FINAL REPORT (DEVELOPMENT AWARD)

AWARD CODE and TITLE

2008/328.17 FRDC People Development Program: 2012 Visiting expert busary

Multiverses – a new way to research, monitor and forecast fish stocks

AWARD RECIPIENT: Prof Gudrun Marteinsdóttir

ADDRESS: SARDI, 2 Hamra Ave West Beach, SA 5024

HOST ORGANISATION: SARDI

DATE: 1 May 2013

ACTIVITY UNDERTAKEN

10 Feb – 5 May: Project scoping and development discussions to design the blueprint of a Multiverse

26 Feb: GM gave seminar on stock structure and management of Icelandic cod stock

1 Mar: Meeting with Tim Moltmann to discuss IMOS and data monitoring

1-15 Mar: Discussions with individual SARDI scientists (Middleton, Doubell, Rogers, Ward)

21 Mar: Internal SARDI workshop – discuss ideas, concepts and knowledge gaps

10 Feb – 5 May: Drafted paper on intra- and inter-stock diversity and implications for fisheries management to be submitted to the 2013 honorary volume of the ICES journal

3 Apr: Meeting with the University of Adelaide research group (Prof Bronwyn Gillanders)

3 Apr: Initiation of a virtual student symposium to be conducted between the University of Iceland, University of Adelaide, SARDI and the Marine Research Institute (Iceland)

9-10 Apr: Visit to CSIRO Hobart; meetings with Drs Beth Fulton, Mike Herzfeld, Karen Wild-Allen, Mark Baird and Vince Lyne

2-3 May: Meeting and discussions with Dr Eva Plaganyi (CSIRO) on the use of MICE in the Multiverse

OUTCOMES ACHIEVED TO DATE

The time spent at SARDI has been used to construct a blueprint for a Multiverse; a 3D modelled and data assimilated world of ocean physics and the ecosystem. Collaboration with Prof Gavin Begg and introduction of the idea to SARDI and CSIRO scientists has led to fruitful discussions and new ideas of problem solving; all of these have helped to form the Multiverse concept, as well as to establish relevant activities already being undertaken. Whole-of-system studies (such as those proposed by the Multiverse concept) are limited; albeit these are required in moving fisheries and ecosystem based management forward.

Additional activities undertaken during the bursary included drafting a paper on intra- and inter-stock diversity and implications for fisheries management in collaboration with Prof Begg and Dr Shijie Zhou (CSIRO); and seminars, meetings and introduction to the University of Adelaide Southern Seas Ecology research group (Prof Gillanders) that has led to the initiation of a virtual student symposium that will be conducted later this year.

Acknowledgments

Thanks are extended to the staff and scientists of SARDI, especially Gavin Begg, John Middleton, Mark Doubell, Paul Rogers, Simon Goldsworthy and Tim Ward for fruitful discussions and collaboration. Thanks also to Beth Fulton, Mike Herzfeld and Eva Plaganyi (CSIRO), Tim Moltmann (IMOS) and Bronwyn Gillanders (University of Adelaide) for helpful discussions and beneficial information. The Visiting Expert Bursary was supported by funding from the Fisheries Research and Development Corporation on behalf of the Australian Government, and further in-kind support from SARDI and the University of Iceland.

Background/Need

A major challenge in ecology and conservation is to forecast the responses of ecosystems to future environmental and climatic changes, and provide fisheries and conservation managers with scientifically sound predictions that can be used to prepare for these and other changes dictated by driving forces such as anthropogenic or evolutionary actions. Despite the large research effort of the last and current century, information on critical subjects such as the behavioural response of key organisms to the immediate environment is surprisingly rare. This is especially true for marine organisms. Most studies on the effects of environmental and hydrodynamic variation on marine organisms have focused on its effects on dispersal and survival of early life stages. Much less is known about the effects of hydrodynamic variation on behaviour, distribution, growth and prosperity of the adults that comprise exploited marine fish stocks.

The Integrated Marine Observing System (IMOS), notably through the Australian Animal Tagging and Monitoring System (AATAMS) is an important initiative that is beginning to monitor and collect data on individual behaviour of marine organisms.

Uncertainty due to lack of knowledge and understanding of species behaviour and interaction with the surrounding environment can limit effective management. Significant efforts are made by fishing nations to estimate numbers and condition of exploited fish stocks, but assessments frequently bring unexpected results that range from relatively small shifts from former prognoses to changes of a significant and potentially detrimental magnitude. Such errors may be due to limited data, biased calculations or unaccounted causes of mortality, but can also stem from unforeseen (and unaccounted) changes in fish distribution or behaviour.

Stock sizes are usually modelled estimates based upon numerous assumptions and data thwart with potential errors. Uncertainty increases when stock forecasts are made, particularly when these attempt to predict temporal and spatial dynamics. It is upon these predictions that catch quotas are typically allocated; the uncertainty therefore poses challenges to industry for achieving profitable businesses.

To meet this challenge, SARDI and the University of Iceland aim to work together towards a solution that involves construction of a whole-of-system modelling environment, a "multiverse", which is a 3D modelled and data assimilated world of ocean physics and living organisms. This approach may be a suitable method for integrating diverse data sets such as those currently being proposed to be collected as part of a large-scale science program to explore mining exploration (and subsequent impacts) in the Great Australian Bight (GAB).

The collaboration will benefit from the complementary nature of the research groups from the highly data rich region of the north Atlantic to the relatively data poor environment of the GAB. The collaboration will facilitate discussion around the concept and potential for its application in an Australian context.

Objectives

The original objective in undertaking the Visiting Expert Bursary was to:

- Construct a blueprint of a three dimensional data assimilated multiverse that describes the ocean physics and the living organisms that can be used to answer key questions on fish distribution, climate change and fisheries monitoring/management.

This objective has been achieved, with the conceptual model developed and blueprint constructed.

Methods

A. Outline the multiverse concept

A blueprint of a multiverse was constructed based on the different needs of the two regions, i.e. Icelandic waters and Great Australian Bight. The blueprint was designed so as to demonstrate the main compartments of work, as well as the potential case studies that are likely to provide tactical solutions and be of an interest and benefits to managers, scientists and industry.

The blueprint was divided into individual tasks and listed along with potential challenges likely to arise at each step.

B. Discuss the concept with interested and relevant scientists and stakeholders

The multiverse concept was discussed with a number of interested parties (see list in activities undertaken above). The distinction of this concept in comparison to ecosystem models providing broader strategic solutions was clarified. As a result, the multiverse tactical concept was reformed and moulded in response to discussions and suggestions.

Results/Discussion

A construction of a Multiverse

Through collaboration and integrated discussions the blueprint of the multiverse was constructed.

A multiverse is a 3D modelled and data assimilated world of ocean physics and the living organisms that can be evaluated with hindcasts and used to produce short- and long-term forecasts. What distinguishes it from other similar modelling efforts is the data assimilating feature of this 3D world. The idea is to use all available data on ocean physics, environment and living organisms in the past to understand how target species have responded to changes in climate and fishing effort. Based on this knowledge and improved *in situ* data recordings (such as IMOS data streams), the intention is to be able to use the multiverse to: a) provide information on ocean conditions and forecasts on hydrodynamics; b) locate fish aggregations; and c) describe/understand behaviour and responses of target fish stocks to changes in ocean conditions, cumulative fisheries impacts, size of competing or prey stocks, etc.

One of the key components of a multiverse is an ocean model that simulates the hydrodynamic variability and outputs hindcasts and forecasts for the regions of interest (Figure 1). As the outputs will be used to create the physiosphere for the species of interest, the outputs need to give an accurate three dimensional picture of the past in relatively high spatial resolution. For this purpose, the ocean model may need to be data driven, or at least evaluated through comparisons with empirical data on ocean physics.

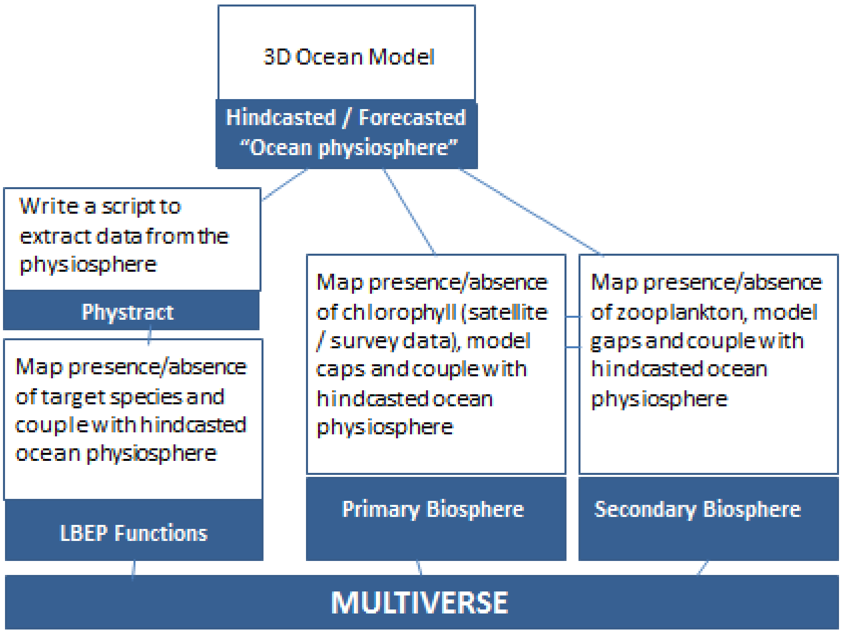

Figure 1. Construction of the data assimilated spatial and temporal frame of a MULTIVERSE. LBEP stands for "Life-history-Behavioural-Environmental-Probability".

A hindcast for an ocean region will consist of three dimensional information on essential physical parameters (e.g. temperature, salinity, currents, stratification, fronts) outputted at predetermined time intervals (e.g. every three hours – 3 times every 24 hours) over a selected time frame. A hindcast for 1-15 years will therefore consist of a large amount of data that together create the physiosphere for the selected time frame. A script (Phystract) will be needed to extract the data from the physiosphere. Therefore, data for a certain species in a specific area could be extracted from the physiosphere and the parameters of interest for the spatial/temporal resolution needed to create the environment inhabited by the target species at the time of interest (Figure 2).

Fish distribution is often linked with ocean physical properties and productivity. The overall objective of the multiverse is to identify/forecast high catch areas of target species by linking physical features of the ocean with prior knowledge on fish behaviour and their response to key environmental variables (Figure 2). Fish select habitats, and are often distributed, in response to several physical features of the environment, of which temperature, salinity and depth are believed to be important predictors. However, knowledge on the behaviour of target species is often lacking.

Fishers most likely possess the greatest knowledge of fish distribution. Many fishers have kept track of migrations and dispersal of target species in relation to geographical location, season, temperature and depth. Some of this information can be obtained from mandatory logbooks, fisheries observers or fishery-independent surveys. Studies on behaviour using data storage tags are also likely to provide valuable information on individual fish behaviour and habitat selection. All of these information sources need to be assembled under a common framework.

For many species, additional studies on behaviour will be needed. The outcome should consist of a probability distribution of target species in relation to ocean properties, season, life history and stock dynamics that can be superimposed on oceanographic maps from the ocean model. One of the aims could be to create a LBE-probability function for species presence in each square mile of the targeted areas. LBE stands for life-history-behaviour-environment and the probability function will predict the likelihood that a target species will be present in high, low or medium catchable numbers. The actual modelling procedure needs to be designed but to give an example, the following actions represent what may be needed to create the LBEP-function.

a. Define areas; life history stages of target species and preferred habitat niche characterisation (e.g. in terms of temperature and depth).
b. Within an area and season, define frequency of occurrence for each life history stage of target species in all years presented in database.
c. Compare results of (b) with hindcast ocean conditions from the ocean model and attempt to explain the annual difference in presence/absence with variation in environmental conditions.
d. Create LBEP-function maps for selected species, season, area, life history stages and simulated ocean conditions.

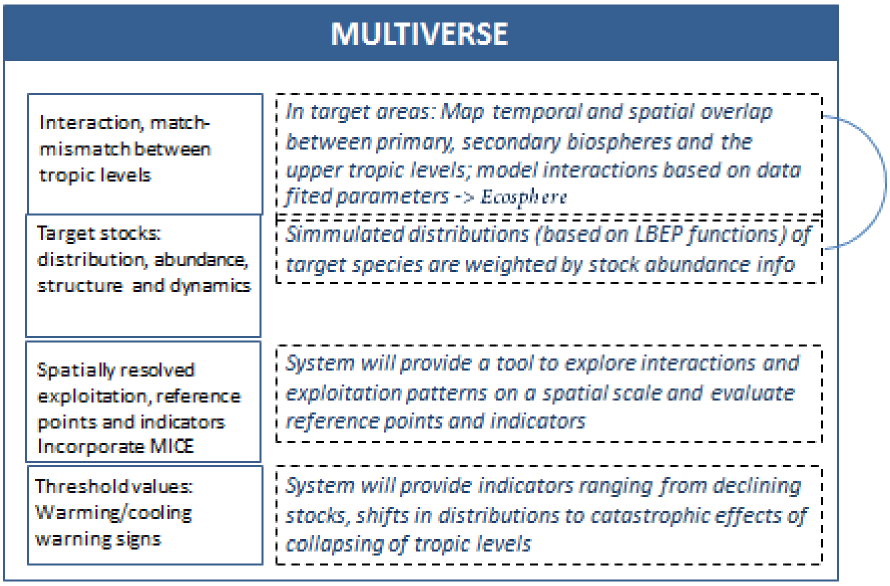

Figure 2. Models of intermediate complexity of interaction of tropic levels and destinies of target species and outputs of indicators for health of stocks and whole tropic levels.

The construction of the primary biosphere (Figure 2) will require the collation of all available data such as from surveys, fluorescence data storage tags and other information sources such as satellites. However, satellite data are limited and can be patchy due to cloud cover; hence modelling may have to be used to supplement data gaps. Additional problems are also likely to arise, such as match-mismatch between physical fields and biological processes within the time steps of the models.

The construction of the secondary biosphere (including the data assimilation of secondary production) is challenging and has not been explored extensively at this stage.

When the temporal and spatial frame of the multiverse has been constructed (Figure 1), the next step is to explore the overlap and interaction between the tropic levels (Figure 2). Several projects are likely to be of an interest at this stage that involve relatively simple procedures such as spatial mapping and identification of overlap or match-mismatch of interacting tropic levels. Also at this stage, spatial modelling such as GAMs or boosted regression trees are likely to be of an interest to explore the interaction between the ocean environment and different tropic levels. Finally, for individual stocks or a selection of interacting stocks and lower tropic levels, models of intermediate complexity (MICE) can be constructed on top of the spatially and temporally resolved distribution, abundance and behavioural trends of the species in question. This will enable us to address tactical questions such as past, current and predicted catch rates in a multispecies ecosphere driven by hydrodynamics and modelled species and fleet interactions.

When constructed, the multiverse opens up endless possibilities of use and detection of the role/effects of hydrodynamic variation on the interactions and processes within the ecospheres. Two case studies will potentially be examined; one in Iceland and the other for the Great Australian Bight.

In Iceland, the foremost case studies will include studies on the behaviour and distribution of capelin, mackerel and herring. As an example, every year an enormous effort is spent on searching for the capelin schools. The direction and path taken by the migrating spawning schools are unpredictable and likely to be driven by hydrodynamic variation. Any attempts to reduce the uncertainty of this behaviour and shorten the time and effort spent searching for schools of fish benefits industry in saved time, fuel and resources. As well, increased understanding of the behaviour of fish stocks and the drivers behind it provide valuable information for management. Likewise, a comparative case study for the Great Australian Bight involving sardine and southern bluefin tuna will be explored.

Further developments of the multiverse concept will likely contain management, economic and social system modules. For this purpose, other modelling efforts (see for example Plagányi et al. 2012) are likely to fit inside the multiverse frame.

Benefits and Adoption

Benefits for the marine sector

The multiverse is designed to provide near-real time tactical advice in a system that is continuously changing and in many ways unpredictable. As the multiverse is constructed around an operational and data assimilating ocean model that is continuously updated (potentially on a daily basis dependent on data streams), it will produce advice and information that are based on up-to-date intelligence of the environment and forecasted distributions of fish.

An operational multiverse may be used to create a Fish Finder Tool and Ocean Information system. The value of such a system for industry is significant, with save time and resources through faster location of catch and selection of fishing routes.

Benefits for fishery management

The multiverse is designed to produce tactical advice based on ocean conditions and its effects on fish stocks, plus the ability to be able to forecast the distribution and condition of target stocks. The potential benefits to management include: a) decreased uncertainty regarding decision making (i.e. TAC setting) and survey design/sampling; b) understanding changes in growth, condition and reproductive potential of target stocks; c) better estimates on abundance over diverse spatial scales; and d) indication of areas of high/low catches that may not have been included in original monitoring programs.

All of these will assist in lowering the uncertainty associated with stock assessments and future prognosis on stock estimates.

The multiverse may also open up unexplored opportunities manifested in a better understanding of fish behavior in terms of migration, distribution and habitat selection; foraging success; reproductive performance; growth and condition; survival or extinction.

Further Development

A focus group will be established that will keep contact and continue to develop the multiverse blueprint, as well as assemble information on on-going activities in an effort to incorporate useful components into concept design. Avenues to meet and set up discussions will be established; for example at joint meetings such as the World Fisheries Congress and/or through Skype/IT channels.

Interested parties will attempt to increase collaboration through joint grant applications, student exchange and scientists visiting and assisting in modelling activities.

Also, interested parties will explore the possibility of collaborating on scientific papers that will address the effects of hydrodynamic variation on, e.g. how indices of ocean condition can be used to give information on fish behaviour.

References

Plagányi, E. E., Punt, A. E., Hillary, R., Morello, E. B., Thebaud, O., Hutton, T., Pillans, R. D., Thorson, J. T., Fulton, E. A., Smith, A. D. M., Smith, F., Bayliss, P., Haywood, M., Lyne, V., and Rothlisberg, P. C. (2012). Multispecies fisheries management and conservation: tactical applications using models of intermediate complexity. Fish and Fisheries. doi: 10.1111/j.1467-2979.2012.00488.x

Intellectual property

The multiverse constructed for the north Atlantic will be a part of a service provided by the start-up company entitled Marsýn ehf, which is partially owned by the University of Iceland. However, the blueprint and the construction method/technique itself will not be the property of any company and will be published freely and open to all.