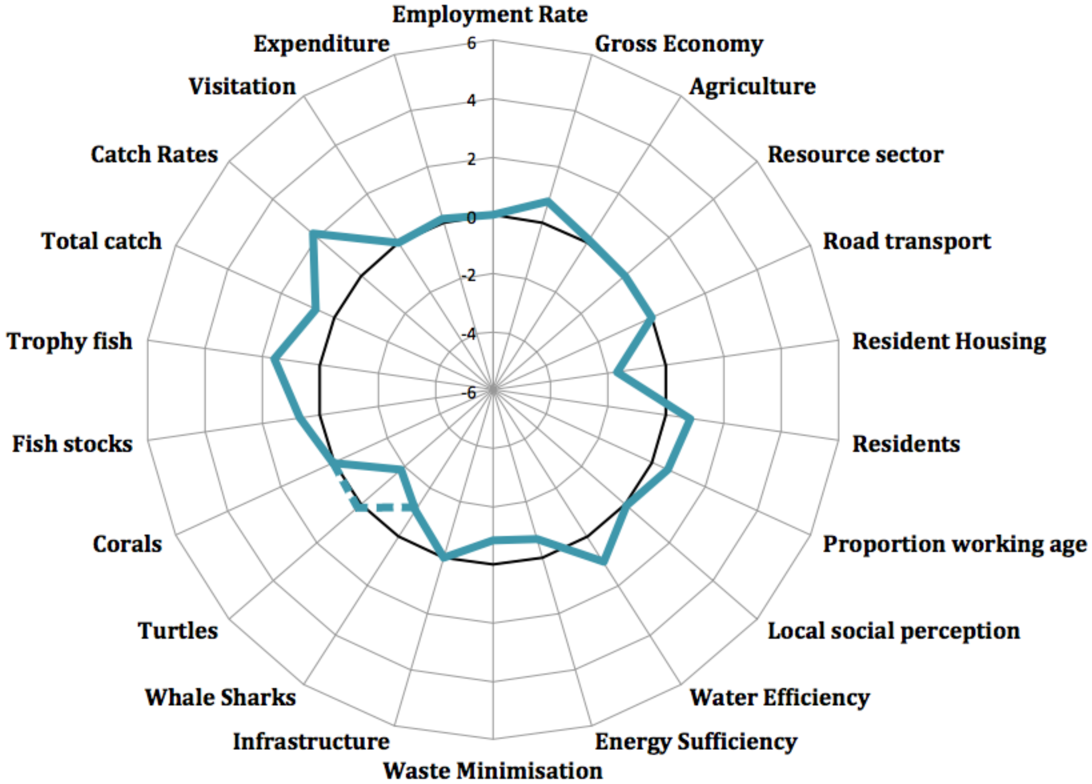


Figure 27: (h) summary of results when there are large developments (resorts or in the resource sector) ; the black circle indicates the zero mark (i.e. no change)

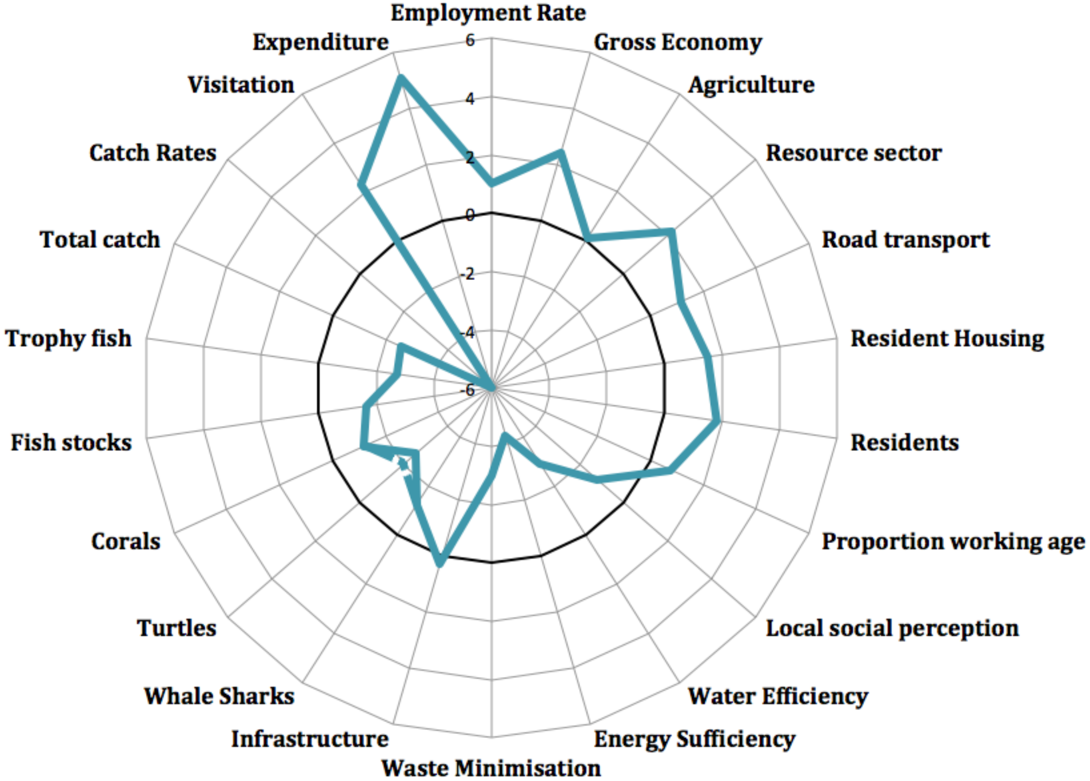


Figure 27: (i) summary of results when there are large developments (resorts or in the resource sector) and the introduction of modified bag limits; the black circle indicates the zero mark (i.e. no change)

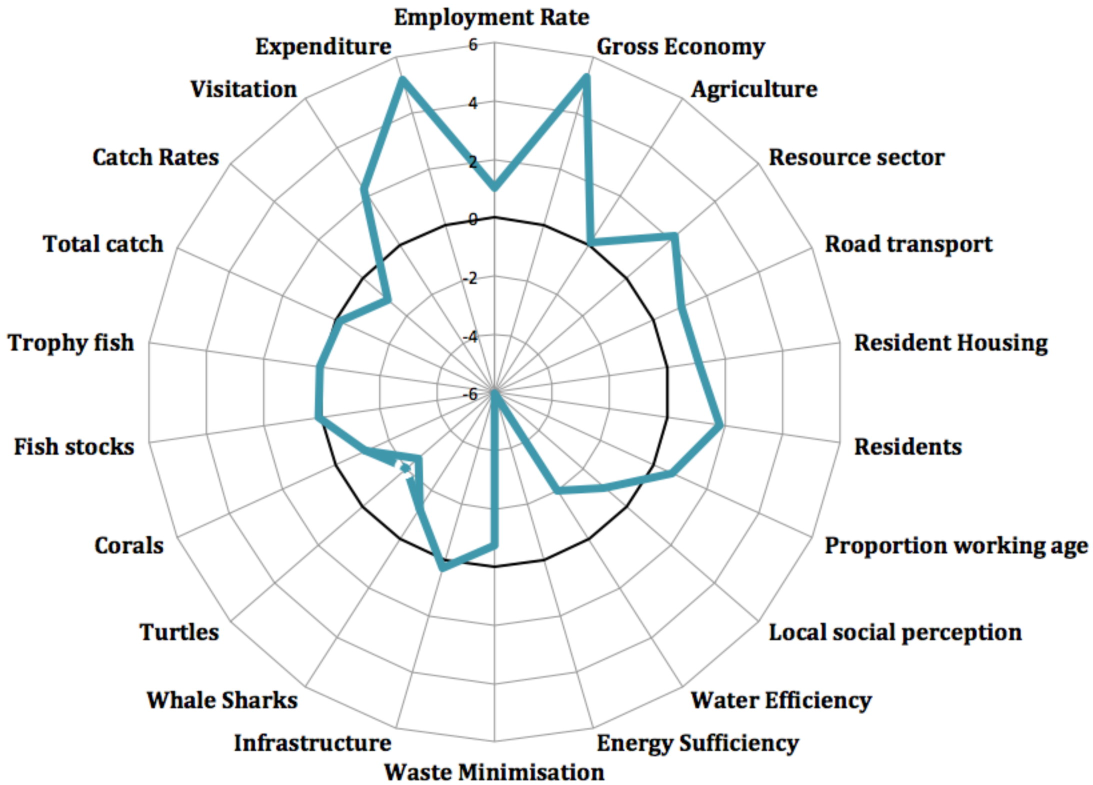
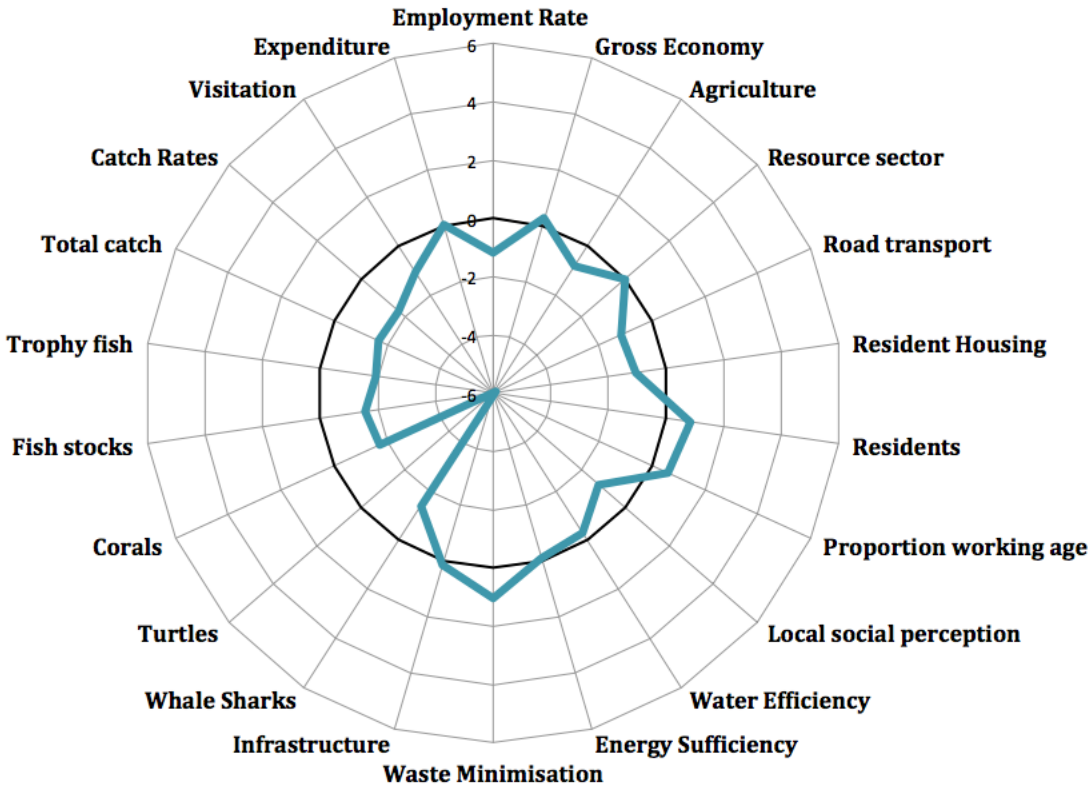


Figure 27: (j) summary of results when there is a changed climate; the black circle indicates the zero mark (i.e. no change)



Management Strategy Performance

Current management arrangements and small variants on that (e.g. small rezoning or increased education and enforcement) did not lead to improved environmental outcomes of the magnitude possible with large scale rezoning (in what way?) of the region or the introduction of modified bag limits. However, in terms of economic and social disruption the bag limits supports further growth, while a large rezoning (of what?) could see tourism use (especially that associated with recreational fishing) drop away. In terms of broader cross-sectoral use of the system, agriculture is marginal in the region, and so any substantial drop in tourist numbers impacts the long term viability of the pastoralists (whose property incomes are heavily dependent on toursim), especially of there is a steep rise in other costs. Other sectors, e.g. mining, are little impacted irrespective of how the park is managed (unless it directly prevents transiting or zoning of the region). Management arrangements for those sectors would likely have a greater effect, but they were beyond the scope of these initial simulations (but could be considered in future ones to load into the virtual online library).

Implications of industrial development

The main effects of industrial development are dependent on whether the labour force is based locally or whether it is largely a fly-in and fly-out arrangement. If the workforce is not housed locally then the greatest impacts stem from activities associated with industrial activities, road trains and shipping. The level of shipping can become a problem, particularly if port expansions within Exmouth Gulf see increased shipping along the eastern side of the Gulf. Two of the greatest potential effects are on whale sharks and humpback whales. While collisions with shipping are unlikely to have a significant population level impact on the whale sharks, they can still have a significant effect on the individuals that the tourism industry focuses on (i.e. those spending long periods at the surface). Even a 5% drop in the numbers of whale sharks spending time at the surface can mean that tourism operators find it as much as two-fold harder to find a whale shark on any one trip. This not only has economic consequence for the operators (especially if they maintain their current policy of "if you don't see a shark then go again for free if there is room on the vessel"), but also means that those sharks that are found are more intensively visited (potentially meaning the sharks are more stressed). In the case of humpback whales the impacts are more uncertain but potentially more dire. If shipping disturbs the mothers and calves (either acoustically or via stimulating the calves when they should be resting) then it can lead to poorer body condition on leaving the nursery grounds, increasing juvenile mortality and reducing overall reproductive success for that sub-population.

If industrial development leads to greater overall growth in the region (i.e. more infrastructure, port expansion, residential development, increased services to support an expanded population, etc), this may lead to significant system-level issues. Increased population (both local and visitors) means much more waste, higher utility demands and increased crowding. This may result in lowering the value of the tourism experience, leading to a lower dollar-per-night spend, even if gross numbers rising means overall contribution to the economy increases. There is also increased demand for labour, but an equal increase in pressure for housing, even with large residential land releases.

A final potential threat is represented by oil spills. The CONNIE software, developed by the CSIRO (http://www.csiro.au/connie2/), was used to identify the size and location of the footprint of potential spills (at different points of the year). The CONNIE output indicated that the majority of spills from rigs north of the NMP were dispersed away from the coast (Figure 28a, where it either moves directly away form the reef or moves offshore). However, under some current patterns (e.g. those that are occasionally present in May, e.g May 2000) that can see the spill move onshore and extend down the northern arm of the reef (Figure 28). In this case the social, economic and environmental outcomes can be complicated. In that case, the spill would have immediate effects in the area of the main slick (marked in red through to green in Figure 28), where there is detectable water contamination. This contamination sees a drop in local fish stocks, localised habitat degradation and an avoidance of the area by megafauna in the short to medium term (up to a few years). There is also a broader effect of the oil spill on the region. Tourism in general dropped by 5% in the year of the spill (recreational fishing dropping by 10%), taking roughly 3 years to recover in full, though the drop in Exmouth is much stronger with a larger proportion of tourists going to southern destinations in the region in the year of the spill (which puts additional pressure on the more southern components of the fish stocks). In the longer term levels of tourism return to the same trajectory as without the spill except that the level of recreational fishing and top line ecotourism endeavours are permanently depressed in the immediate area of the spill (due to a long-term inertia in public perception).

Implications of climate change

As mentioned above, the climate change effects on the system can be quite extreme for some aspects of the ecosystem. This has less to do with temperature increases and more to do with ocean acidification and sea level rise. In addition to direct environmental effects there is also an impact on tourism as it contracts the tourism season for domestic visitors from outside the immediate region. Both international visitors and the local populace continue to access the area throughout the year, but the extreme weather conditions of the warmer months (both in terms of

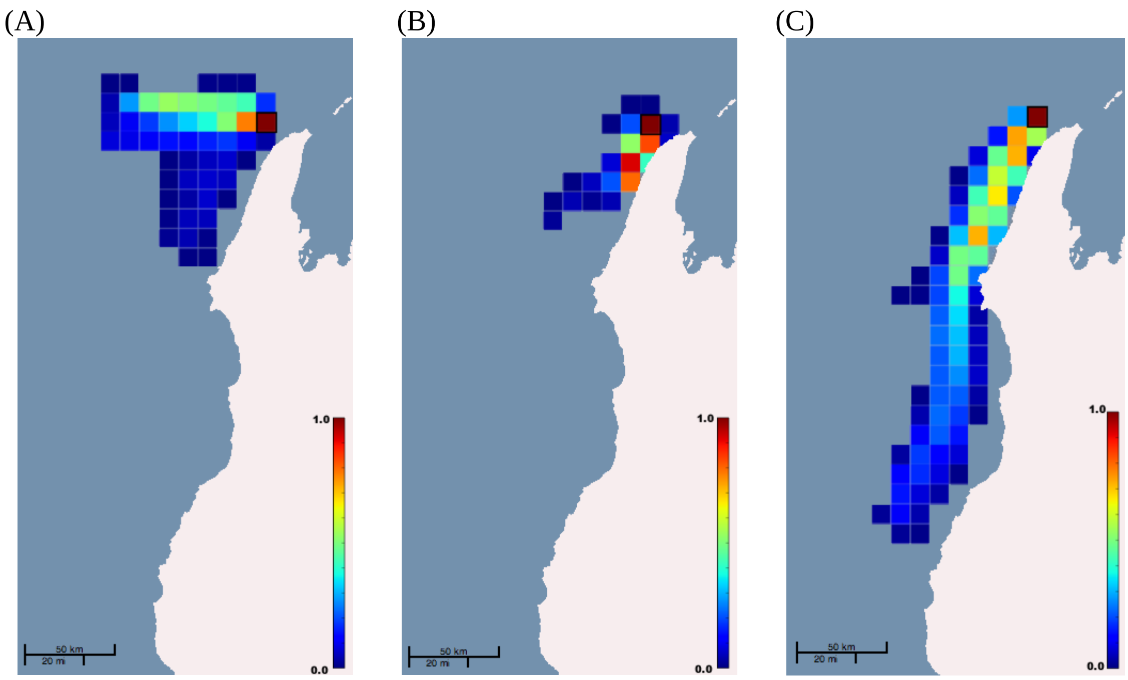


Figure 28: Example oil spills that (A) are advected offshore, (B) are washed on to the reef or (B) parallel to the coast with the potential to effect fishing grounds. The scale is relative from (1.0) at point of release out to 0.0 where concentration of contaminants is negligible after 5 days of dispersal.

very hot days and storms) discourages budget tourists (who find air conditioned accommodation expensive). The changing climate also results in an increase in energy use by the local population. Even in the peak tourism season (through the winter months) sea level rise leads to a significant change in tourism attractions – with less beach visitation in locations where geomorphology prevents beach retreat. With current urban plans and drainage, sea level rise also increases the chance of flooding of the main settlements during periods of high rainfall.

General findings on trade-offs

The simulations highlighted the complex relationships between development and environmental status in the region. The fish stocks have already been depleted due to increasing fishing pressure (especially recreational pressure) over the last 20 years. The simulations clearly show that any further growth in this pressure leads to significant declines in biomass (compared to the 2007 state, which is itself depleted from an untouched state). Additional recreational pressure applied by oil and gas workers may be sufficient to cause a collapse in some key target species (e.g. spangled emperor).

However, the simulations also indicate that without development of some form there is a significant risk of the population decline of previous decades being renewed as the population ages, as younger generations move outside the region and the working age population turns over frequently (i.e. the migration rates amongst the working population is quite high, with people moving into the region, working for a short period, and exiting again). The highest proportional contribution of working age residents occurs when industrial growth is high, as the area attracts new workers. Given the interaction of population size and fishing pressure this suggests that there is a direct conflict between economic and conservation objectives. Nevertheless, sustainable futures are possible. These likely require significant changes to existing regulations, e.g. by adopting modified bag limits where only 1-2 fish can be taken per day for consumption that evening (although enforcement of such a concept may be problematic in reality). Unfortunately, even with significant management changes some components of the system may be very difficult to protect against the effects of climate change and ocean acidification.

Visualising the future

While the magnitude and direction of gross change can be an informative way to consider system-level change over such a broad range of scenarios, it can be hard to relate this to what it really means for a system. To help in interpretation of the simulations, simple computer generated images of what one of the currently minimally developed tourism nodes might look like under a selected set of the non-climate impacted scenarios is provided in Figure 29-Figure 32. Urban locations would see a differing degree of change into the future, particularly depending on the degree of industrial and infrastructure development that takes place.

6.5 Discussion

There is a lot of variation over the entire suite of simulations however some persistent features of the system provide warnings of the system’s vulnerabilities. Environmentally these revolve around the sensitivity of turtles to foxes and sea level rise; the cumulative effects of recreational fishing pressure on the relative composition and abundance of the fish stocks; and the potential vulnerability of habitats to degradation in high use areas (even if they are only the focus of “low impact” activities like snorkelling and diving). Alternative management can help mitigate these impacts, but unconstrained use of the system is (according to the simulations) no longer possible with the number of visitors and local residential population at the level (or above) those in 2010.

The social and economic aspects of the system also have their vulnerabilities. In particular, the resident population is particularly vulnerable to aging. To avoid this new development (or growth of existing sectors) is required. However, growth is constrained by available housing and labour. Growth and development also comes at a cost, especially in the form of extra pressure on housing and increased demand for utilities and waste handling. Targeted growth can reduce impacts or at least better match them to desired objectives and available resources and services. While the models can explore the implications of alternative proposals they will not “just spit out” the best form of development. Instead, the form needs to be decided by people interested in and responsible for the system (e.g. the local shires).

While the requirement for such considered decision-making is evident even within sectors, it is even stronger between them. For instance, development of a resort has largest environmental and utilities footprints (with local fish stocks dropping by about 50% while the demand for water increase smore than 600%), though it also leads to a roughly 50% increase in the local economy (as the absolute spend by tourists increases by fivefold). In contrast, an ecolodge development on the same location has a much smaller environmental footprint (local fish stocks decline by only half as much, while demand for utilities like water increases by less than 80% in total), but is also associated with a much smaller economic injection to the region (only a few percent).

While some of the main drivers discussed above (e.g. the level of development and visitation, housing, access points, toilets and some of the environmental pressures) had already been identified by stakeholders familiar with regional issues, the full extent of the potential interactions could only be assessed via extensive exploration of the alternative futures. The picture we obtain is one of the Ningaloo-Exmouth region as a typical “complex” system; that is a system which is controlled by large scale external pressures as much as by very fine scale processes. The regional future will be affected by global drivers, like climate change and external industrial development (e.g. in the Pilbara), but also by local intervention points (e.g. the availability of utilities and housing), sanctuary zone boundaries, opening or closing of specific infrastructure (e.g. boat ramps) and road access. The outcome of the interplay of processes at such radically different scales can only be studied transparently via models with the complexity of InVitro.

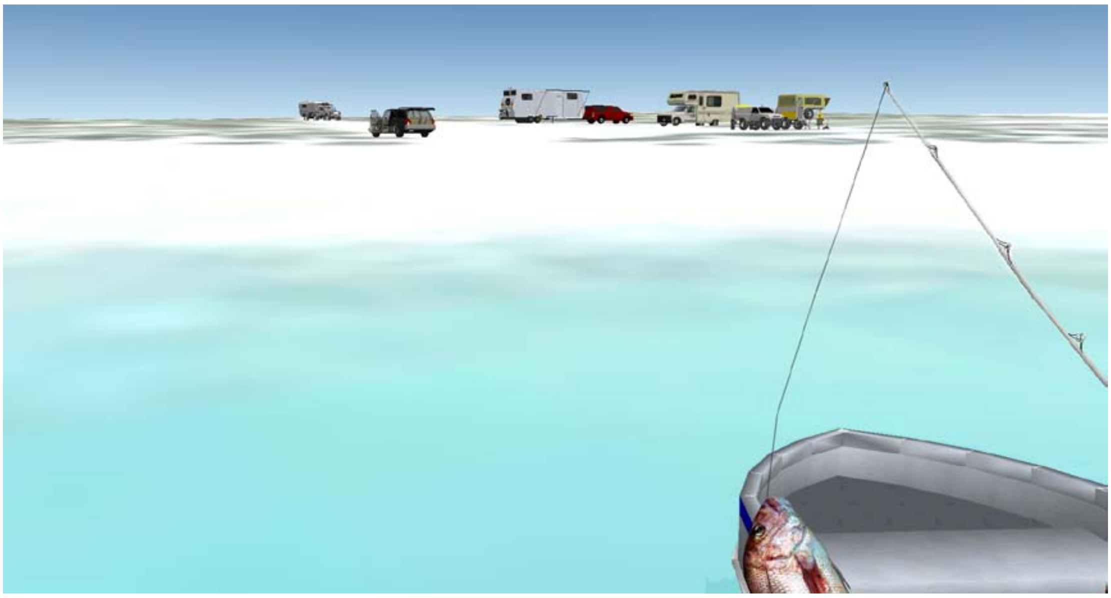


Figure 29: Computer generated image of an undeveloped tourism node if current tourism operations and management regulations remain in place (i.e. beach camping dominates for most undeveloped nodes) and there is no resource sector development beyond those present in 2007. While this situation no longer remains it is a helpful baseline against which to compare the other cases.

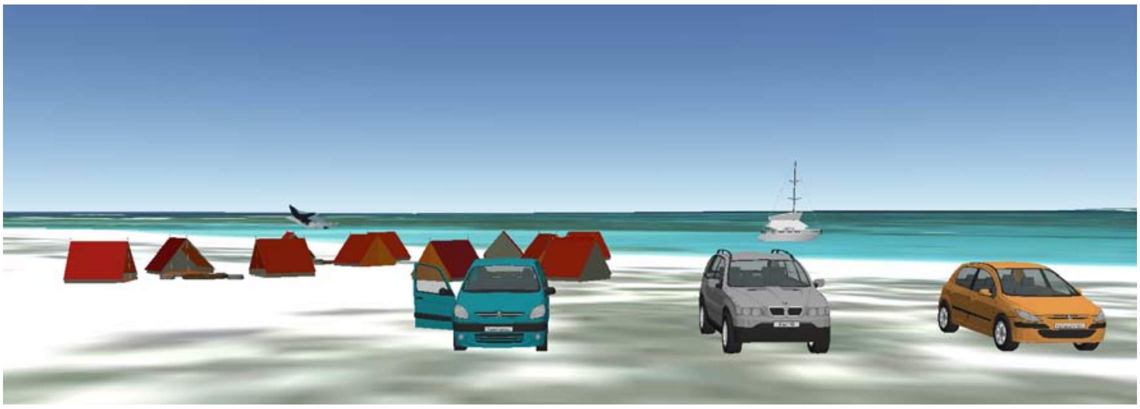


Figure 30: Computer generated image of an undeveloped tourism node if current tourism operations and management regulations remain in place (i.e. beach camping dominates for most undeveloped nodes) and planned resource sector development occurs in full by 2035. There is a much higher density of recreational fisherman and pleasure craft, although not a complete loss of large charismatic megafauna (e.g. whales).

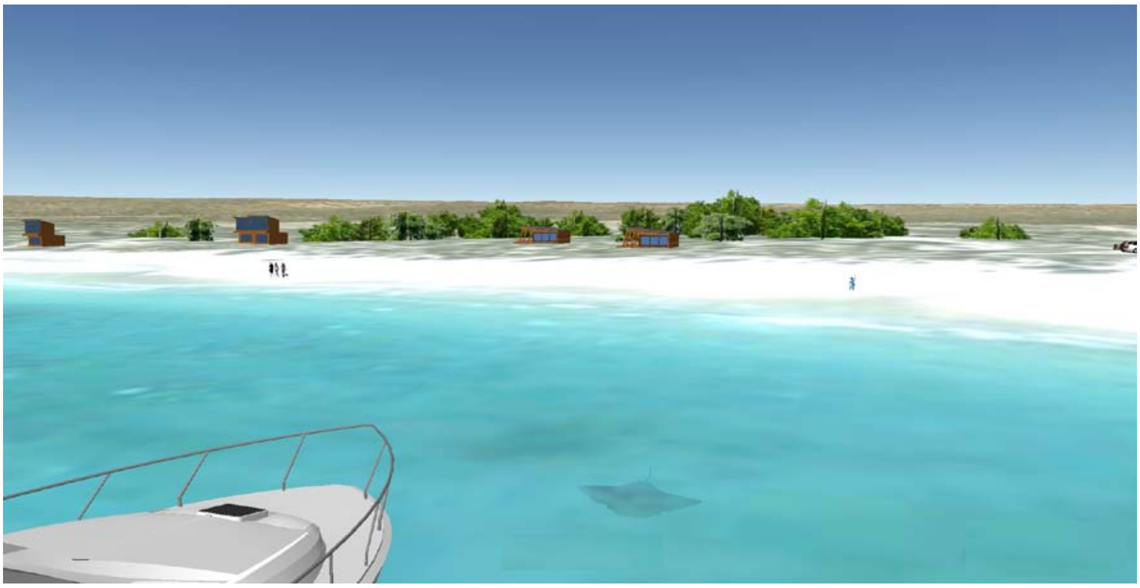


Figure 31: Computer generated image of a coastal tourism node developed with ecolodge accommodation. Planned resource sector development is assumed to occur in full by 2035, meaning that there is a much higher density of pleasure craft (and potentially recreational fishing, though whether this is accommodated by ecolodges will likely vary depending on lodge regulations), though not a complete loss of large charismatic megafauna (e.g. large rays, though heavy use or repeated approaches could see their frequency of visitation drop). Nevertheless broader environmental impacts of development (e.g. higher numbers of road trains, shipping etc) does not always impact more sheltered sites (so may not effect the ambience at well sited ecolodges).

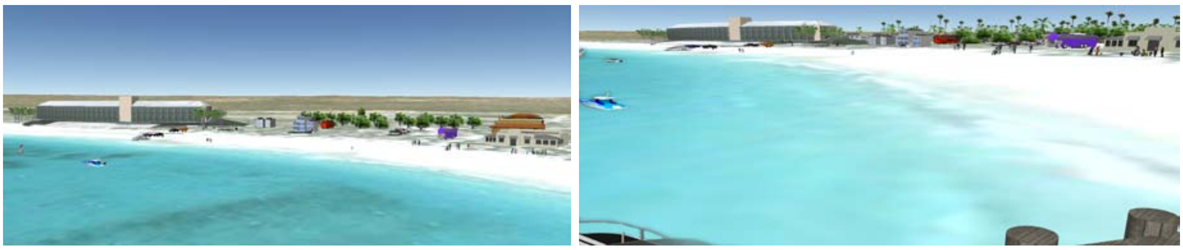


Figure 32: Computer generated images of a resort (and retail) development on a coastal node, with differing degrees of residential development; there is little extra housing provided beyond the resort in the image on the left, while urban-like development (on the scale of Coral Bay, but largely hidden amongst the extensive landscaping in the rear of the scene) has been allowed in the image on the right. Planned resource sector development is also assumed to occur in full by 2035. This form of development has, by far, the largest environmental and utilities footprint, especially if located on a previously undeveloped site.

7. CONCLUSIONS

Very diverse futures are possible for the Ningaloo-Exmouth region over the next 30 years. Fortunately, it appears management interventions are available to steer (at least some components) towards desired directions. Among these management strategies, fishing regulations, housing plans, marketing and catering for specific tourists type and infrastructure development are likely to provide the largest impact. While some of these results were evident in other smaller models of the system (see Jones et al 2011, Little et al 2011) the interconnection between the industrial developments and larger marine state (even though not physically co-located) was only evident once the system information was integrated in the InVitro model. This information (and the simulations available via the online virtual library portal) should provide useful insights into specific concerns such as fishing and conservation zoning, returning the coastal strip from pastoral leases to State Government management, alternative regimes of land release for development and the likely impact of construction of new landing areas, bitumen roads and other infrastructure.

Despite the system dynamic understanding gained from this study, perhaps the even bigger lessons include how to (i) successfully communicate complex information to people with varying degrees of scientific background, and (ii) support these communities to let them understand and deal with complex highly interconnected systems. While the InVitro model described here can provide valuable information, its usefulness depends on whether the results and recommendations are taken up by stakeholders, which in turn depends on engaging them and addressing their concerns. By the end of the project this engagement accounted for roughly 43% of the overall modelling team's effort and resulted in a number of one-to-one meetings, workshops and seminars. This level of engagement highlighted that: a) stakeholders have very different levels of knowledge and understanding of modelling, what it does and what it can provide, which affects their attitude towards its use in planning and decision making; b) allowing stakeholders to play with simpler models that still capture key nonlinearities of the system (e.g. the other models described in this volume) can provide experience in dealing with complex systems (e.g. significant insights were gained by shore council members during training workshops held in Exmouth); c) the network of interactions among stakeholders and/or researchers can change as a result of one-to-one meetings, workshops and model use; d) the style, language and attitude required to showcase models and results differ considerably depending on the stakeholder types and expectations; e) communities hold local knowledge that can greatly benefit model development and tuning; f) similarly, communities and stakeholders may formulate questions not envisaged by modellers and project developers; and g) the level of community reception depends crucially on the amount of effort locally invested – this is true especially when scientists need to overcome the perception of being 'outsiders' to both the community and problem. These lessons on successful engagement represent perhaps the most important learning gained from a system level understanding of Ningaloo – including the role of science.

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APPENDIX A - SYSTEM DIAGRAMS

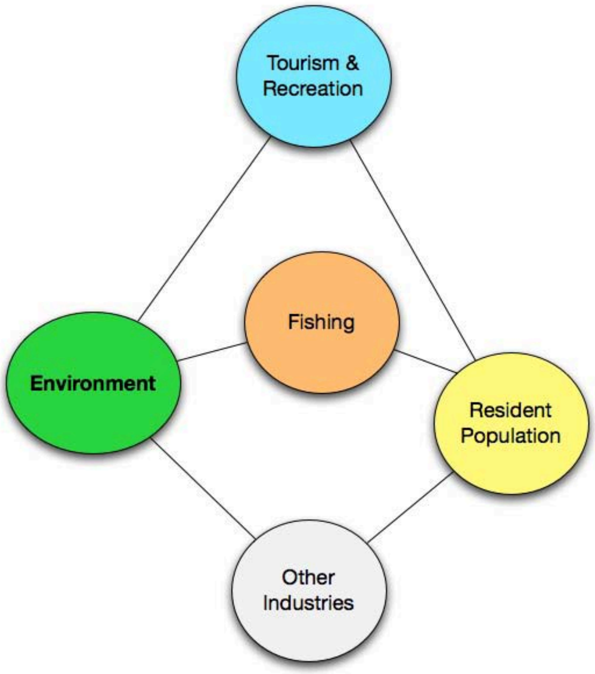


Figure 33: Conceptual model of the Ningaloo-Exmouth region (as defined by stakeholders in the region)

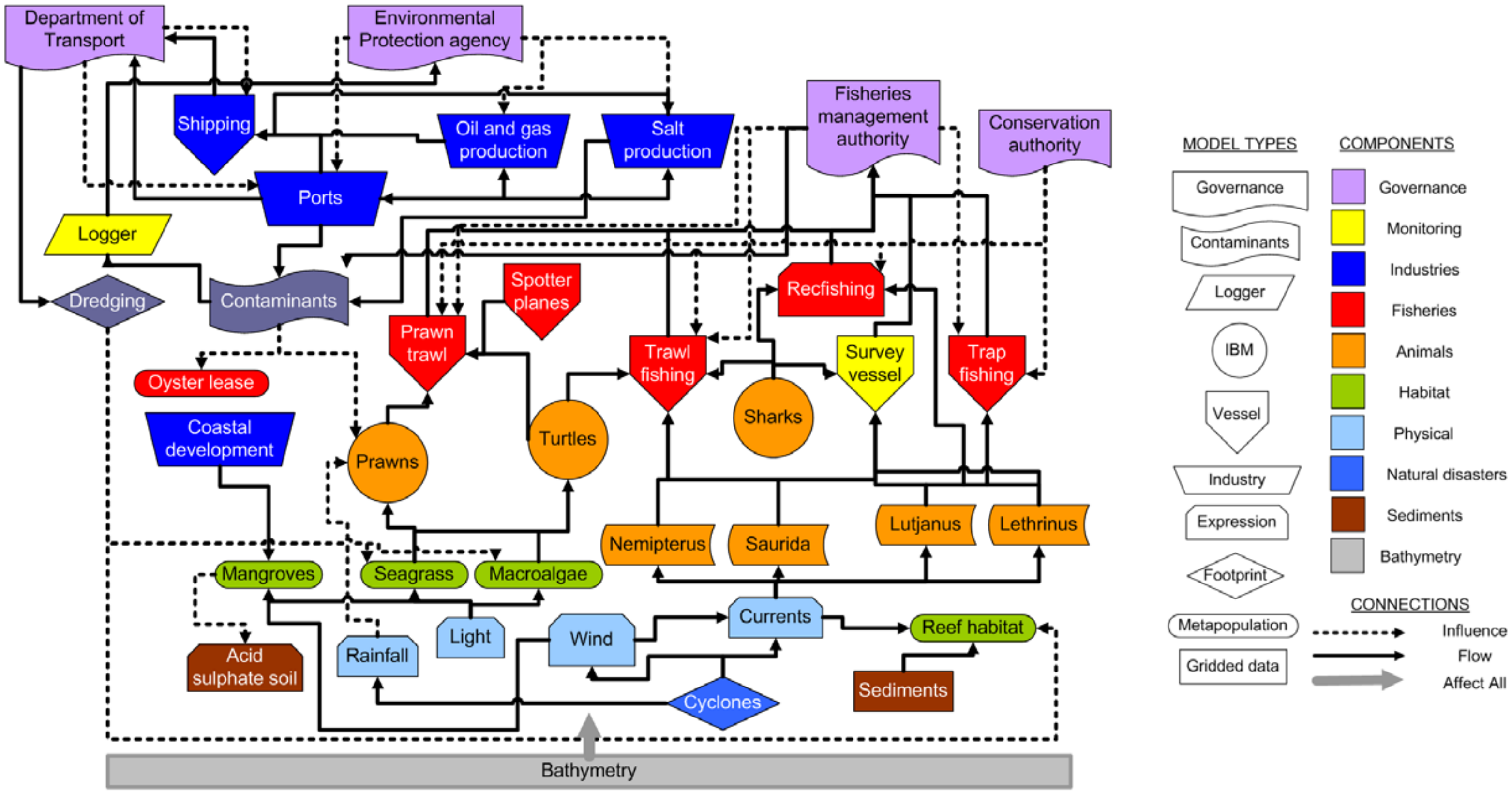


Figure 34: Pilbara InVitro model structure, which was used as a starting point for a system model of the Ningaloo-Exmouth region.

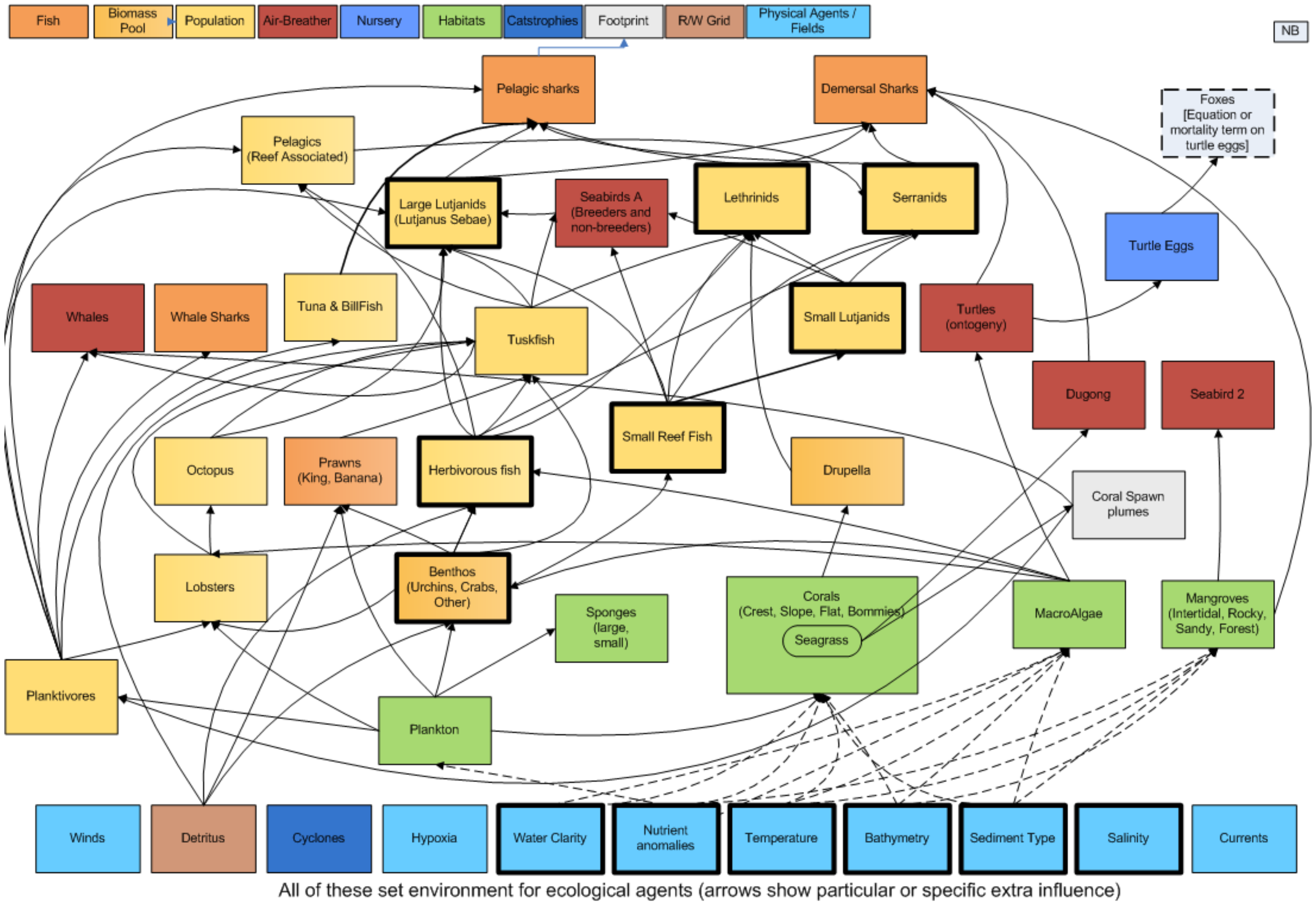


Figure 35: Ecological components of the system (after consultation with biological experts working in the Ningaloo-Exmouth region).

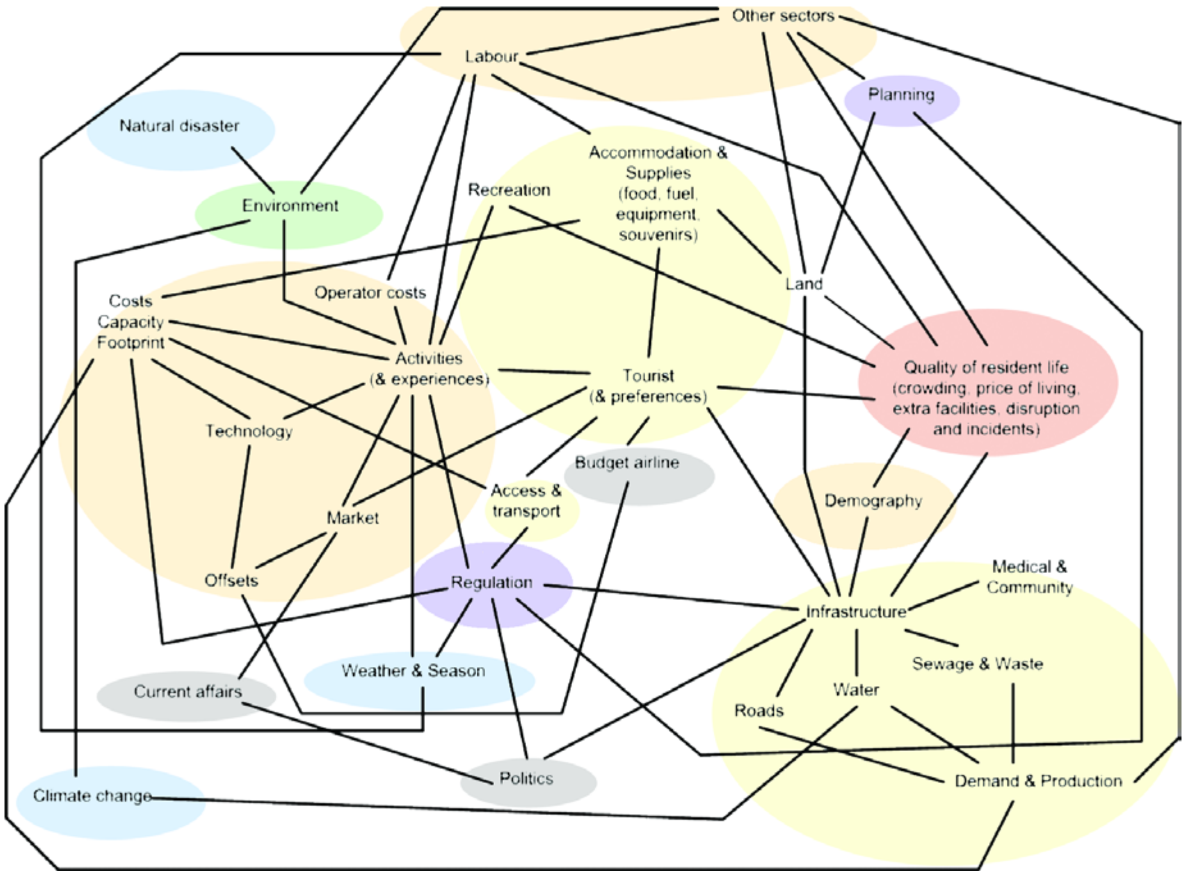


Figure 36: Tourism relevant components of the Ningaloo-Exmouth region (after advice from people living in the region as well as expert advice by tourism researchers and social scientists). Colours indicate where those components would sit in the final full system model, see Figure 39 (e.g. physical-chemical is blue, governance is purple etc).

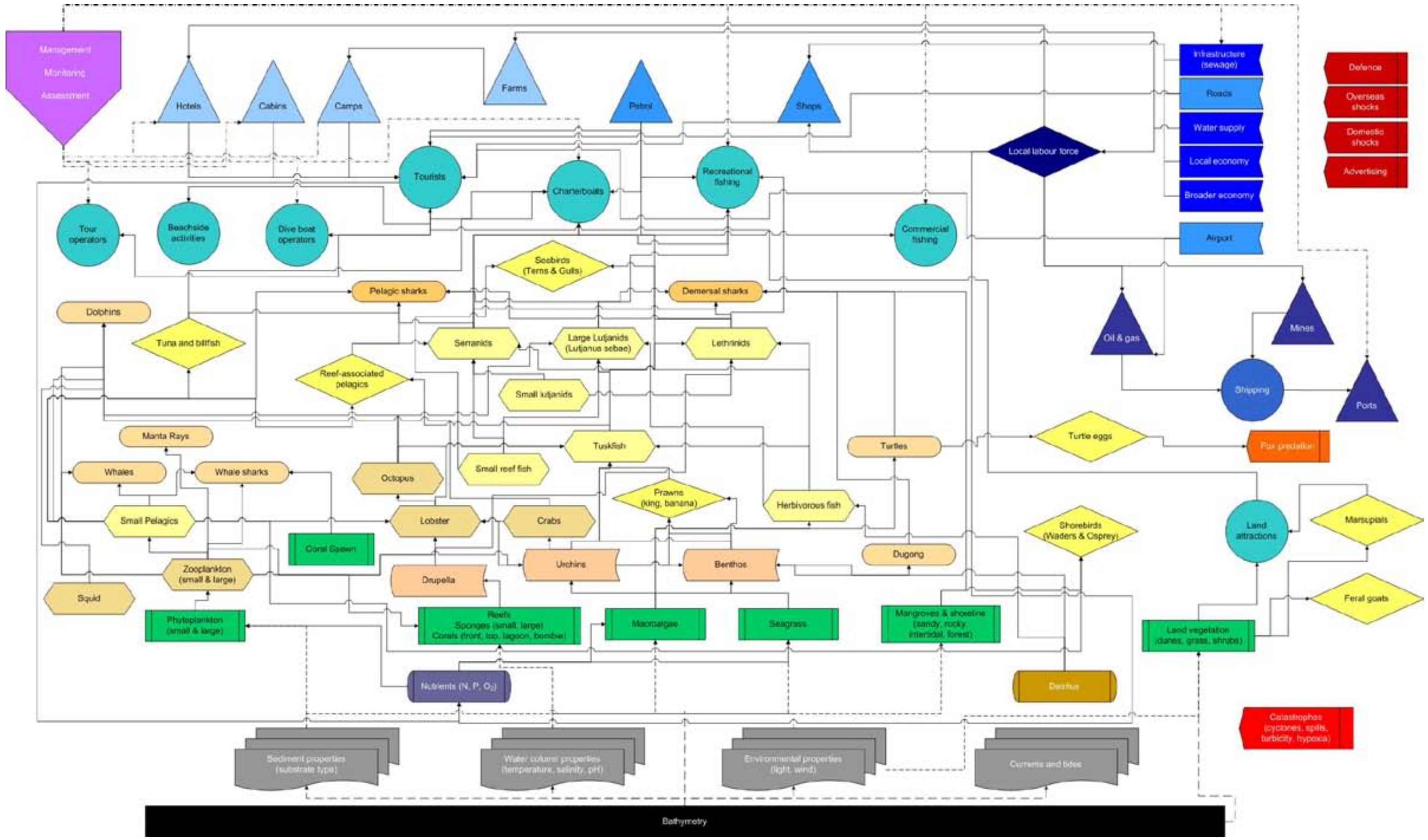


Figure 37: Initial diagram of the full system model of the Ningaloo-Exmouth system (focusing on direct connections).

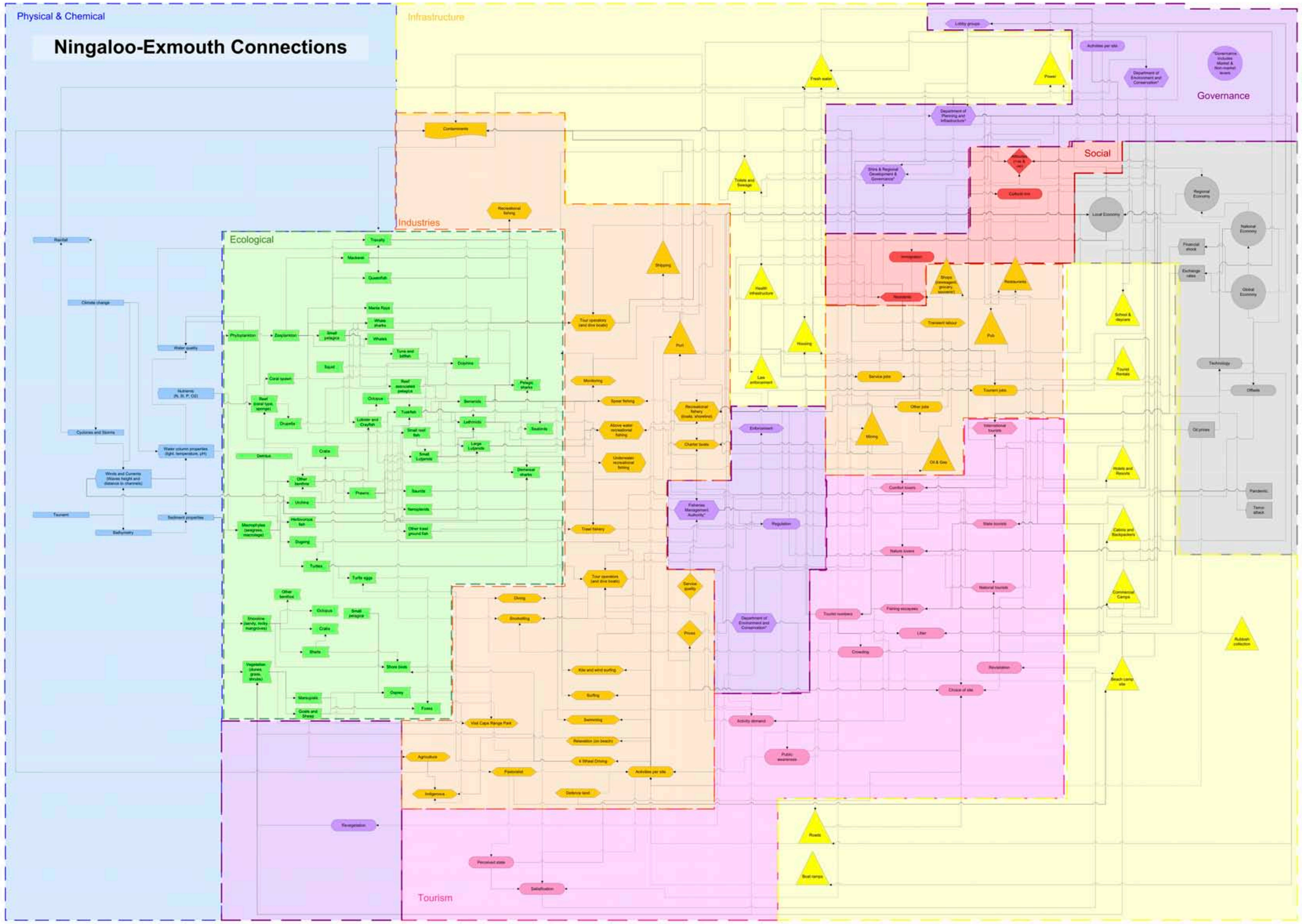


Figure 38: Final full system model of the Ningaloo-Exmouth region (after consulting with all stakeholders and researchers working in the region).

APPENDIX B – SUMMARY OF RESULTS

Table 3: Glossary of scenario components and management strategies used for the simulations presented in Figure 39

Base case: state and trends in the region (levels of tourism remain around 200000) in 2006 continues into the future with no new developments (growth rates roughly 1%).

Reduced growth: as for base case, but with lower base levels of growth in any industry or population segment that was growing in 2006 (growth rates around 0.5% or even contracting)

Reduced costs: costs of land transport, food and services drop by 10% vs 2006, airfares remain at around the levels of March 2011 (i.e. $100-300 instead of $600).

Increased costs: costs of land transport, food and services increase by 20+% vs 2006, airfares remain at $600+ and petrol reaching $5/L by 2020.

Large resort: 2000-4000 bed resort built on currently undeveloped node on the coast.

Ecolodge: 200 bed ecolodge built on currently undeveloped node on the coast, with existing "executive tents" expanded (by 2-3x) at Red Bluffs and Mandu.

Extra infrastructure: new boat ramps built at Quobba, Gnaraloo Bay and expanded permanent structures built in Carnarvon, Coral Bay, Tantabiddi and Bundegai.

Gnaraloo road paved: Gnaraloo road paved (two lane) all the way to Gnaraloo homestead.

Coastal road circuit and access opened: entire coastal road paved and a loop circuit is created; boat ramps added as for "extra infrastructure" with an additional boat ramp added on Ningaloo Station and just north of the defence lands.

Resource sector development: All current and planned resource sector developments in the Gascoyne and Pilbara are completed, a deepwater port is established at Carnarvon, all phases of the marina and causeway developments are completed, with the resource sector also using the Navy Pier and a significant increase in shipping traffic within Exmouth Gulf.

Increased cruise visits: Number of cruise ships increases per year until it reaches 30 per year.

Reduced air services: Air services are reduced to twice per week (timed around shift changes for the resource sector).

Climate change: water temperatures increase by 2-3 degrees Celsius on average (in line with an emissions scheme in line with the current trajectory), sea level rise of 20-40cm by 2035 and increased frequency of storm and flood events (as often as once per 5 years).

Coastal strategy: Coastal strategy in place until 2010 continues unchanged.

Small rezoning: Additional large closure only in the north – see orange area in Figure 39b.

Large rezoning: Additional large closure in the north and the closure of the Cloates region – see orange area in Figure 39c.

Limited access: Much of the NMP area has restrictions on use (especially extractive use), see orange area in Figure 39d, though a few areas remain under the same usage guidelines as of 2010.

No shorefishing in sanctuaries: No fishing from shore in sanctuary zones.

Increased education: Compliance rates (which are begin in excess of 80%) increase by 10%.

Modified bag limits (in line with the wilderness fishing concept): Bag limits for all species reduced by 75-80% (with a minimum of 2 for most species, except the most heavily impacted large fish where the bag limit could drop to 1 if at 2 or lower in 2010).

Oil spill: Oil spill from rig north of the park, which lasts 5 days, see Figure 28.

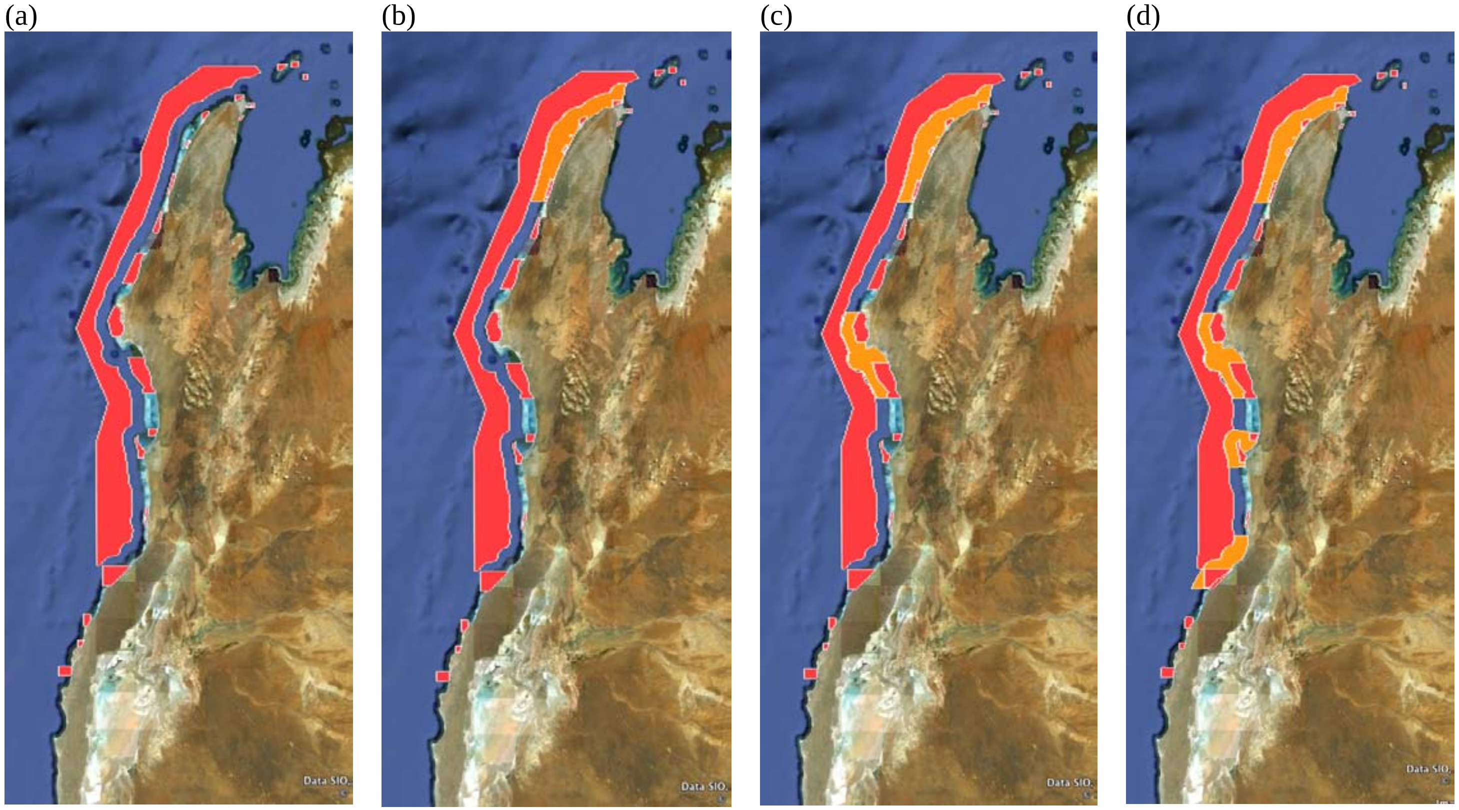
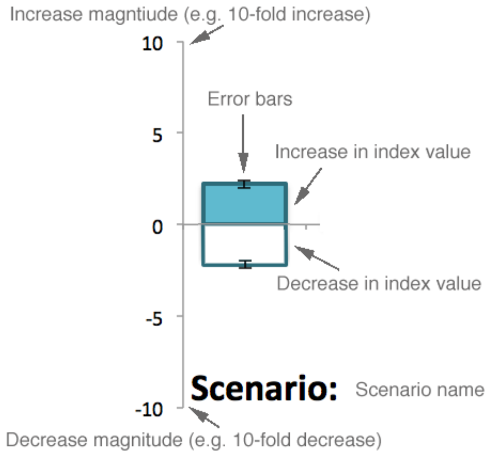


Figure 39: Alternative spatial zoning: (a) base case, (b) small rezoning, (c) large rezoning, (d) limited unregulated access. Red marks spatial management areas of 2006 and the orange areas represent alternative potential spatial management zones.

Figure 40: Outcome of MSE simulations. To ease interpretation of the complicated and large outputs we have taken a standard presentation form (see panel to the right). The size of the bar represents the increase (or decrease if negative) in the property vs its state in 2010 – the change is the magnitude change (so +2 means double the original level whereas -2 is half the original level)[10]. The error bars represent the 95% confidence intervals (calculated across multiple stochastic runs for each scenario-strategy combination).

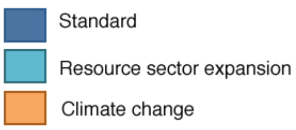


of

The indicators on the plot are (from left to right in each plot):

Resource sector	Tourism (Gross $)
Number trucks on road	Number of visitors
Agriculture	Fishing hours (effort)
Local population	Waste
Proportion retired	Infrastructure
Proportion children	Biodiversity
Proportion working age	Habitat (coral)
Local housing	Abundance of turtles
Social perception	Abundance of sharks
Unemployment rate	Abundance of whale sharks
Migration rate	Abundance of spangled emperor
Gross economy	Biomass of fish stocks
Electricity use	Catch rates
Water use	1+ trophy fish caught per trip

The figures have also been coloured to help identify exceptional conditions, using the following colours:



[10] See the footnote to figure 27c for an explanation of why this scale was used.

Figure 40: continued

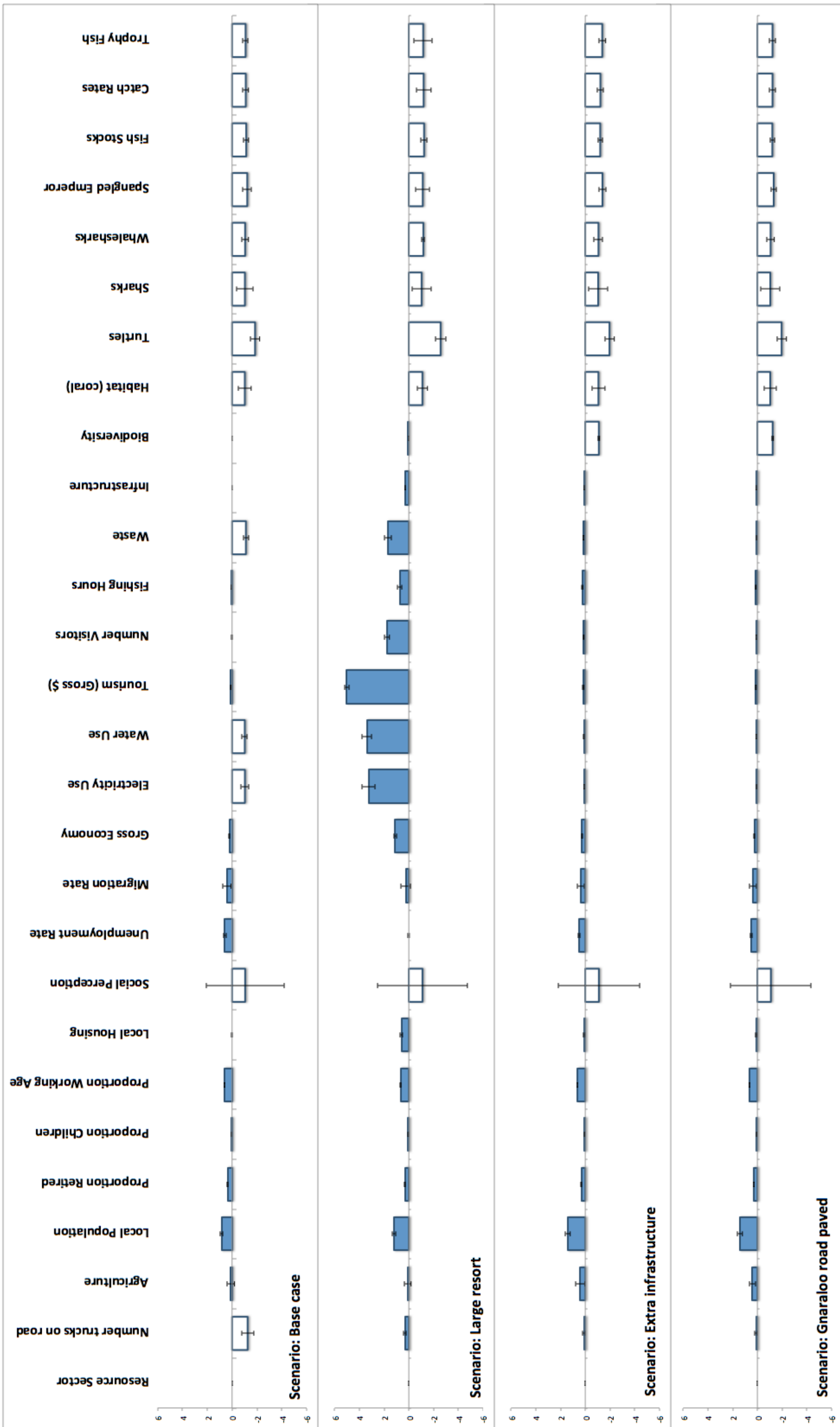


Figure 40: continued

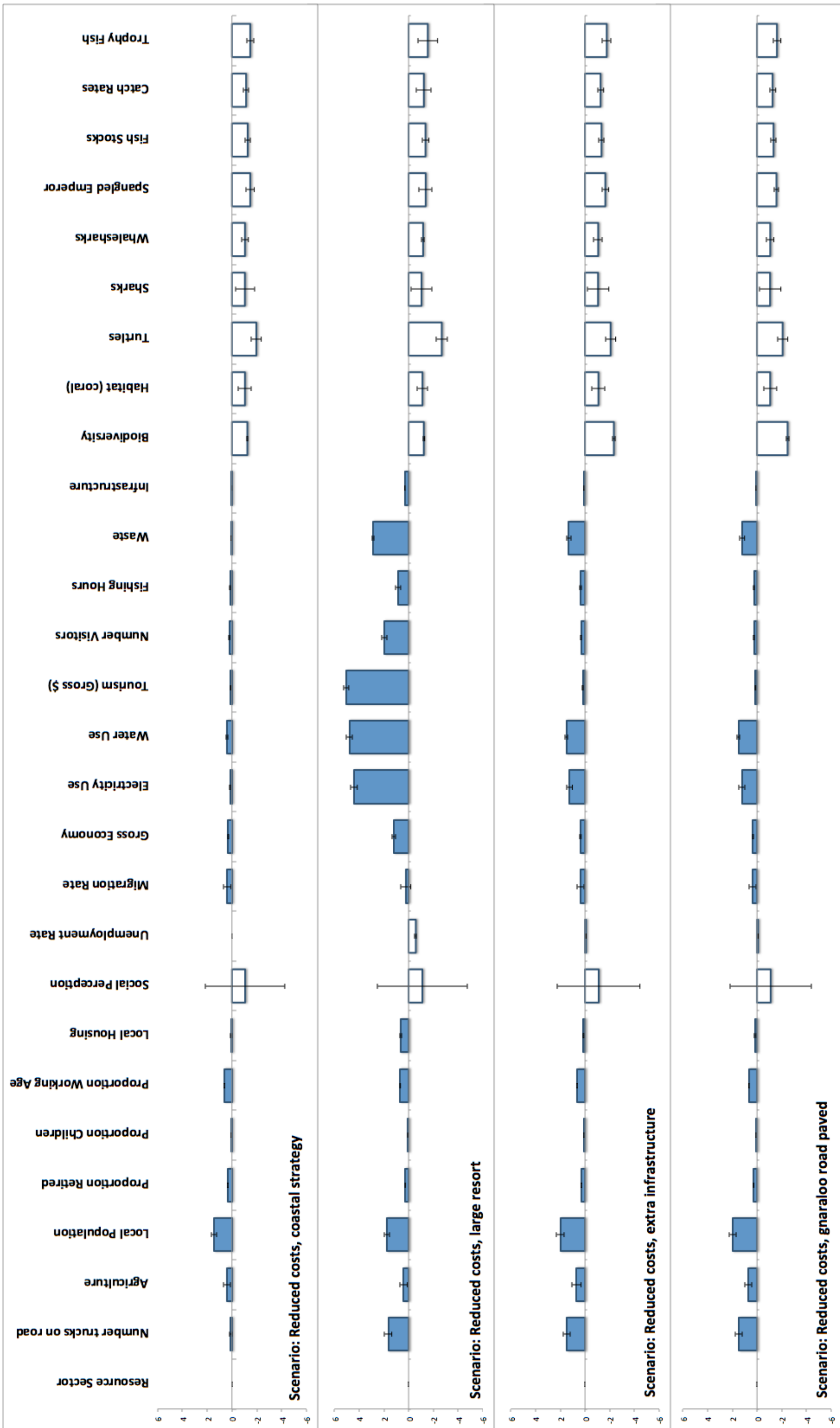


Figure 40: continued

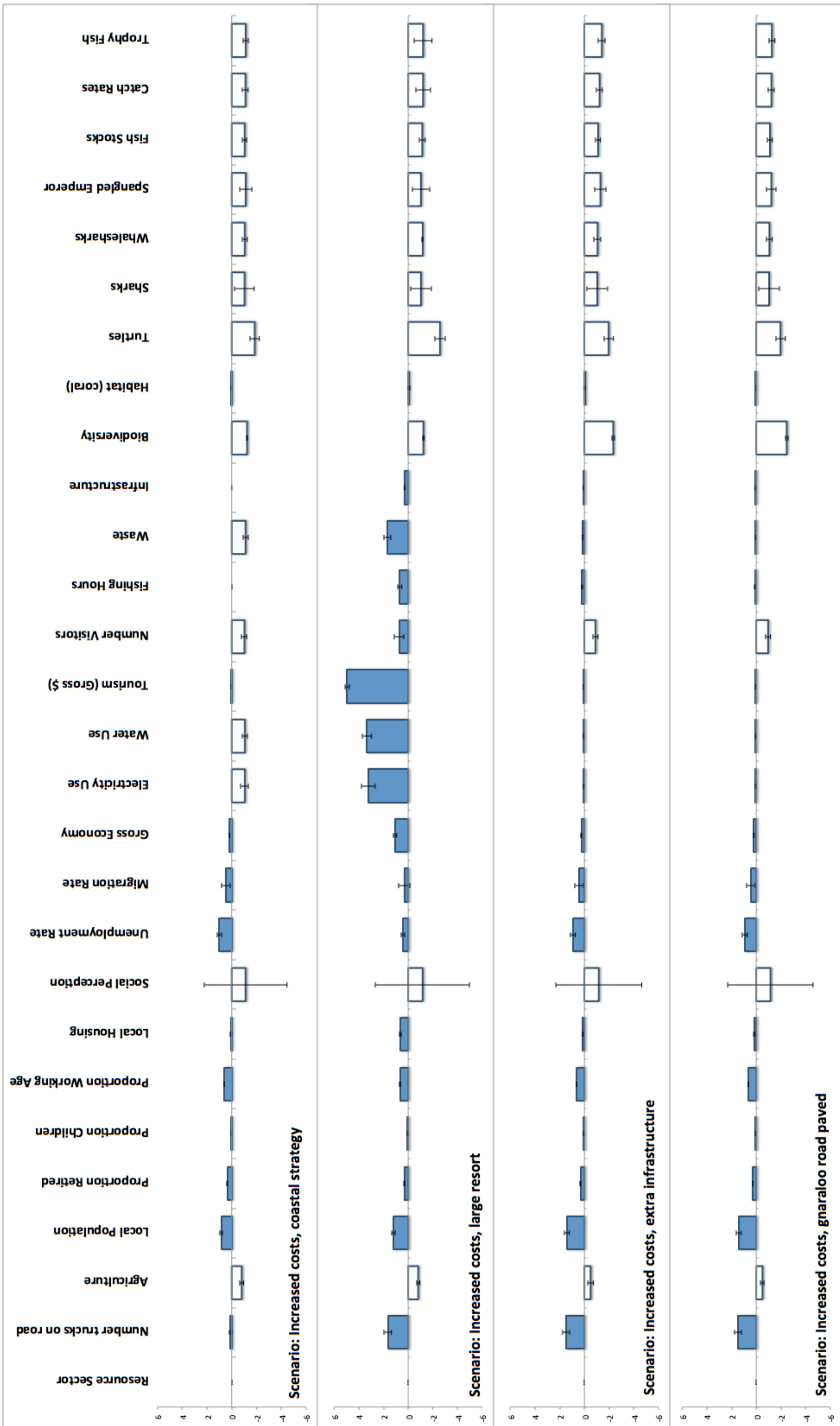


Figure 40: continued

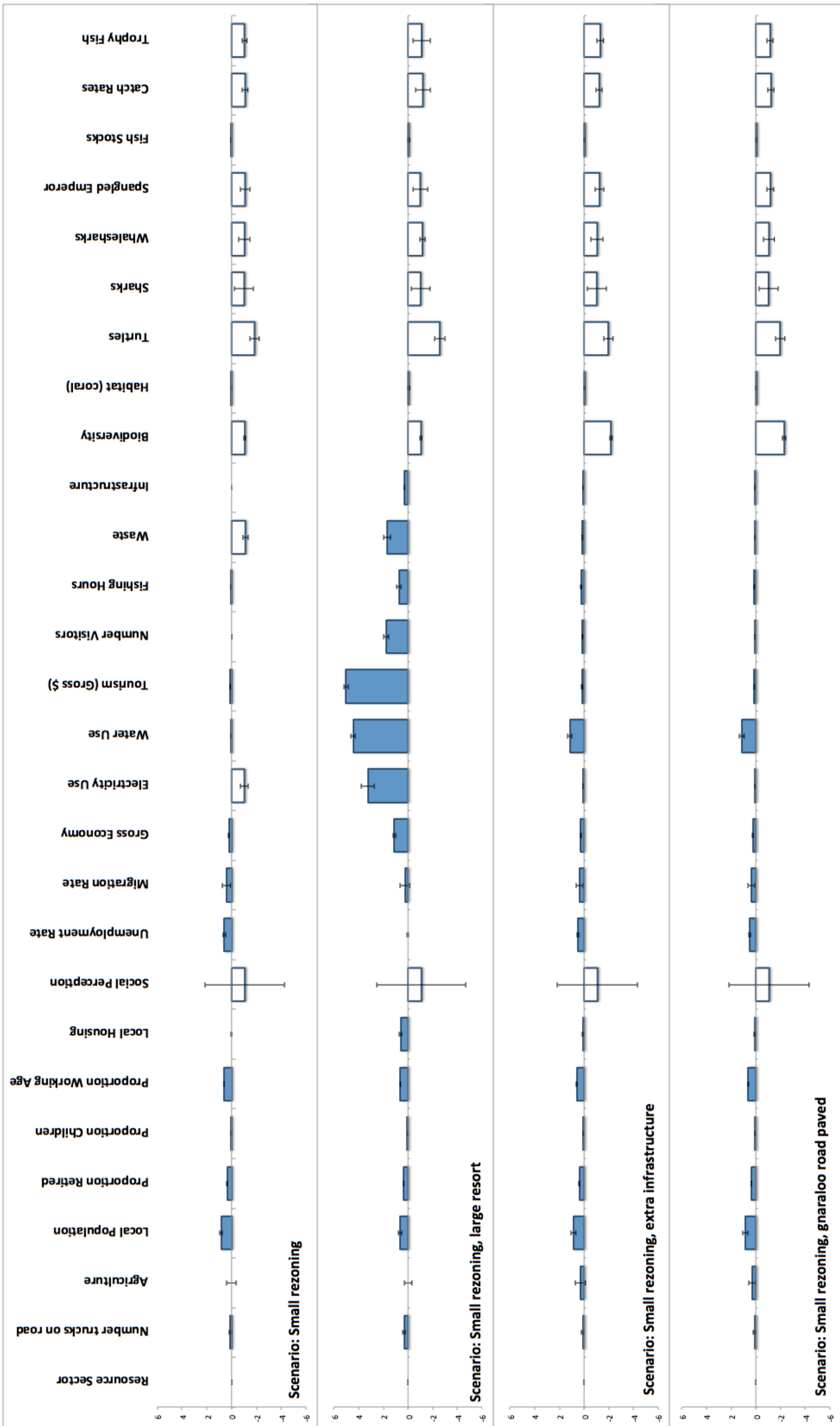


Figure 40: continued

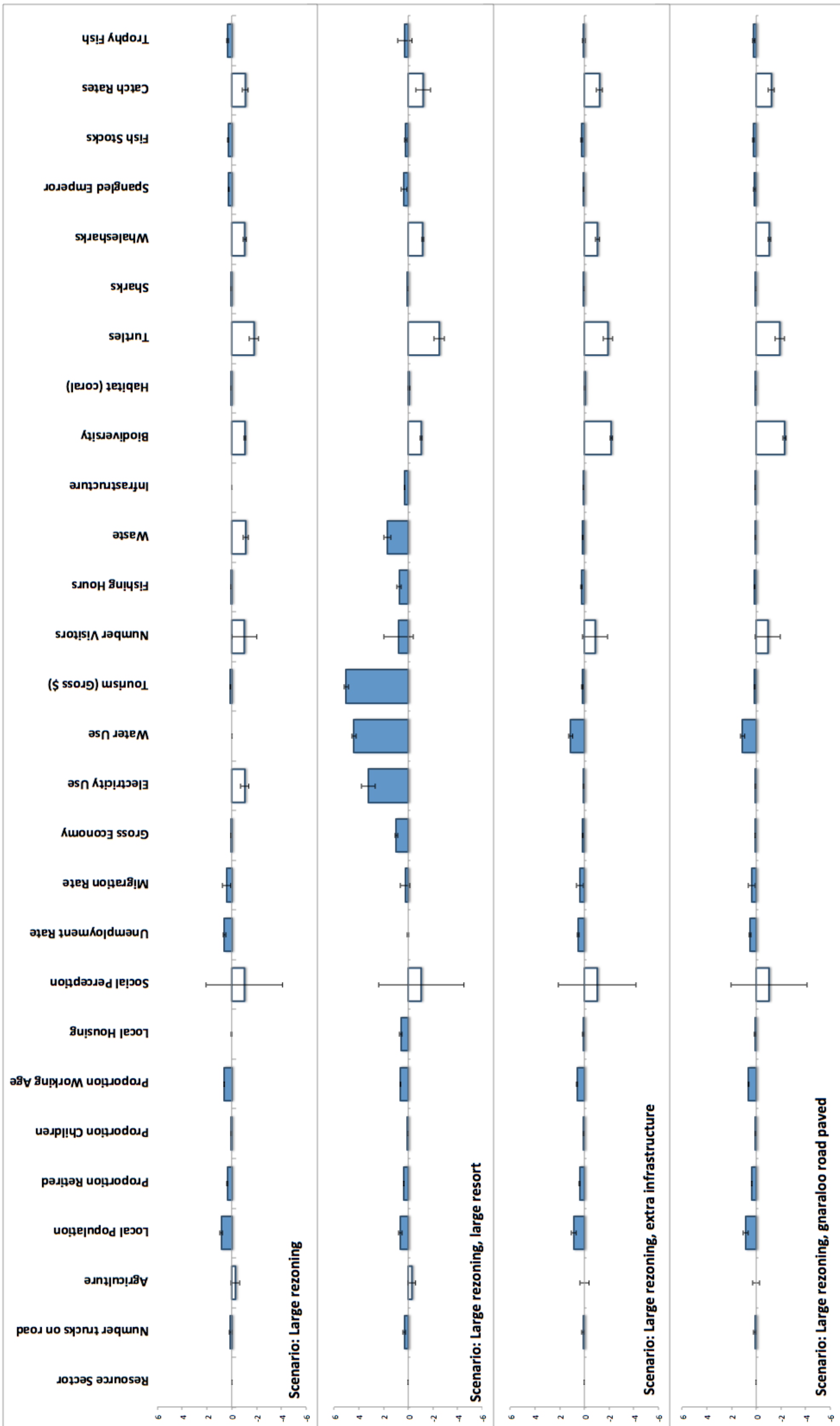


Figure 40: continued

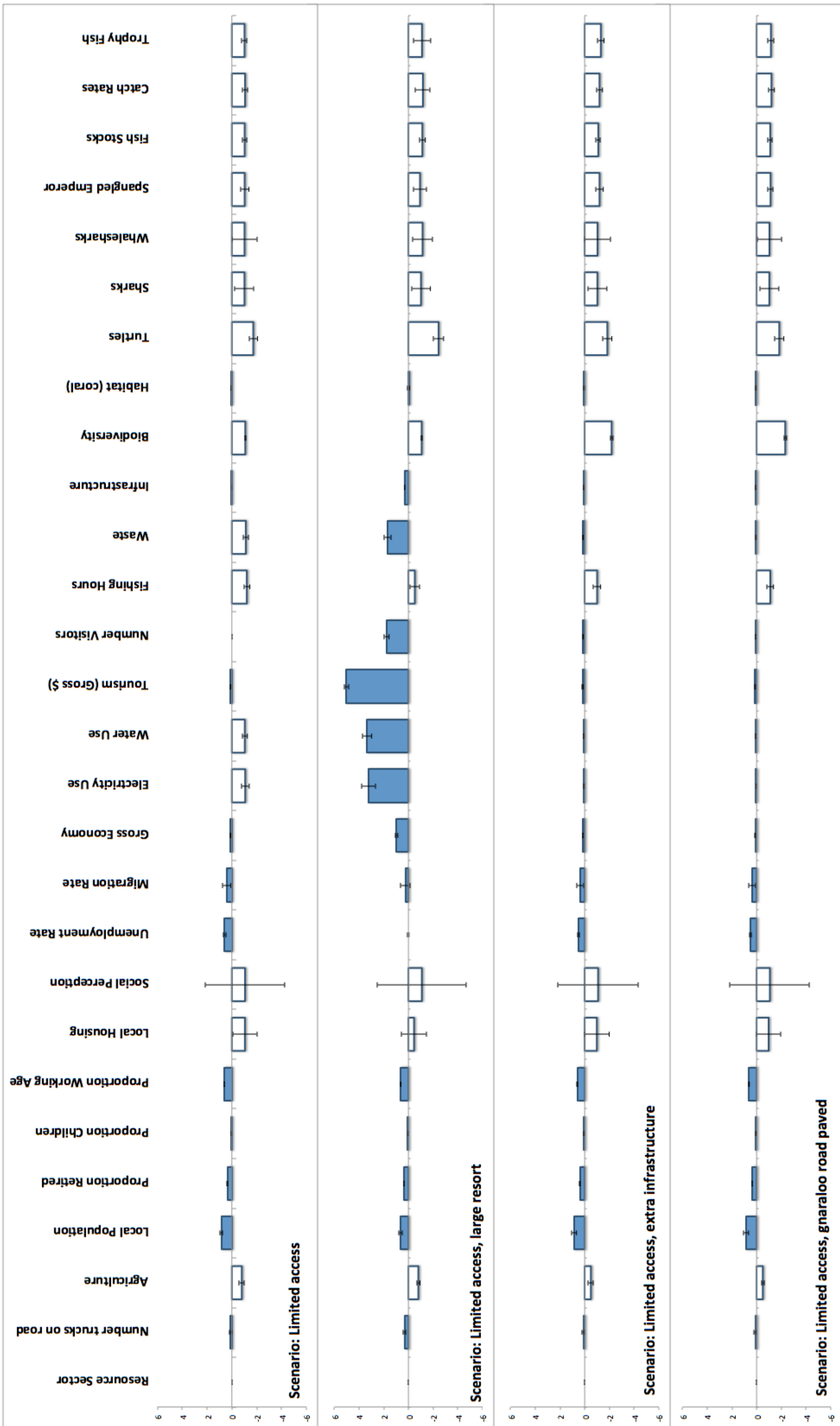


Figure 40: continued

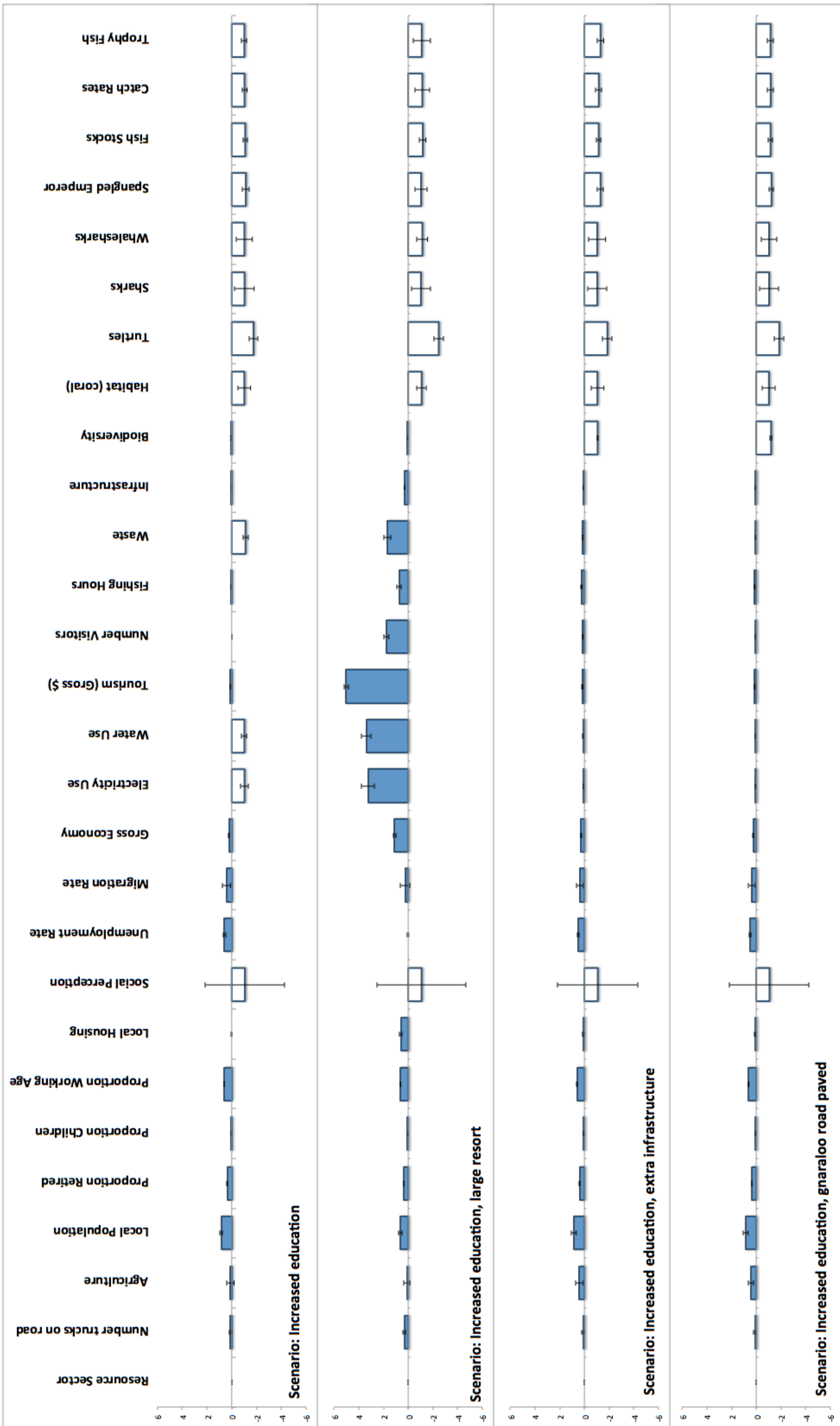


Figure 40: continued

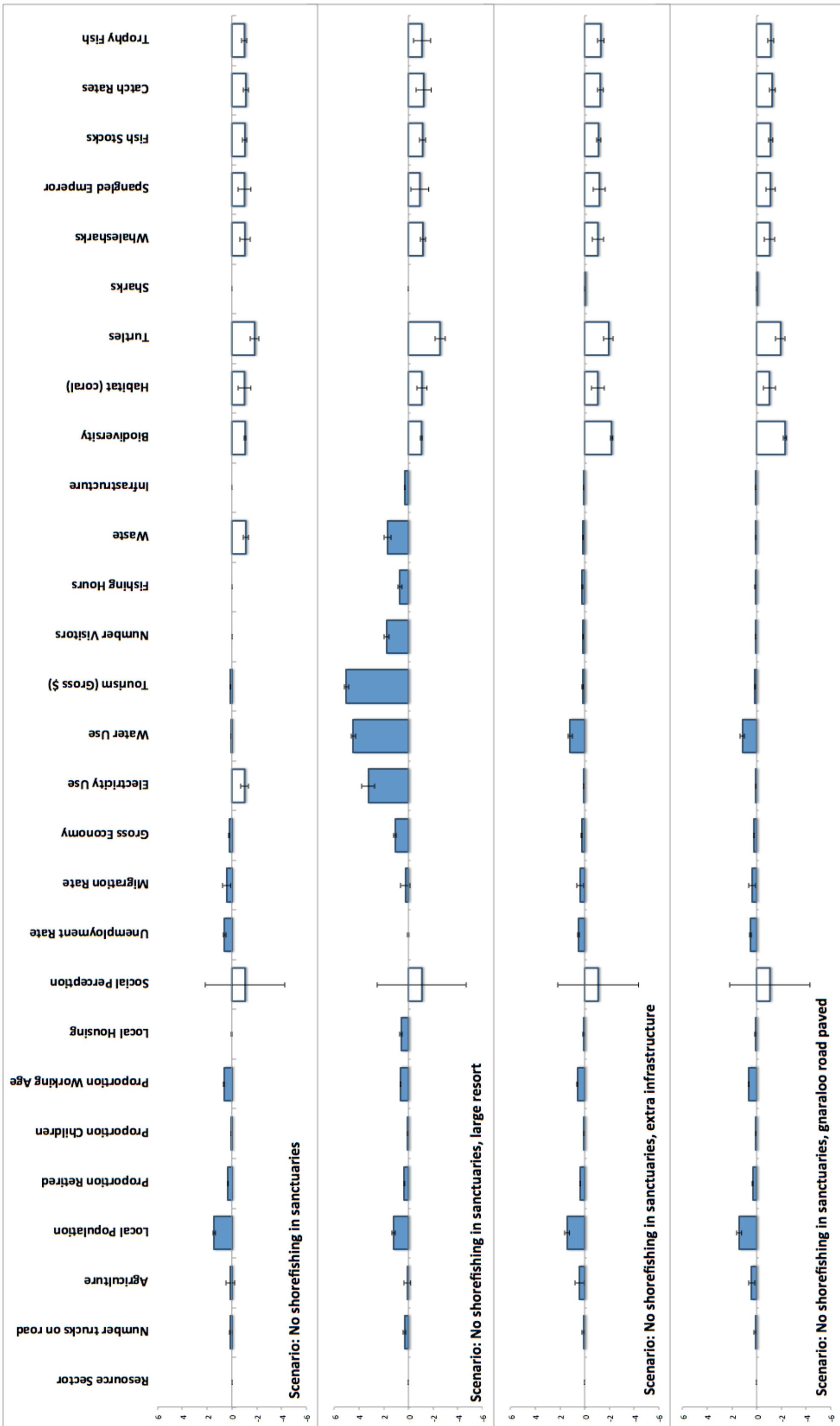


Figure 40: continued

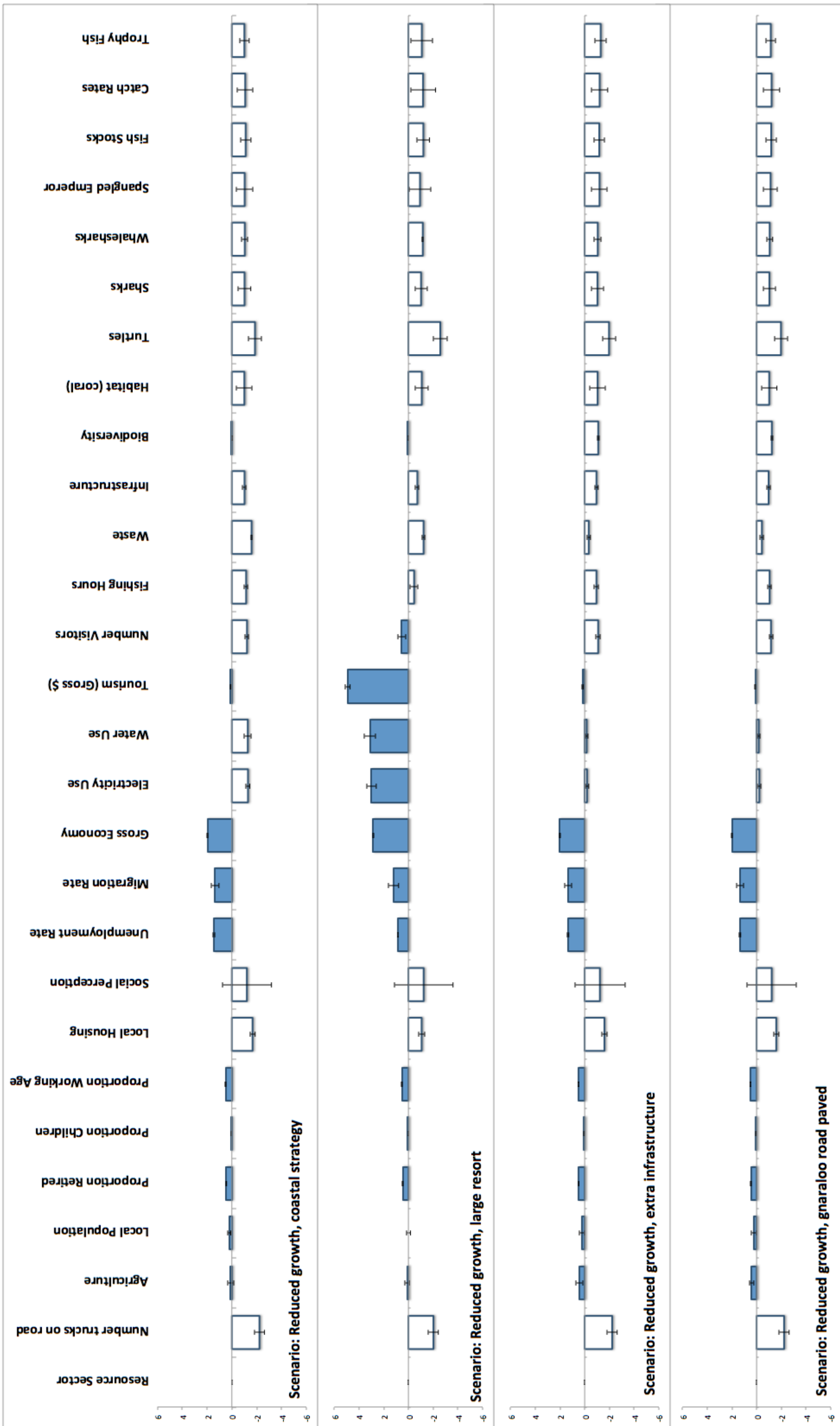


Figure 40: continued

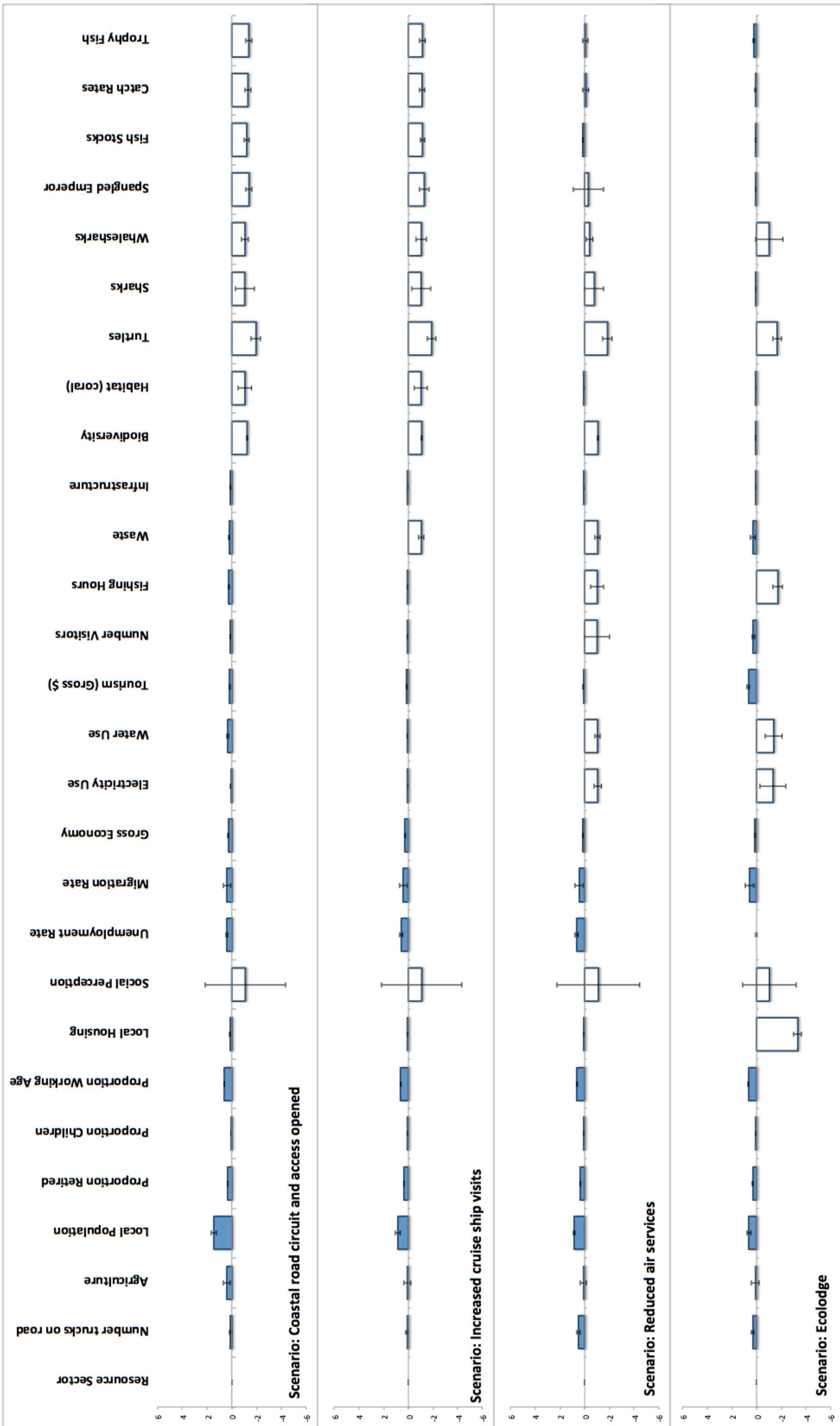
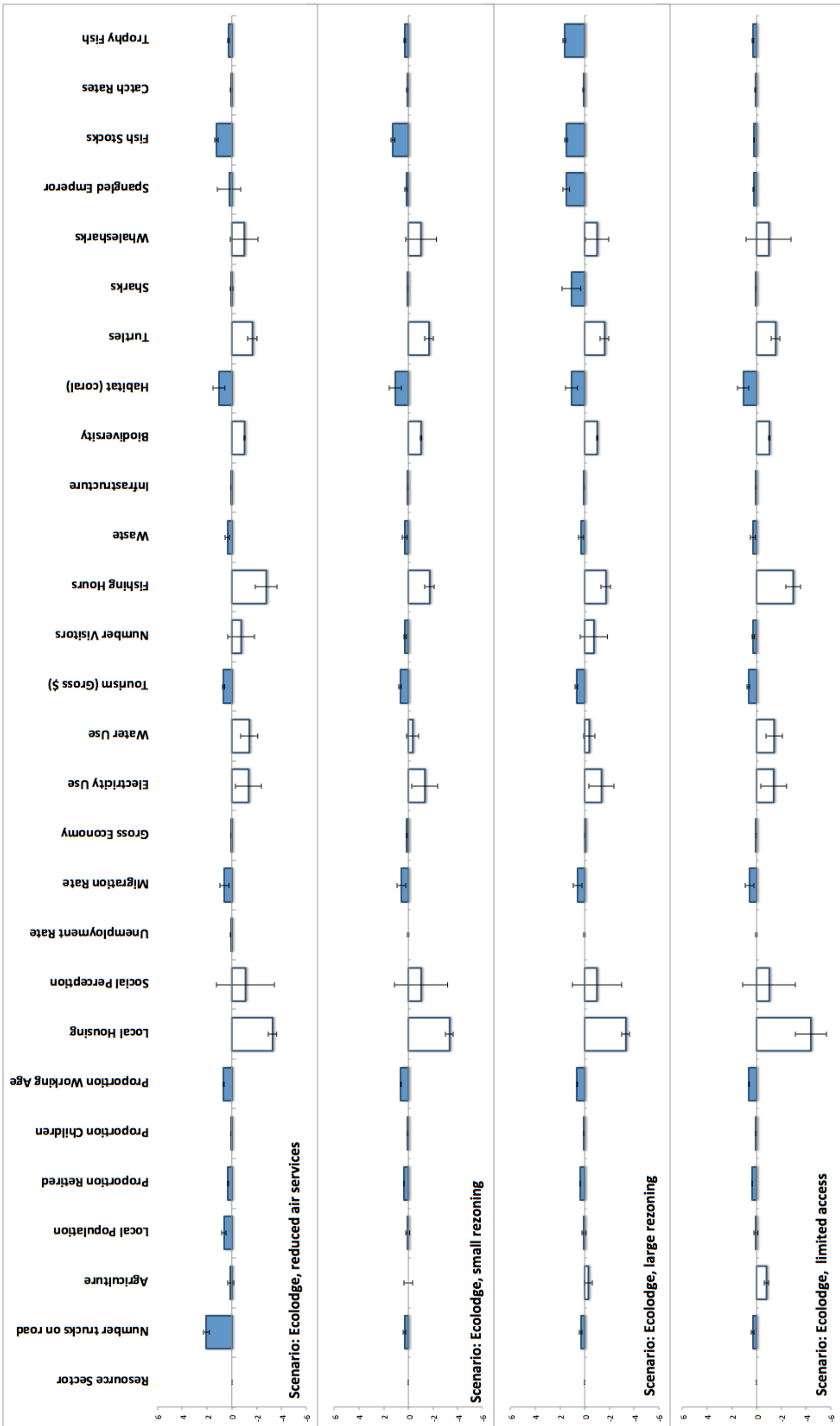


Figure 40: continued



`Figure 40: continued (Resource sector focus)

Figure 40: continued (Resource sector focus)

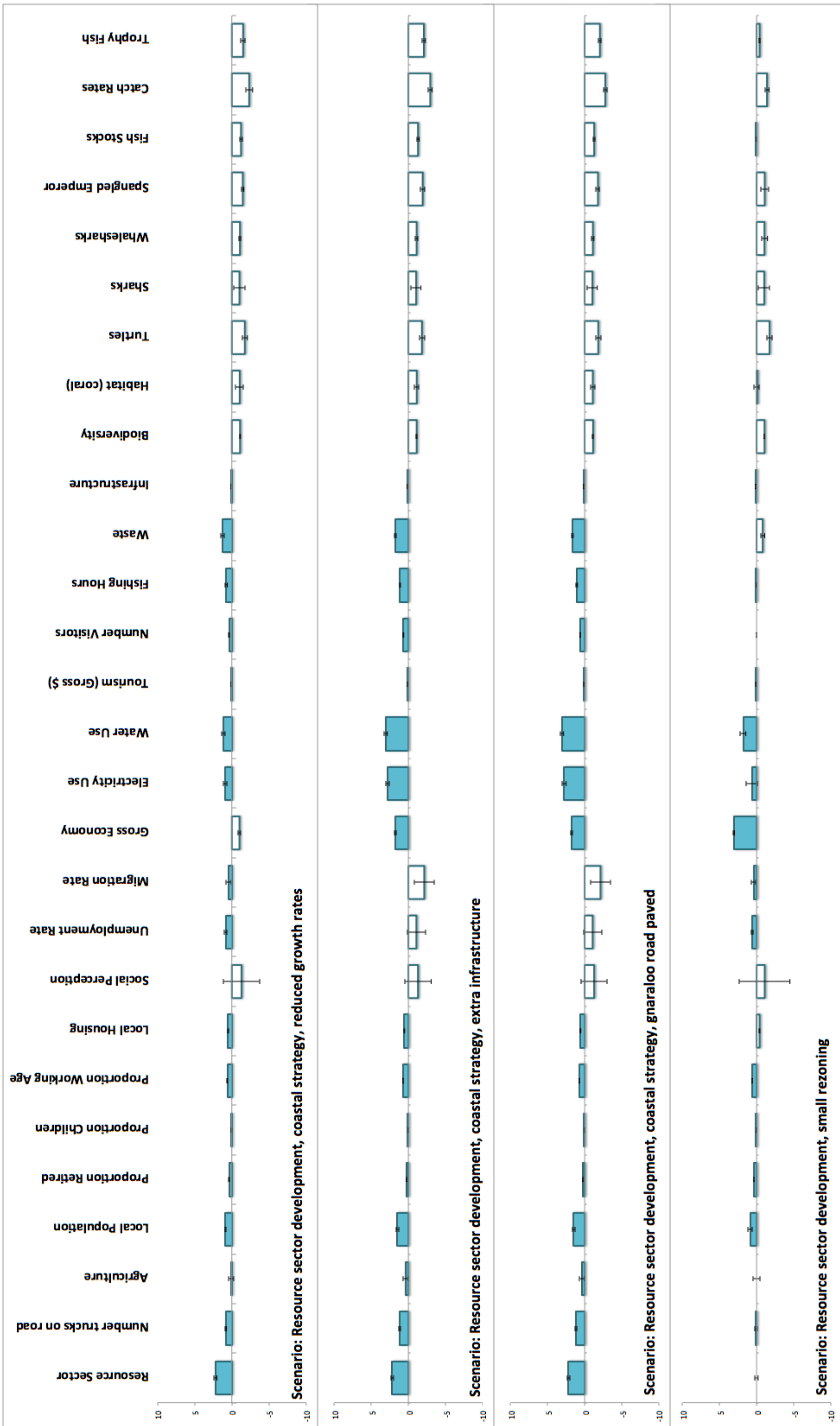


Figure 40: continued (Resource sector focus)

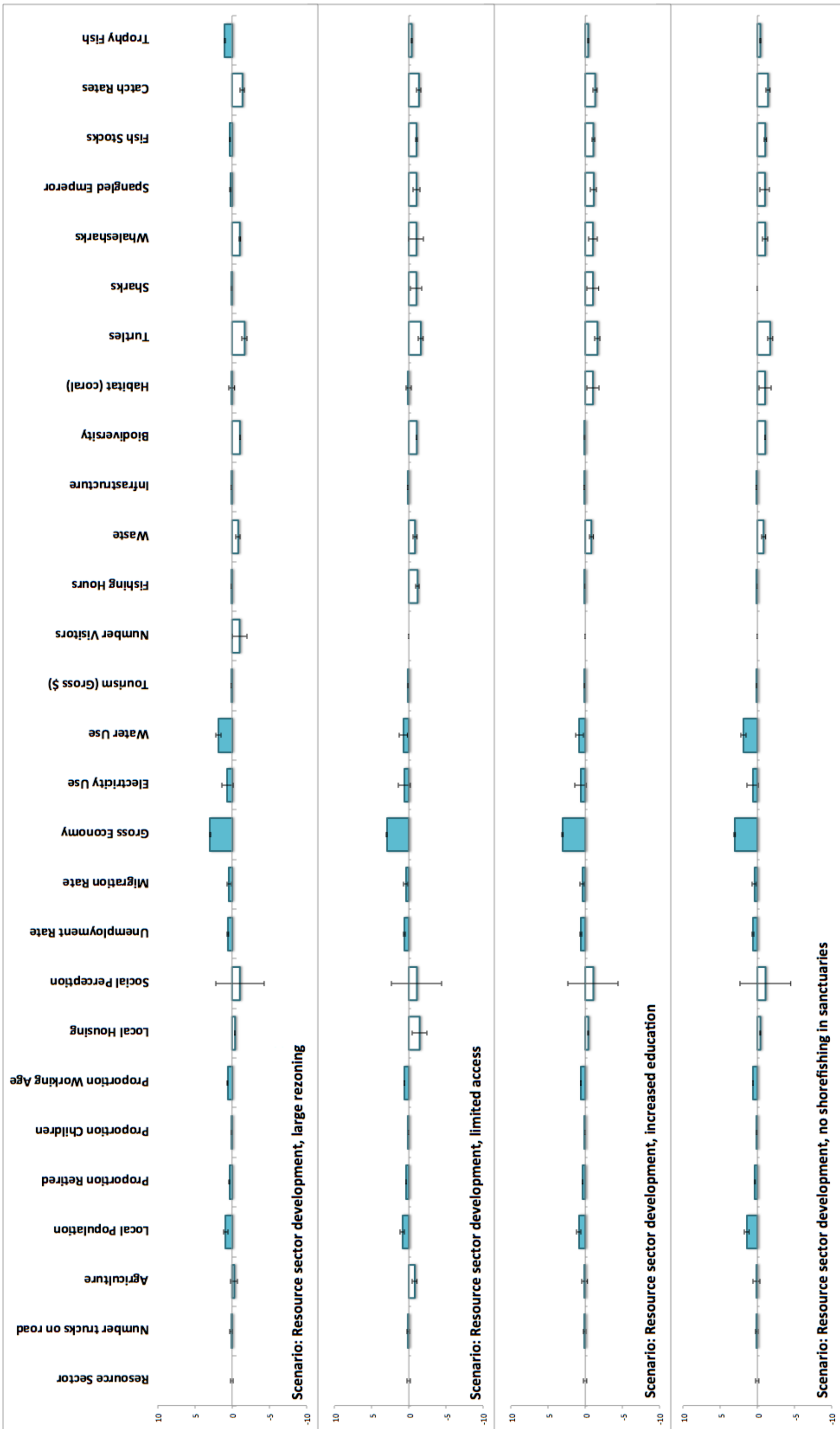


Figure 40: continued (Resource sector focus)

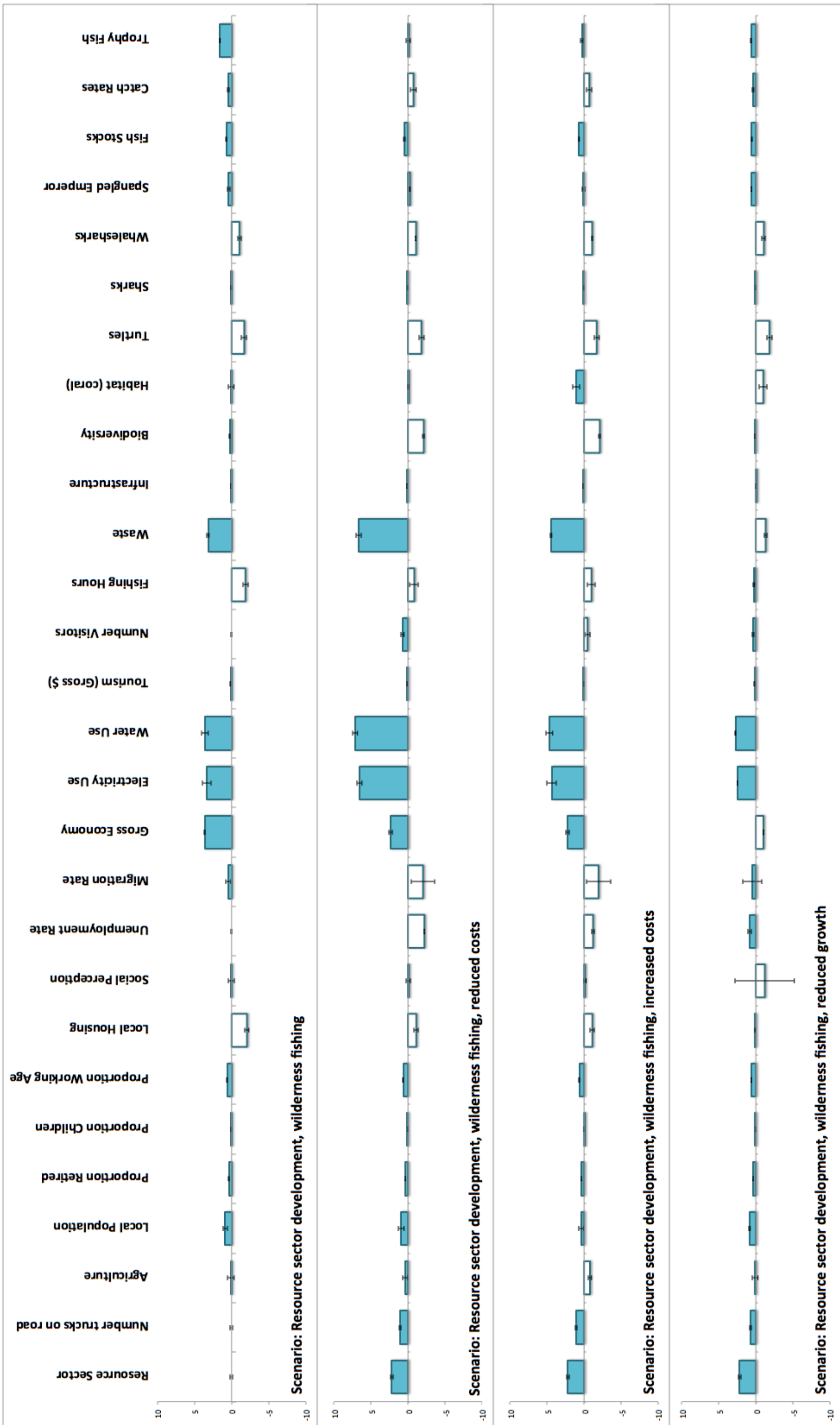


Figure 40: continued (Resource sector focus)

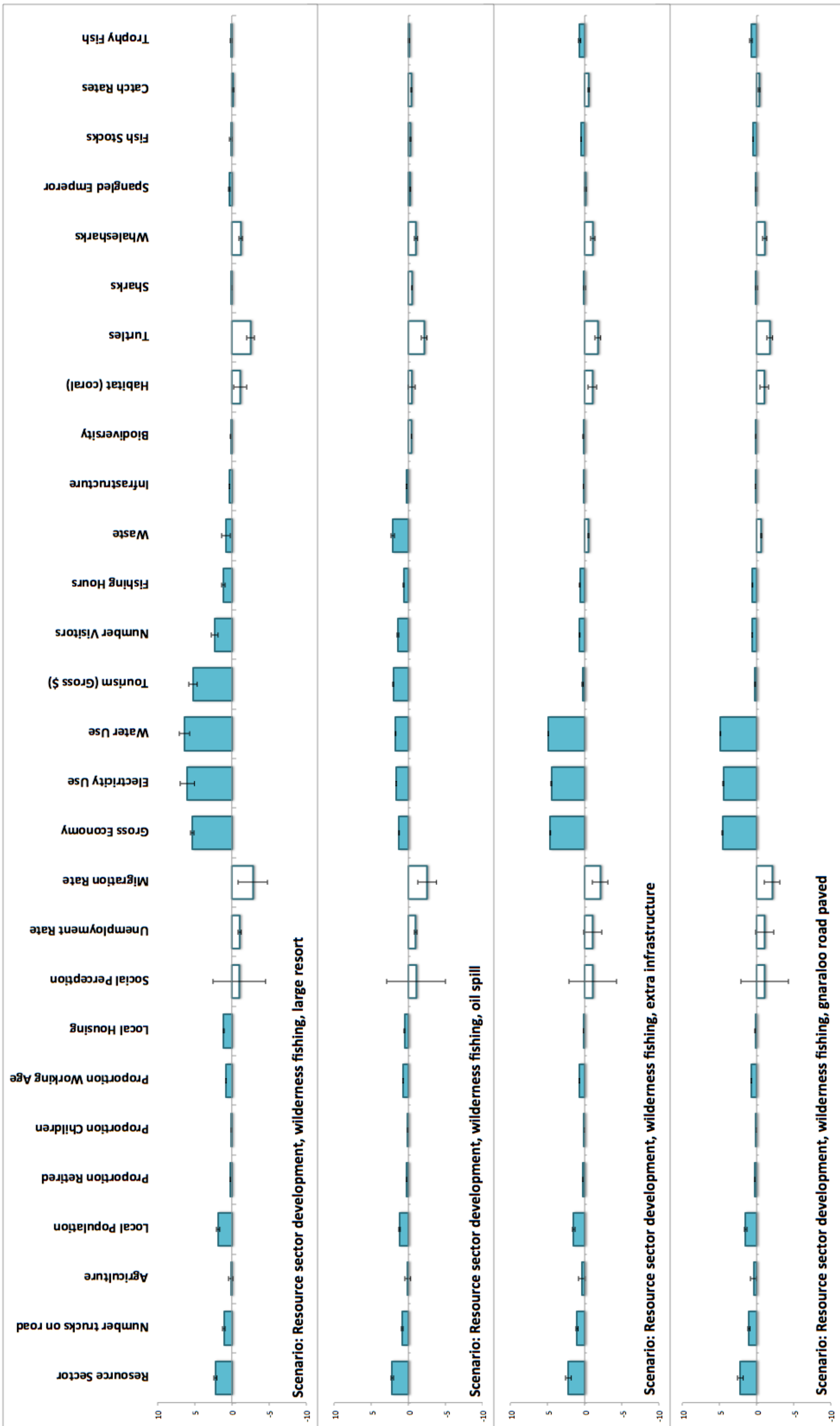


Figure 40: continued (Resource sector focus)

Figure 40: continued (Resource sector and Wilderness fishing focus)

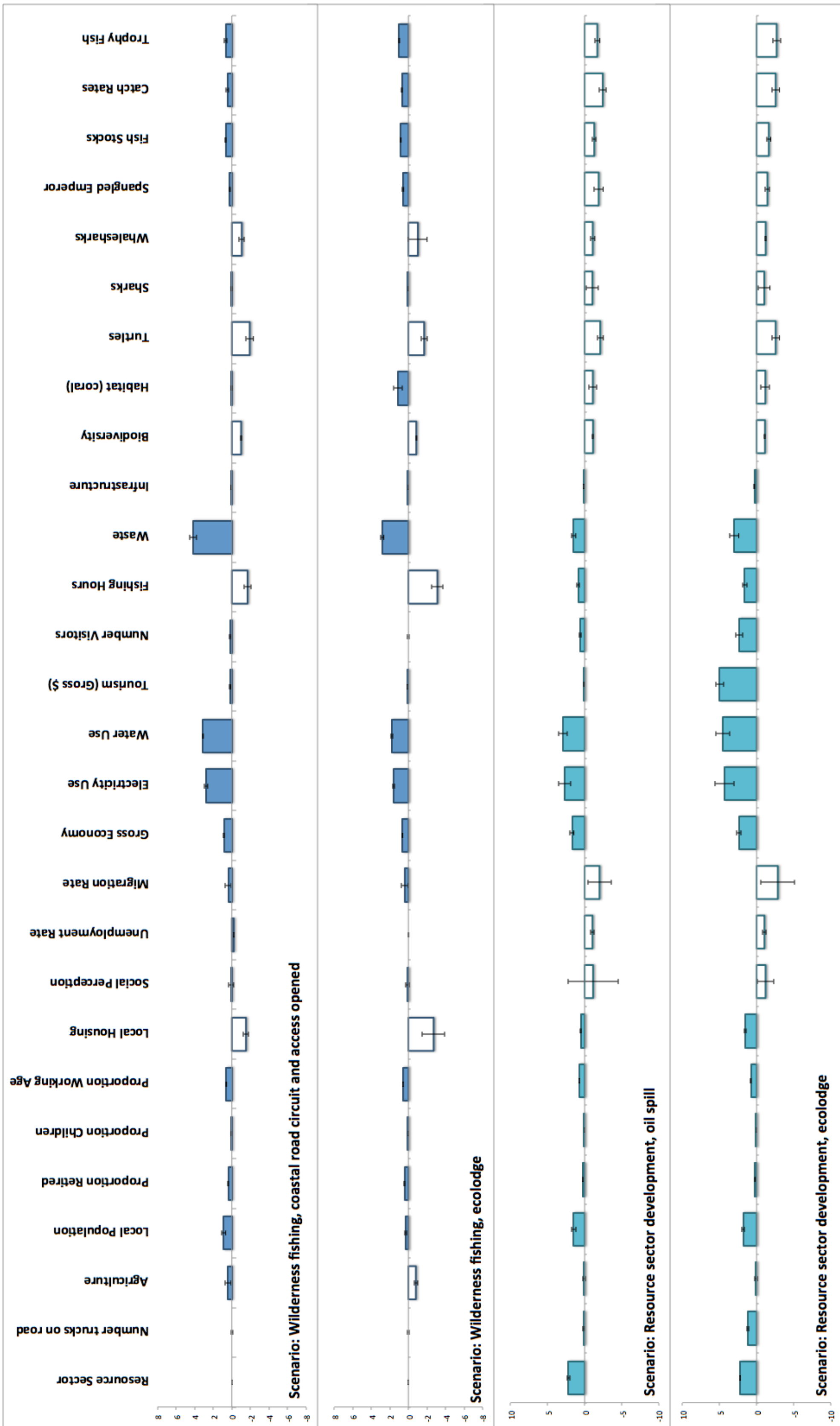


Figure 40: continued (Wilderness fishing focus)

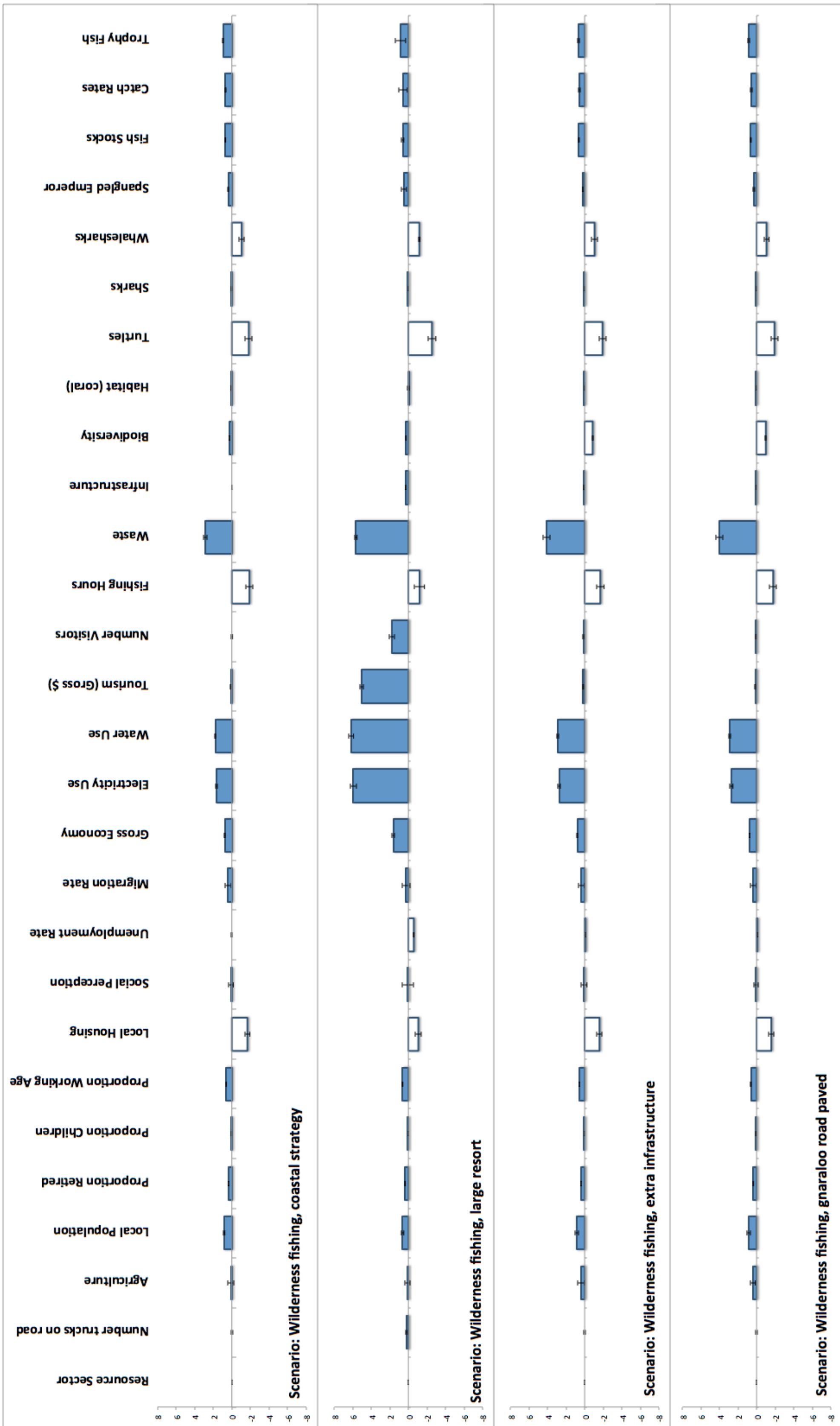


Figure 40: continued (Wilderness fishing focus)

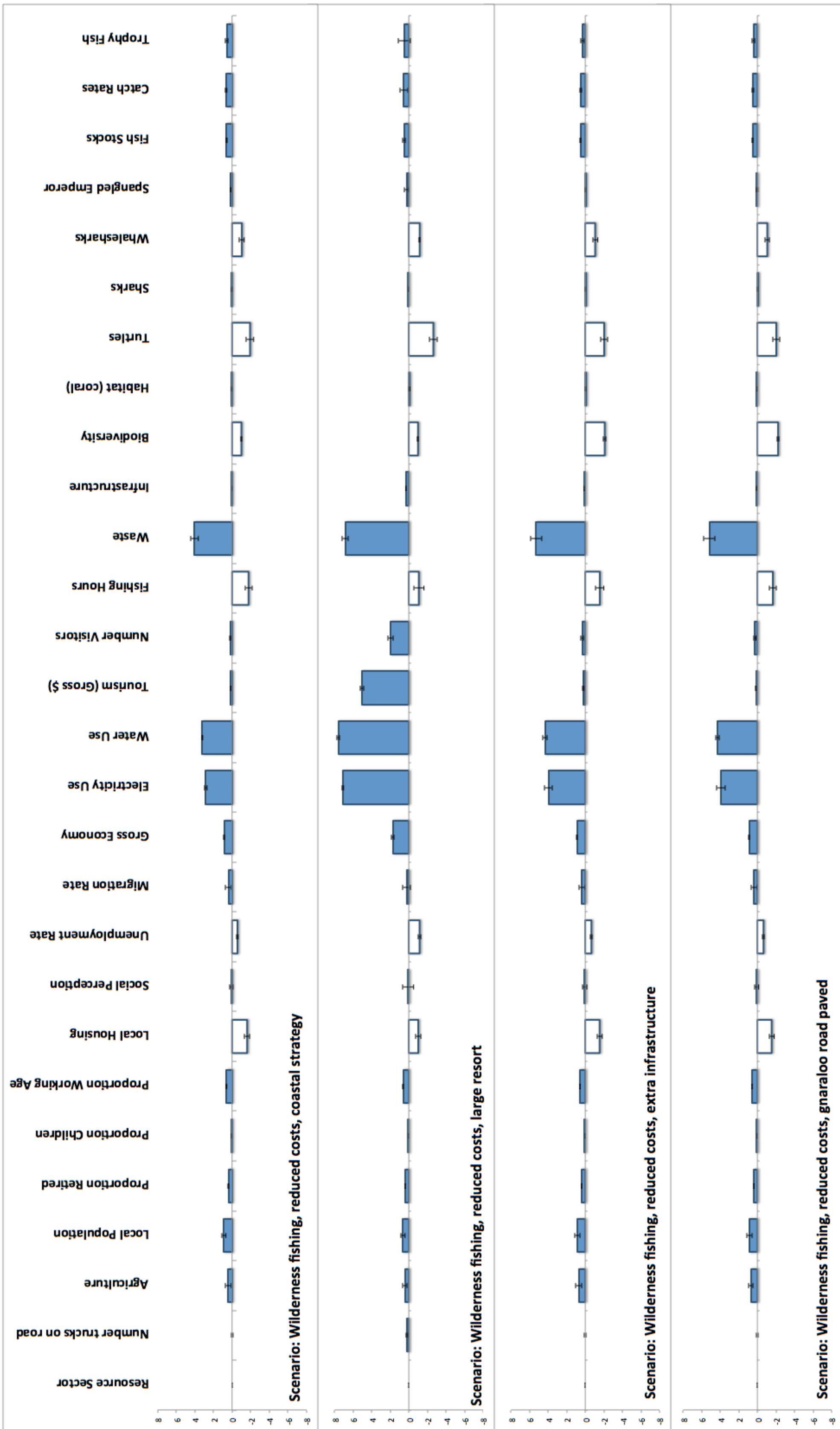


Figure 40: continued (Wilderness fishing focus)

Figure 40: continued (Wilderness fishing focus)

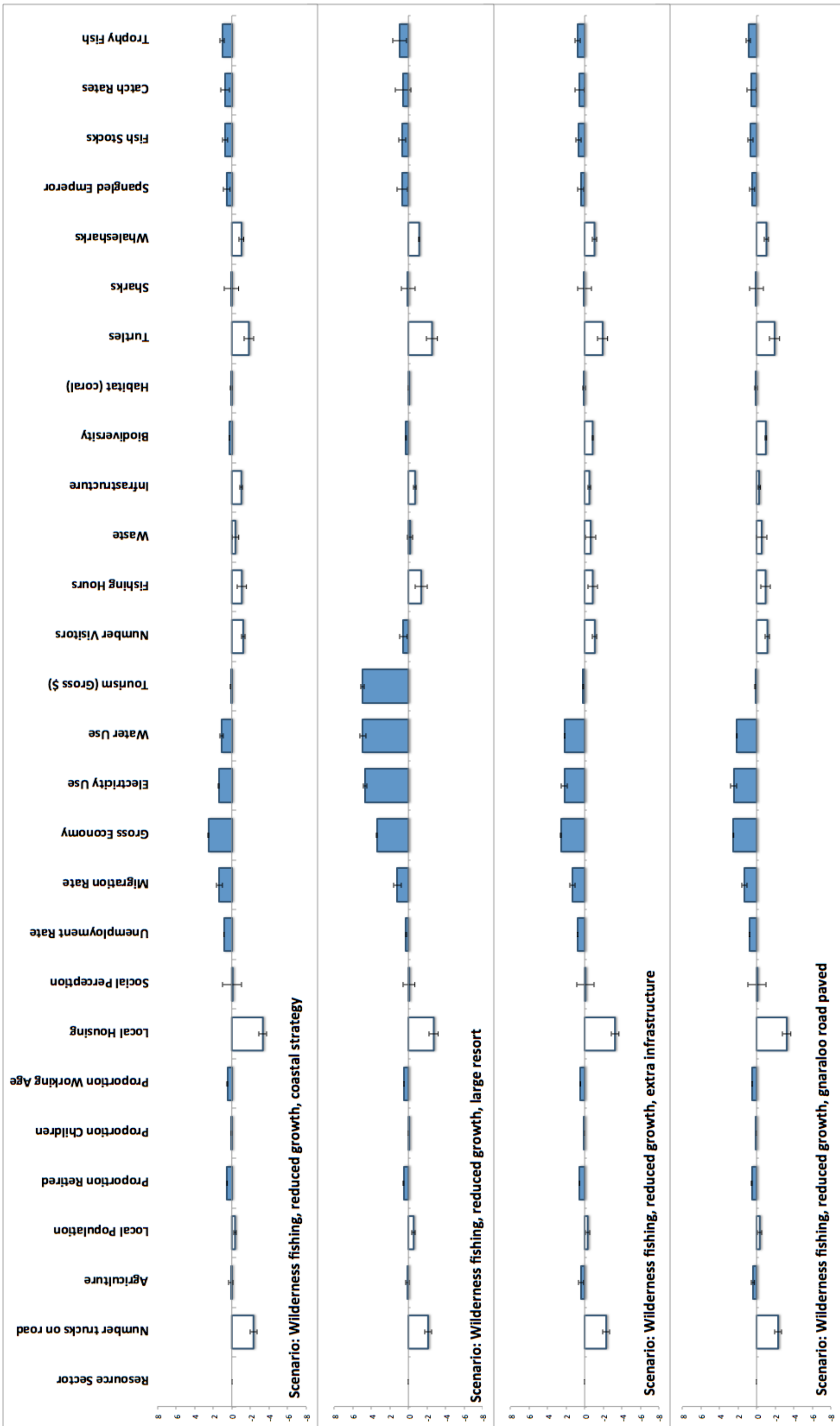


Figure 40: continued (Climate change focus)

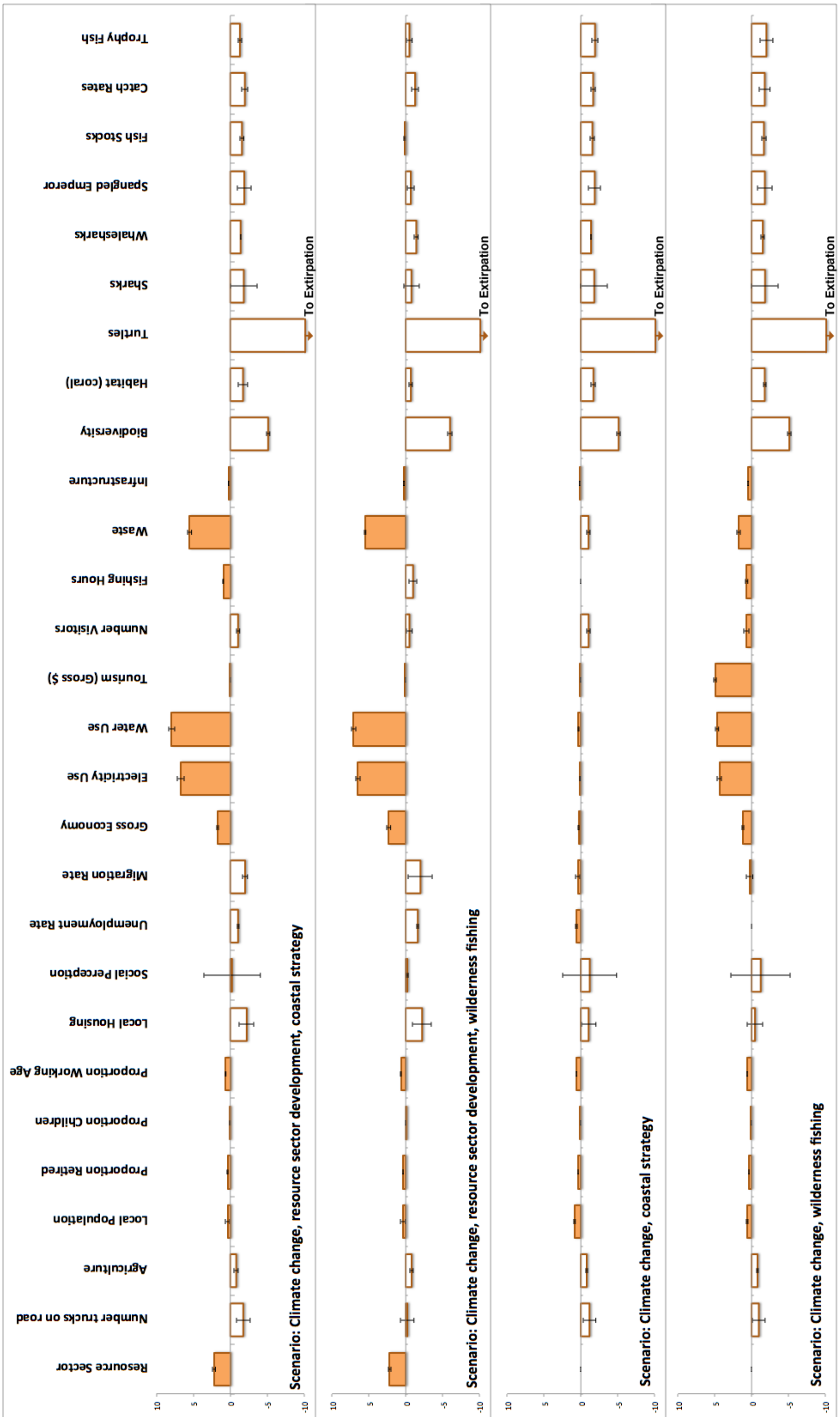


Figure 40: continued (Climate change focus)

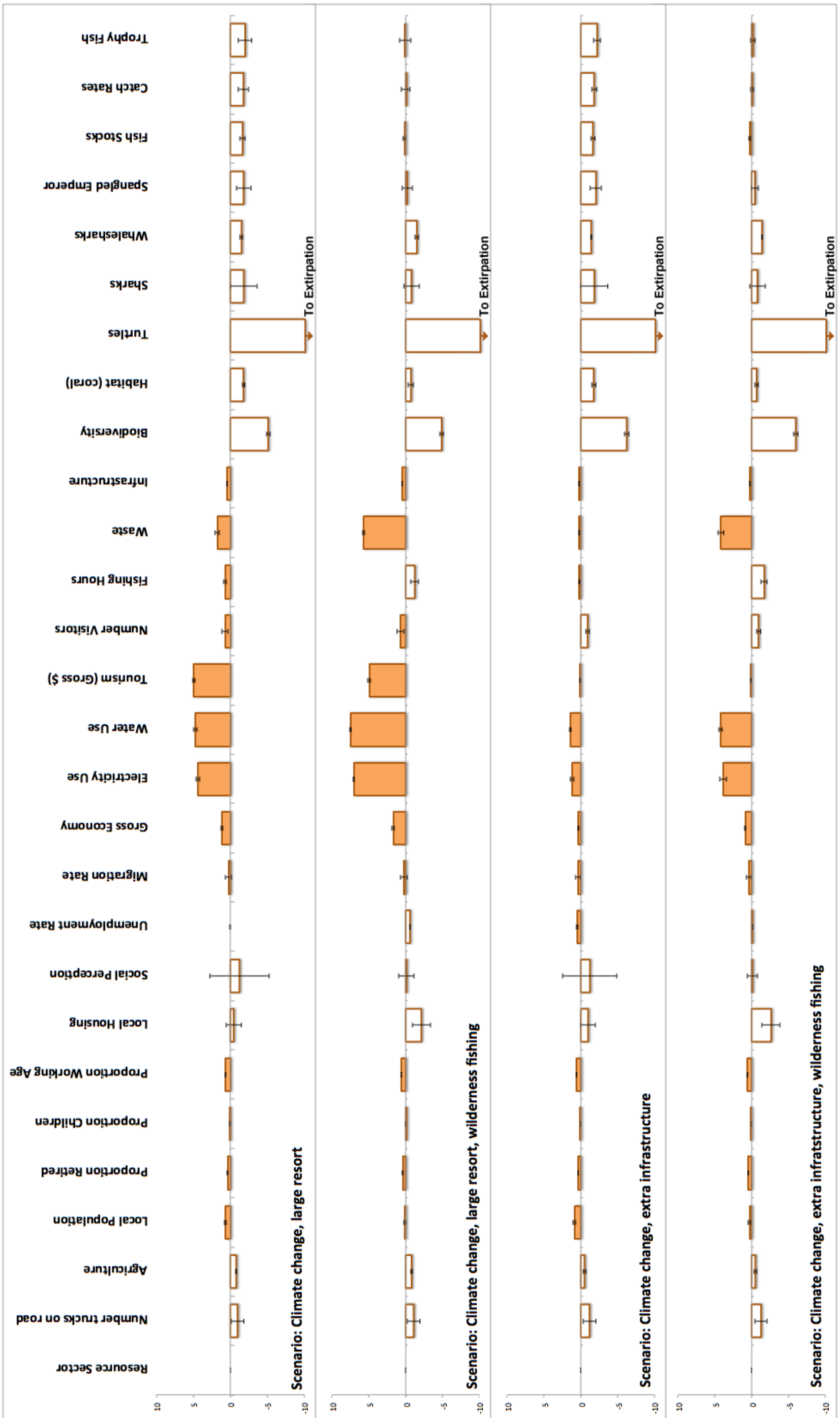
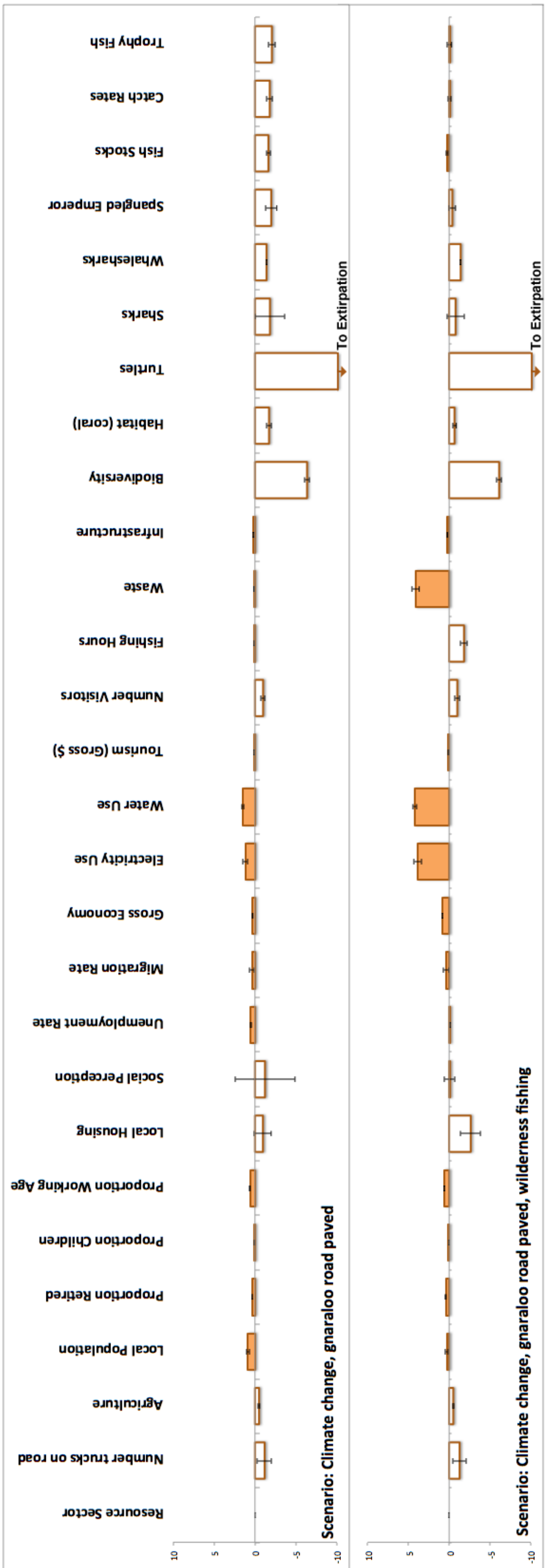


Figure 40: continued (Climate change focus)



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