A. TITLE OF PROJECT

5.1.1 Ecosystem models

B. IDENTIFICATION

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C. ABSTRACT

Ecosystem models can be used to simulate the real world, and explore "what if" scenarios to help managers and stakeholders understand the implication of alternative management or environmental conditions. Such understanding is critical to balancing trade-offs between contrasting resource use strategies, and successfully implementing EBM. The Ecosystem Models project forms a key component of the *Managed Seas* programme, developing state-of-the-art "end-to-end" models, linking ocean conditions to plankton productivity up through the food chain to commercial fisheries and humans, and including important feedbacks between these levels. The project will develop, test and compare a range of these complex models to explore their strengths and weaknesses, and in conjunction with other *Managed Seas* projects, compare end to end models with simpler approaches, to determine the most useful approach to provide advice at particular spatial scales, or for particular issues. Close engagement with stakeholders (through the *Our Seas* programme) will ensure the models developed address end user needs, and can be used to support the decision making process.

The research will initially focus on the Tasman and Golden Bay area, and expand into the Chatham Rise region, and to other case study areas in phase 2.

D. INTRODUCTION

Ecosystem models provide a framework for consolidating and integrating data and knowledge, for explicitly recognising links and trade-offs, testing ideas and simulating alternative scenarios (both for management or environmental drivers), and for ultimately providing quantitative advice on EBM. Ecosystem models such as EcoPath with EcoSim (EwE) and Atlantis have revolutionised EBM worldwide, and are now being extended to include not only the biophysical realm, but also social,

economic, and management strategy components [1-10]. This project will build, compare, and evaluate different ecosystem model frameworks, and their assumptions, to identify how the model-based ecosystem, social, and economic management advice can be best applied in the EBM process in a New Zealand context.

Geographically, the studies will initially focus on the Tasman and Golden Bay area, and will be later expanded into the Chatham Rise region, and to other case study areas (e.g., Marlborough Sounds) in phase 2. The project builds on and integrates with aligned funding (NIWA Fisheries and Coasts & Oceans centres), which has already undertaken preliminary engagement with key stakeholders in the Tasman and Golden Bay region, identified key specific concerns to be examined[11], and developed a base Atlantis model[12], has developed non-dynamic balanced food web model for the Chatham Rise[13], and will start the development of a Chatham Rise Atlantis model in 2015/16.

This initial phase of the Challenge will develop Atlantis models for the Golden and Tasman Bays area and the Chatham Rise (the later conducted through aligned funding), and will link with *Our Seas* through engagement processes to work with stakeholders and practitioners on development of scenarios and potential management actions to investigate. The project will also link with development of a dynamic food web model (analogous to Ecopath with Ecosim) for the Chatham Rise (from the existing balanced food web model[13]), being undertaken with aligned funding. Phased in over time, the project will also develop stochastic food web ("Null" models[14,15]) and size-based (allometric[16,17]) models for both the Tasman and Golden Bays and other case study areas, as part of the process of evaluation, comparison, and validation of the ecosystem modelling approach.

E. AIM OF THE RESEARCH AND RELEVANCE TO OBJECTIVE

EBM advice is required across a range of spatial scales, and to address a variety of issues or trade-offs, including spatial planning and the implications of environmental change, with different levels of complexity. No single approach is likely to be possible, suitable or appropriate in all circumstances, and so a range of different EBM tools or frameworks are likely to be required. The *Managed Seas* programme will develop, validate and compare different models, in order to identify the most appropriate approach for particular situations. The Ecosystem Models project will focus on state-of-the-art "end-to-end" models, that combine physical, lower trophic level and higher trophic level modelling approaches, and include important feedbacks among these factors[18]. Once we have undertaken a validation exercise against empirical data, to confirm how the models perform in different situations, we will use these end to end models to test underlying assumptions, and to compare with simpler models (e.g., the Spatially Explicit Decision Support models[19,20] developed within project 5.1.2, or Models of Intermediate Complexity[18,21,22]). These end to end models will also form the basis of the participatory models[23] developed within project 5.1.4. In the initial 3.5 years, an existing ATLANTIS model will be refined and applied, while new models are developed, and approaches to compare models are established and tested. The models developed within the Ecosystem Models project and the wider *Managed Seas* programme will form the core framework by which the *enhanced utilisation of our marine resources within environmental and biological constraints* will be managed and communicated.

F. PROPOSED RESEARCH

This project will develop, compare and validate ecosystem model frameworks and assumptions to evaluate their veracity for developing ecosystem, social, and economic management advice in the EBM process. Integrating with marine resource management practitioners we will ensure models and outputs have utility and are fit for purpose. There are three closely integrated components to this work during the first phase of the Challenge:

(1) *ATLANTIS model for Golden Bay and Tasman Bay* –
Within aligned core funding, NIWA has developed a set of base ATLANTIS end-to-end models for the Golden and Tasman Bays area. These models describe the key biological habitats, physical processes, ecosystem components and food web linkages for the study area, and have been developed in conjunction with preliminary stakeholder consultation, to explore issues particularly related to factors affecting fluctuations in the abundance of scallops and snapper. These models will form the basis of further ecosystem model development, refinement and application within the Challenge. In conjunction with *Our Seas*, the project will engage with resource managers, Māori, and stakeholders to identify issues over which decision support are required. Through consultation at an early stage in the project, a range of societally-relevant, well defined historical and future environmental and management scenarios will be identified, addressing key issues of concern. These may include trade-offs associated with the effects of fishing on the seabed and habitat requirements for juvenile fish recruitment, aquaculture development and other marine users, terrestrial impacts on the marine environment, and the implications of climate change for marine ecosystems.

Depending on the scenarios developed, it is likely that the current preliminary model structure (spatial and ecological components) will need to be revised to ensure it can address the issues raised appropriately. This may require modification of food web species groups, the dynamics of fishing fleets, or the addition of other spatial components. Following model validation (integrating with component 3 of the project), the models and their exploration of the defined issues will form a key component of end user engagement, and help support practitioners and decision makers through provision of informed advice on the implications of alternative scenarios.

There are currently no dynamic end-to-end ecosystem models available for New Zealand managers, Māori, and stakeholders to use to examine the potential implications of future management or environmental scenarios, and therefore the delivery of this component (producing Output 1) will go well beyond "business as usual".

(2) Alternative food web models –
All ecosystem models simplify ecosystem processes using assumptions in order to make their use tractable. However, the extent of simplification and the assumptions used varies between models, and changes their predictions[24]. We will develop models to evaluate the effect that different model assumptions have on model predictions and management advice. Some researchers have advocated that tactical ecosystem models are most likely to be based upon substantially simplified ecosystem models[25]. We will first develop alternative ecosystem models for Tasman and Golden Bays, and then Chatham Rise. The alternative models will include stochastic food web ("null" models[14,15]) and size-based[16,17] models.

The use of null models to evaluate complex models of natural systems is relatively recent. In the study of biodiversity and biogeography, the recent impact of null models, called "neutral theory", has been hugely influential in increasing our understanding of the dynamics of biological communities[26]. In ecosystem modelling, the use of null models has only recently been suggested, but hasn't yet been developed or adopted[14,15]. In our context, the null model will be developed as an alternative framework, and also used to evaluate whether model-predicted changes (from the mass-balanced model, or ATLANTIS) are greater than those that could occur by chance (the Null model).

Size-based models also greatly simplify trophic interactions. Marine systems are strongly size-structured, and individual species can vary size by several orders of magnitude, and by several trophic levels, during their life cycle. As a result, body size has a strong influence on population

interactions and dynamics[27]. Size-based models have therefore been used as a simpler alternative to species-based models[24,25,28]. A size-based model will be developed as a simpler alternative to the mass-balanced and Atlantis models.

The null and size-based models will be constructed using the same extensive data set used for all models. Models will be built in R or other suitable statistical software. The models will initially be focused upon food web interactions, but will then be extended towards full end-to-end equivalent models as the project progresses. Developing these models will be the focus for the post-doctoral position.

Most ecosystem modelling approaches are restricted to a single method and area, often due to logistical constraints. When combined with the aligned research and other projects within the *Managed Seas* programme, this study provides a unique opportunity to conduct an in-depth and novel multi-model approach and evaluation. This will produce Output 2.

(3) *Model evaluation and validation* –
Several assumptions are currently limiting the ability of ecosystem models to provide, or be seen to provide, credible projections; these include natural stochasticity, the use of deterministic relationships between components, the use of past data to inform the future (i.e., assuming that the range of past conditions adequately describes the potential scenarios in the future; or that the empirical data informing the model are representative). Such concerns have led some researchers to doubt predictions of ecosystem models and consider them "the great illusion"[29]. Model evaluation and validation is therefore a critical task in bringing credible ecosystem models to the stakeholders.

Since real life questions can be diverse, a diversity of tools with relevant abilities and assumptions is also needed[30]. The first step in establishing credible models will be the systematic and formal documentation of the characteristics (assumptions) of each of the models developed and applied during this project, documenting commonalities as well as differences, and determining circumstances under which different assumptions might be more accurate.

The second step will be sensitivity analyses (model runs), to better identify and rank the major sources of uncertainty that need to be communicated to stakeholders, and which may need further empirical research (potentially through *Dynamic Seas*).

The third step will be the comparison of model predictions with the large existing empirical data sets resulting from historical and ongoing research programmes, commercial fishing records, and other sources such as customary knowledge. The comparison, evaluation, and validation of models will lead to recommendations on the use of different modelling frameworks, and produce Output 3.

Potential research for Phase 2

A specific research plan will be developed on the basis of developments made and lessons learnt within Phase 1, but at present we anticipate Phase 2 of the project will build on the initial modelling and model comparison and validation advances in the first 3.5 years, incorporate management strategy evaluation (MSE) approaches, work towards an Integrated Coastal Zone Management model[31] for the Golden and Tasman Bays focus area through incorporation of terrestrial components, and expand beyond the initial focus area, into the Chatham Rise region (representing a deepwater ecosystem), and possibly also into the Marlborough Sounds area. Further modelling approaches (such as tactical Models of Intermediate Complexity[18,21,22]) and modelling considerations (such as how to best deal with uncertainty) will be examined both within the Challenge and aligned

core funding, and integration cross the *Managed Seas* programme will allow exploration of a model ensemble approach across model frameworks, to see how various models compare, contrast and contribute towards a collective answer to a problem, and determine which EBM frameworks and tools care most useful in which circumstances.

G. ROLES, RESOURCES

Ian Tuck	NIWA/UoA	Leadership, ecosystem effects of fishing
Alistair Dunn	NIWA	Cross programme integration, population modelling
Matt Dunn	VUW	Food web and size based modelling, null model
Matt Pinkerton	NIWA	Food web modelling, dynamic food web models
Niall Brockhuizen	NIWA	Ecosystem modeller
Beth Fulton	CSIRO	Ecosystem modeller, ATLANTIS expert
Vidette McGregor	NIWA	Ecosystem modeller, ATLANTIS developer
Sophie Mormede	NIWA	Fisheries and ecosystem modeller, MICE, ATLANTIS
Post doc TBA	VUW	Ecosystem modeller, food web, size based, null model
Nokuthaba Sibanda	VUW	Statistician
Richard Arnold	VUW	Statistician

Not all of these investigators will be active in each year and a number are in essentially consultative roles within the challenge budget and supported elsewhere.

H. LINKAGES AND DEPENDENCIES

The Ecosystem Models project has linkages with all programmes within the Challenge.

The four projects within the *Managed Seas* programme will all work closely together in both model and framework development, but also in validation, comparison and application.

Inputs from other projects

- 1.1.1 & 1.1.2: Best practice engagement and participatory processes
- 2.1.3: Ecosystem services and values, assessment of impacts
- 3.1.3 & 3.3.1: Kaitiakitanga, Māori resources, strategies and lore
- 4.1.1 & 4.2.2: Provision of quantitative descriptions of physical and biogeochemical controls and fluxes
- 4.2.1: Understanding ecosystem tipping points

Outputs to other projects

- 4.1.1, 4.2.1 & 4.2.2: Modelling uncertainties to be clarified in the field, and fed back to improve models
- CP2.1: Provision of ecosystem models and approaches to compare them, to determine most appropriate approach for particular circumstances, for use in trialling EBM.

I. COLLABORATIONS

Dr Beth Fulton, CSIRO, the developer of the Atlantis modelling package, will be a key collaborator within the project.

There will be significant in-project partnerships developed, and significant interactions with aligned funding.

J. INTERNATIONAL LINKAGES

The project will also link closely and collaborate with the EU FP7 funded project MareFrame, and the Horizon 2020 proposal ClimeFish. Both of these studies (addressing the barriers to EBM implementation, and examining the effects of climate change on fisheries) have components that align closely with the Ecosystem Models project, and involve a wide range of European and other international research institutes.

K. ALIGNED FUNDING AND CO-FUNDING

This project uses and builds on significant recent developments within NIWA's Fisheries and Coasts and Oceans Centres core funding. In particular, the NIWA Fisheries Centre Ecosystem approaches to fisheries management programme has developed a set of base ATLANTIS models for Golden Bay and Tasman Bay, which will form the basis of the ATLANTIS model development, refinement and application within Phase 1 of the Managed Seas project. This core funding will also be developing an ATLANTIS model for the Chatham Rise area (for implementation within Phase 2), along with other simpler ecosystem models (e.g., Models of Intermediate Complexity for Ecosystems) for comparison with more complex models within the Managed Seas project. The NIWA Coasts and Oceans Centre Ecosystem Structure and Function programme has collated the data to support, and developed balanced foodweb models for coastal and offshore regions which will included in the model comparison activities, into the future aims to develop dynamic Ecopath with Ecosim like models for further comparison. The project is also likely incorporate plankton-zooplankton-nutrient models developed within NIWA's Aquaculture core funding within Phase 2.

$48 K co-funding has already been provided to attend MareFrame annual meetings, collaborating with international research partners on ecosystem model development and implementation.

L. VISION MĀTAURANGA (VM)

Vision Mātauranga is seeking to unlock the innovative potential of Māori knowledge, resources and people to assist New Zealander's to create a better future. There are four themes in the Vision Mātauranga (VM) policy framework (Indigenous Innovation, Taiao, Hauora/Oranga, and Mātauranga). It is considered that there is an opportunity in this project to develop innovative and/or distinctive products, processes, systems, and services.

One of the four themes in VM is Taiao. This theme looks to achieve environmental sustainability through iwi and hapū relationships with land, and in this Challenge, sea. The ecosystem model structure will integrate tangata mātauranga Māori (tangata whenua cultural knowledge, values, and perspectives), enabling predictions to be evaluated with respect to cultural standards, and iwi and hapū wellbeing. Māori as tangata whenua aspire to live in sustainable communities and live in healthy environments. As kaitiaki, dealing with uncertainty due to the multiple types and magnitudes of stressors on these environments, is becoming an all too common reality.

The intent of VM will be to work with the project leader and team in an observer capacity, alongside project 4.2.1 "Tipping points in ecosystem structure, function and services", to promote and enable the interface of indigenous knowledge with the project's investigation into changes in marine

ecosystems. This will include consideration of what activities are likely to have effects and what parts of the ecosystem are likely to be most affected. This has the potential to contemporise kaitiakitanga in the marine environment by developing a distinctive product, process, system or service.

Current research at Victoria University of Wellington and NIWA is evaluating techniques to collate mātauranga Māori, including interviews, participatory research and site visits, wānanga, and feedback hui. Stakeholder and Māori engagement will be used to inform the socio-economic and ecosystem components to be incorporated into the models, and is likely to be particularly prominent in tactical models (Phase 2). Working closely with the project leader and team will identify whether further investigation is necessary and how the VM programme and Managed Seas programme will work together to address that need.

M. COMMUNICATION AND OUTREACH

The ecosystem models developed within this project will form key components of the communication of the implications of future environmental or management scenarios with government, Māori, stakeholders and the general public. Outcomes from the Ecosystem Models project, and the wider *Managed Seas* programme will form key communication tools for the Challenge.

N. CAPACITY BUILDING

A post-doctoral researcher (Victoria University, Wellington) will be appointed for this project, and contribute throughout but in particular to alternative models, and model validation and comparison. The project team also includes some young and emerging researchers (NIWA), for whom the project will help to establish their expertise and career. Additional funding will be also sought to extend the duration of the post-doc level position into the start of phase 2.

PhD and Masters studentships are anticipated through project links with the University of Auckland and Victoria University Wellington, and may also be developed with collaborators.

O. ETHICS APPROVAL

No animal ethics approval are required. Stakeholder engagement will be coordinated through *Our Seas*, where any human ethics requirements will be addressed.

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