

Indicative PhD Projects 2010



IMAS
INSTITUTE FOR MARINE AND
ANTARCTIC STUDIES

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Impact of ocean acidification on the Southern Ocean coccolithophorid *Emiliana huxleyi*

Supervisors: Prof. Gustaaf Hallegraeff, A/Prof Tom Trull

Increases in atmospheric carbon dioxide concentrations are predicted to change global ocean chemistry resulting in a significant decrease in seawater pH from 8.1-8.2 at present down to 7.7-7.8 by 2100. This has been claimed to both reduce calcification by the coccolithophorid *E. huxleyi* as well as stimulate its photosynthesis. We seek to simulate various climate change scenarios under controlled-CO₂ culture conditions, and aim to predict the future success or demise of a broad range of Australian *E. Huxleyi* culture strains.

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Ecophysiology and ichthyotoxicity of the dinoflagellate *Noctiluca scintillans*

Supervisor: Prof Gustaaf Hallegraeff

Noctiluca scintillans red tide frequency and distribution has increased in Tasmanian waters, Australia since the first sighting in 1994 and severely threatened Tasmanian aquaculture farms in 2002. We seek to identify key prey items for this phagotrophic dinoflagellate in Tasmanian waters from combined culture and field studies, as well as aim to elucidate the production of anoxia, ammonia or polyunsaturated fatty acids as the mechanism for fish morbidity and mortality.

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Microscope PAM fluorometry as a predictive phytoplankton tool

Supervisors: Prof Andrew McMinn, Prof Gustaaf Hallegraeff

Recent technological advances in PAM (pulsed amplified modulated) fluorometry now allow us to characterize photosynthetic parameters of single algal cells viewed under a light microscope. This project seeks to apply this new tool to monitoring seasonal phytoplankton succession in the Derwent River with the aim to predict blooms of individual species and identify critical environmental variables.

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Untangling climate and fisheries impacts on marine resources

Supervisors: Prof. Stewart Frusher, Dr. Caleb Gardner

Climate change is one of the largest challenges facing mankind. In the marine environment, changes in the magnitude of winds and oceanic currents, ocean acidification and the warming of coastal waters are several of the issues that will affect the productivity of marine resources.

Fisheries are dependent on resource productivity and resource assessment models currently ascribe changes in productivity to changes in recruitment on the assumptions of increases and decreases around a mean, or equilibrium state. Unidirectional change, as predicted from climate projections, tends to not be incorporated in such models. As a result, management decisions that are based on model outputs will be flawed and fishery harvests will be sub-optimal.

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Climate change can present non-linear or threshold impacts and there is a need to separate climate impacts from fishery changes and to incorporate climate related changes in assessment models. Tasmania is particularly vulnerable to climate change as it is located in the fastest warming region in the southern hemisphere. Thus impacts on marine resources from climate change are expected to occur earlier in this region and provide early warning signals for other systems. The east coast of Tasmania is also associated with the longest marine temperature recording station in Australia. Temperature and salinity records show that there has been substantial warming in this region since recording began in the 1940s.

This project will focus on southern rock lobsters which are fished commercially and are an especially interesting case study on the effects of climate change. This is due to: (i) the extensive data already available including long-duration time series; (ii) observed extreme changes in the fishery consistent with climate change; (iii) biological traits that imply high responsiveness to climate change, especially their prolonged oceanic larval phase; and (iv) known relationships between water temperature and growth, reproduction and catchability. This combination suggests the project has the potential to make significant contribution to the general understanding of climate change impacts on fisheries and their management.

The project aims to:

- Explore new and innovative methods of interpreting climate change impacts on key fisheries assessment parameters at fine spatial and temporal resolution.
- Develop predictive models that account for climate change impacts, including non-stationary in parameters such as growth, selectivity and recruitment.
- Investigate methods for separating climate from fishery related impacts on exploitable resources

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Mercury bioaccumulation in the Derwent estuary - chemical processes and biological pathways

Supervisors: Catriona McLeod, Jeff Ross, Natalie Moltschaniwsky, Barbara Novak, Ed Butler

Heavy metal contamination is a key issue for the Derwent estuary, with current mercury levels in sediments and biota well above nationally recommended environmental and human health guidelines. While some heavy metals in the most heavily contaminated areas of the Derwent are declining in response to industry regulation/mitigation activities, mercury remains a significant concern due to its persistence and bioavailability. A recent pilot survey of mercury levels in bream from the upper Derwent indicated that levels in this popular recreational species are about three times the national food standards. Mercury availability is strongly linked to the process of methylation, which is particularly prevalent in wetland areas such as the upper Derwent.

The proposed PhD project would investigate mercury cycling in the Derwent, focusing on methylation 'hot spots' such as the wetlands in the upper estuary. The project would investigate methylation processes, biological pathways and would provide a valuable scientific basis for management.

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Contaminant residue levels in key commercial & recreational fish species from S. Temperate Australian waters

Supervisors: Catriona McLeod, Jeremy Lyle, Natalie Moltschaniwsky ,Barbara Novak, Ed Butler

Recent studies have indicated significant accumulation of heavy metals in certain important recreational fish species in S. Tasmania. In a number of instances the loadings were sufficiently high as to be of concern for human health. In determining whether to issue health warnings the relevant agencies expressed concerns regarding the reliability of the data; although these were in the end overridden by the need to ensure public safety, some areas were identified where further research is needed.

It was noted that it is important to ensure that sample size adequately reflects the population for that given area and fishing approach, and may differ between commercial and recreational catches. The size of any particular population will be dependent on i) the species life-history/ distribution and ii) the catch approach. Ensuring an adequate sample size requires that the ecology of the target species be understood.

It is also important to determine the most appropriate sampling of the fish for the likely consumption risk (i.e. flesh, frame, whole fish) Metals are often disproportionately deposited in particular areas/ organs and consequently risk of contamination will vary with species and consumption. Where species are being caught for export, sampling requirements are generally very clearly defined, but for effective health management this should reflect the actual/ proposed consumption pattern. Contaminant monitoring generally only applies to commercially caught fish. However, recreational fishing is generally undertaken much closer to shore and to potential sources of contamination than commercial fishing and so may be subject to higher levels. To date there has been little or no evaluation of contamination levels in recreationally caught species in southern temperate Australia.

Mercury is one of the metals of greatest concern with respect to human health. Often, where sampling is undertaken it is total mercury which is reported; however, it is methyl mercury which represents the greatest risk to human health. A more detailed description of the relationship between methylated mercury and total mercury levels for key fish species could highlight options for simpler and more cost-effective monitoring.

Proposed Project Objectives:

- To define generally expected levels of contamination (incl. mean/ min/ max) for key species on a regional basis (a distribution map??)
- To examine differences between levels in recreational and commercial catches
- To examine differences between fish flesh levels and other measures (i.e. whole fish/ skin on / frame/ gills) and consider implications for both human consumption & monitoring
- To examine different analytical assessment techniques (eg. measurement of MeHg levels versus total Hg) and identify relative strengths/ weaknesses (practically & economically as well as in relation to sensitivity and relevance to human/ fish health)
- To relate this information to current national/ international seafood reporting standards and make suggestions/ recommendations re: standards and protocols

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Maternal and paternal influences on growth in cephalopods.

Supervisors: Jayson Semmens and Gretta Pecl

An expansion of a recent PhD study into the influence of factors affecting octopus growth, is the examination of additional factors such as maternal nutrition, temperature, yolk reserves and paternity. Maternal nutrition is known to influence the condition and size of eggs, where a malnourished mother under stress will lay fewer and smaller eggs. Temperature can also alter embryonic development and yolk production, when at the extremes of a species temperature range. Variation in individual yolk reserves can potentially effect growth during the days prior to and immediately after hatching. In addition to these factors, there is also a possibility that eggs could be preconditioned for optimised growth in relation to surrounding water temperatures and seasonality.

Mixed paternity has been observed in squid and may also occur in octopus. Investigating mixed paternity could provide insights into the effects of genetic diversity on growth and how this is related to individual growth heterogeneity. We are currently developing microsatellite markers for *Octopus pallidus*, which would allow mixed paternity to be examined.

By testing for the combined effects of these variables on growth in the laboratory, and then applying the results to field studies investigating trends in egg batch composition in relation to female condition and paternity throughout the year; the potential effects of size selective fishing mortality on fecundity and recruitment could be further investigated.

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Population dynamics and ecological role of an exploited subtidal gastropod, *Turbo undulatus*

Supervisors: Jeremy Lyle, Natalie Moltschaniwsky and Jeff Ross

Turbo are harvested commercially in Tasmania as part of the Commercial Dive Fishery. The species is found on reef habitats and exhibits highly patchy distributions, forming large localised aggregations in some situations. Studies on the age and growth, spawning cycle and settlement dynamics along with factors influencing aggregating behaviour and population responses to harvesting are required to inform on the sustainable management of the species. Industry research levy funds are available to support this project.

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Recruitment and retention of scallops in the D'Entrecasteaux channel: is there a relationship with scallop density?

Supervisors: Jayson Semmens, Jeremy Lyle, Sean Tracey, Natalie Moltschaniwskyj

Recent literature has suggested the importance of maintaining high density regions of scallop beds as a source of recruitment. This correlation has, in part, been attributed to improved synchronisation of spawning events within high density regions. Given that scallops are broadcast spawners, releasing male and female gametes from the same individuals but at different times, such synchronisation of gonad development, and maintenance of high densities of adult scallops may be vital for the success of recruitment. The density of adult scallops on a bed may also influence the settlement of scallop spat and retention of recruits; however, there is little understanding of this relationship.

The D'Entrecasteaux channel supports an important recreational scallop fishery; however, there is a concern that the beds in this region could be serially depleted if recruitment and retention is limited by recreational catch levels/patterns. This project will look at recruitment and retention of scallops in the Channel and determine if high density regions of scallops need to be maintained to promote these processes.

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Investigating the determinants of population structuring in the temperate reef fish *Cheilodactylus spectabilis*

Supervisors: Jayson Semmens and Jeremy Lyle

Cheilodactylus spectabilis is a large temperate reef fish which is common in shallow coastal waters in southern Australia. *C. spectabilis* demonstrates complex behaviour, with populations structured by sex, size, depth and available habitat. Recent work in Tasmania using acoustic telemetry showed a clear repeatable pattern of *C. spectabilis* moving to depths and showing greater activity during the spawning period, with an apparent segregation of males and females across the reef. Additionally, recent detailed reproductive staging over the duration of the spawning period of *C. spectabilis* has provided further information on the spawning behaviour of this species, which is likely to be key to determining the population structure. This project would further this recent work using a combination of acoustic tracking, dive surveys, remote camera monitoring (fish are highly site attached) and reproductive staging in order to better understand the factors structuring the population.

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Establishing a historic baseline of Tasmania's marine resources

Supervisors: Stewart Frusher

Linking socio-demographics and activity in recreational fishers

Supervisors: Jeremy Lyle and Elaine Stratford

Genetic variability in giant kelp and relationship with environmental variables

Supervisors: Neville Barrett, Graham Edgar and Dorothy Steane

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CSIRO-UTAS PhD Program in Quantitative Marine Science approved projects

Modelling the cycle of iodine: sea to air, air to land surface

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Supervision Team: Dr Andrew Seen (UTAS), Dr Edward Butler (CSIRO), Dr Jill Cainey (CGBAPS), Dr Ole Hertel (NERI, Denmark).

Background

Iodine is decisively a marinogenic element; its delivery to the land (and to terrestrial life) depends on the efficiency of its transport from the sea to the land surface via the atmosphere. The deficiency of iodine in many regions of the global land-mass remains a pivotal issue for human health, as it does for agriculture—especially that of raising livestock.

The sea-air transfer of iodine is enhanced proportionately over the other halogens chlorine and bromine by volatile forms of iodine (organic and inorganic) formed in surface seawaters by biological and photochemical processes. These iodine volatiles in the atmosphere are extremely reactive. They are not only capable of catalytic decomposition of ozone, but they also form very fine aerosols that can influence global climate.

Delivery of iodine to land surfaces is either by wet or dry deposition, but a third pathway also exists with the uptake of gaseous iodine (e.g. methyl iodide) by plants and soils. The extent of retention of iodine is determined by the nature of the soils and the physiology of the plants. Regardless of the importance of either soils or plants in intercepting iodine, neither can be considered as lasting repositories for the halogen. Iodine's reactivity ensures that it is either volatilised back to the atmosphere, or solubilised in surface run-off to enter again into the hydrologic cycle.

For the reasons touched on above—iodine's role in key atmospheric processes (cloud-condensation nuclei, albedo, and ozone destruction) and the efficiency of its transfer to land surfaces that ultimately underpins the nutrition of all higher terrestrial animals—it is critically important to be able to predict and understand the pathways, cycling and ultimate distribution of iodine throughout Earth's ecosphere.

Objective

The broad goal of this project is to develop a predictive, numerical model to describe the sea-air flux of iodine, its reactions and cycling in the atmosphere, and deposition to/emission from land surfaces. It is expected that the model will be calibrated and validated against relevant Tasmanian environmental data on iodine.

The PhD study can either involve

- The development of a broadly based model to cover the full path (sea to air to land), or
- Focus on development of a more detailed module (or nested model) for the full model—e.g. evasion of iodine from the sea, and its entry and cycling in the 'reactive iodine pool' in the atmosphere.
- An associated task will include participation in the collection of atmospheric iodine data, relevant to the model, at the Cape Grim Baseline Atmospheric Pollution Station in North-West Tasmania.

Approach

The focus for this study will be the island of Tasmania and its surrounding seas. The reason for this is that a useful data set has been, and continues to be, obtained for the distribution and the biogeochemistry of iodine in the regional sea through the collaboration of Institute of Antarctic and Southern Ocean Studies

(University of Tasmania), CSIRO Marine and Atmospheric Research and the Antarctic Climate and Ecosystems Cooperative Research Centre. This is importantly complemented by the measurements of atmospheric iodine compounds by the Cape Grim Baseline Air Pollution Station (joint Bureau of Meteorology/CSIRO Facility) on the north-western tip of Tasmania. Furthermore, records exist in Tasmania relating to iodine deficiency in the island's landscape (e.g. state-wide distribution of goitre among livestock). This complete database on iodine provides the basis for calibrating and validating the model.

The development of the model is vitally dependent upon the modelling expertise (and model code) of the Danish National Environmental Research Institute—a principal partner in this project. For example, their DEHM-REGINA long-range transport model is seen as a likely key tool in the project. Local expertise, such as that involved with oceanic transport and biogeochemical models, and the resources of the CSIRO Atlas of Regional Seas, will also be required to construct the iodine model. It is also conceivable that satellite data (e.g. estimated chlorophyll) will contribute to this work.

Given the key role of the National Environmental Research Institute at Roskilde in Denmark, the PhD student is expected to make a number of short-term visits to this facility during their candidature.

Match to QMS Research Area(s)

The outputs of this project are most relevant to QMS *Marine Environmental Prediction*. It incorporates aspects of the biogeochemistry and photochemistry of iodine into specialist log-range transport and deposition models to understand the evasion of iodine from the sea, its dynamic cycling in the atmosphere and its deposition to land surfaces. Data will be gathered from marine source areas and the Tasmanian atmosphere by specialist monitoring systems. The very nature of iodine as an essential element to many life forms makes this a project with significant interdisciplinary appeal.

Since iodine in the atmosphere is an important source of micro-aerosols leading to cloud-condensation nuclei, and its concentrations in the landscape can have influence on specific economic management decisions in terrestrial environments, this project has secondary relevance to the other QMS research areas of *Climate and Ecosystems* and *Climate Variability and Resource Management*, respectively.

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Alternative strategies for sustainable environmental management of nutrient loads in aquaculture.

Supervision Team: Craig Johnson (UTAS), Catriona Macleod (UTAS), Karen Wild-Allen (CSIRO)

Discipline

Applied marine biogeochemical modelling

Background

Finfish aquaculture has the potential to significantly contribute/enhance to the nutrient loads in estuarine and coastal systems. The ultimate sustainability and further development of the industry is contingent upon the system being able to cope with these additional inputs. If the nutrient carrying capacity of the system is exceeded then eutrophication may result with the potential for catastrophic consequences for both the industry and the environment.

In Tasmania the Australian salmon farming industry continues to expand in coastal waters amidst growing concerns of water quality degradation and environmental sustainability. In South Australia the highly successful tuna ranching industry is holding more fish for longer periods and the farming of mulloway and yellowtail kingfish is increasing. The complementary farming of species with the capacity to reduce nutrients is one possible solution. Polyculture of fin-fish, shell fish and algae in coastal systems is becoming increasingly popular in Europe, Canada and the USA . Nutrient and detrital waste resulting from fin-fisheries provides additional resources for filter-feeding shellfish and macrophytes and in addition to mitigating the environmental impact of fish farm waste products these components can add value to aquaculture activities.

Using and developing the biogeochemical models currently available/ being developed for the Tasmanian and South Australian aquaculture industries to examine the system wide benefits of polyculture for nutrient stripping in these local environments would be both innovative and worthwhile. This PhD project has the potential to influence the Australian fin-fish aquaculture industry in a positive way by demonstrating the environmental viability of polyculture farming techniques. The project would compare the environmental and economic costs and benefits associated with key potential polyculture species identifying the most advantageous options for the local aquaculture industry. In addition the PhD student would become skilled in modeling techniques which are currently in high demand both generally and in the area of environmental management specifically.

In the current climate of environmental accountability this project provides a particularly important and timely opportunity to quantify the broader environmental effects of traditional and novel farming practices and evaluate whether polyculture is an environmentally sustainable solution for the expansion of the fin-fish farming industry in Australia.

Objective

To quantify the spatial and temporal environmental impact and risks associated with alternative aquaculture management strategies for nutrient loads in Australian coastal waters using a state-of-the-art dynamically coupled quantitative 3D biogeochemical model.

Key Tasks

- Construct a biogeochemical model of a fin-fish polyculture system (building on existing model components) and implement at multiple (nested) scales from an individual lease to system wide
- Review existing polyculture systems and identify appropriate organisms for fin-fish polyculture in temperate Australian waters
- Validate the model against new and existing observations, evaluate the model sensitivity to small variations in key parameter values and estimate model error

- Use the model to quantify the individual lease to system wide environmental impact of traditional and polyculture farming practices
- Understand the perceived risks associated with polyculture farming practices and use the model to quantify risks such as oxygen depletion, feral dispersion and disease transmission
- Design an optimal model solution for a low risk environmentally sustainable fin-fish polyculture system and evaluate its economic viability

Approach

Information in the literature regarding existing and potential polyculture species will be collated and critically reviewed. The environmental parameters that differentiate aquaculture in Australian waters will be explicitly identified, and these will direct the approach required. An existing coupled hydrodynamical, sediment and processed based biogeochemical model will be augmented with additional functional groups to simulate a polyculture system. Existing model implementations in fin-fish farming regions in Tasmania and South Australia can be used to design scenario simulation experiments and test hypothesis relating to traditional and polyculture farming practices. Model simulations will be validated both against existing data sets and, where necessary, with laboratory and/or fieldwork. It would be desirable for the student to visit at least one polyculture system (likely overseas).

The existing model couples 3D hydrodynamics, sediments and biogeochemistry to simulate the turnover of carbon, nutrients and oxygen in multiple pelagic, epibenthic and sediment layers. The biogeochemical model includes four groups of microalgae (small and large phytoplankton, dinoflagellates and microphytobenthos) and two macrophytes (seagrass and macroalgae) which grow at a rate determined by access to dissolved nutrients (nitrogen and phosphate) and light (photosynthetically active radiation). Micro- and meso-zooplankton are also modelled and nutrients are recycled through the remineralisation of particulate detritus and dissolved nutrient pools. It is envisaged that this model will be augmented and extended to include additional functional groups key to the simulation of polyculture systems. These will likely include specific macrophytes and filter feeding organism such as mussels and oysters. Existing lease to regional scale hydrodynamic implementations will be utilised to underpin biogeochemical polyculture simulations for scenario and hypothesis testing.

Skills

This PhD would suit an applied mathematician with an interest in marine ecosystems; or a marine scientist (particularly an ecologist) with maths and/or programming skills.

On successful completion the candidate will have skills in applied biogeochemical modelling, coastal marine ecosystem management and a good understanding of the marine aquaculture industry.

Fit to current research programs

This project would build on existing understanding of the environmental impact of the Tasmanian Atlantic Salmon Industry and the South Australian tuna ranching industry [Aquafin CRC projects: 'Environmental Issues for Salmonid Aquaculture' and 'Southern Bluefin Tuna Risk and Response, Understanding the Tuna Farming Environment']. The proposed project would tie in specifically with research on macroalgal nutrient uptake rates currently being undertaken at TAFI as part of the Aquafin CRC and through the Derwent Estuary Program.

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Estimating diffusion coefficients from ocean hydrography

Chief Investigator and contact: Dr Trevor McDougall (CSIRO)

Supervision Team: Prof Nathan Bindoff (UTAS), Dr Trevor McDougall (CSIRO), Dr Bernadette Sloyan (CSIRO).

Background

A prominent use of ocean models is to predict future climate change under various greenhouse gas scenarios. This is done using coupled ocean-atmosphere-ice models. A key parameter in such models is the strength of ocean mixing. Ocean mixing controls the rate at which heat and CO₂ are absorbed by the ocean. These models need the strength of ocean mixing processes to be prescribed.

As ocean models have improved over past decades, their ability to accurately model the present ocean is being more obviously limited by the realism of the imposed mixing coefficients. For example, vertical mixing is commonly set as a constant, or near constant parameter despite it being known to be highly spatially variable. What are lacking are global estimates of rates of vertical and lateral mixing.

To overcome the lack of direct mixing observations we have recently developed a new inverse method; the Tracer-Contour Inverse Method, which is able to deduce the strength of both the vertical and lateral mixing in the ocean, as well as giving superior estimates of the mean ocean circulation (Zika et al. (2009)). This Tracer-Contour Inverse Model is much more skilful than the three prior inverse methods that have been used in oceanography since 1978.

This inverse method uses the hydrographic data that is becoming available from the Argo floats; autonomous floats that are providing oceanographers with more data than has been available to date from research ships, although the ship-derived data is vital below 2000m depth.

This PhD topic will develop the Tracer-Contour Inverse Method (TCIM) so that it can be applied in a general way to any region of the world ocean, and conduct inversions of an isopycnally averaged hydrographic climatology systematically around the world ocean. The global application of the TCIM will provide an understanding of the spatial variation of the vertical and lateral ocean mixing that are appropriate to be used in coarse-resolution ocean models. Simple spatial functions of the magnitude of these diffusivities, accompanied by the uncertainties of the estimates, can then be included as mixing parameterizations in climate models. This will improve the model simulation and prediction of the ocean circulation and change.

This research uses the new ocean observing infrastructure (Argo floats) and a new inverse method technology to obtain estimates of ocean mixing, estimates that are needed by ocean modellers for the purpose of climate prediction.

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Modelling biodiversity related ecosystem processes as a Complex Adaptive System

Supervision Team: Prof Craig Johnson (UTAS), Dr Beth Fulton (CSIRO)

Background

Evidence is accumulating that biodiversity is a strong determinant of the ecosystem services delivered by an ecosystem and therefore ultimately the form of sustainable use of a system (Loreau et al 2001, Tilman et al 2001, Sala and Knowlton 2006, Butler et al 2007, Palumbi et al 2009). Thus, a steep decline in biodiversity has potentially larger consequences for ecosystems (of which humans are part) other than just the lost of species and direct implications for humans use of those species.

Moreover there is significant potential for global change to lead to shifting diversity locally, regionally and globally (Vitousek et al 1997). Unfortunately, current ecosystem models (e.g. Ecopath with Ecosim (Christensen and Walters 2004) or Atlantis (Fulton et al 2004)) that are used to consider natural resource management and the impacts of human activities and climate change do not include an explicit handling of shifts in biodiversity. While complicated, these models will not be able to explore the full range of system dynamics (especially those likely to dominate under changing conditions) if they neglect the fundamental adaptability of system components.

The field of complex adaptive systems (CAS) (Holland 1992) offers a dynamic view in which fixed values for species composition of modelled groups (and associated parameters) are replaced with rules that are a function of long term (e.g. species) and short term (typically individual) history, embracing the adaptive capacity of nature. Ultimately, the flexibility of CAS based models of biodiversity needs to be married with existing process-based ecosystem models to allow for exploration of effective adaptive management.

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Project outline and objectives

This project will be aimed at developing quantitative models of how biodiversity and associated ecosystem functioning changes through time, particularly in marine ecosystems. This will begin with a systematic investigation of existing approaches to modelling biodiversity in a dynamic ecosystem setting and then move on to the development of sub-models for ecosystem models (e.g. Atlantis), representing biodiversity in a variety of non-stationary ways.

The specific objectives of the project are:

- Identify the temporal and spatial scale of adaptation and change, and whether it is feasible to include these processes in existing ecosystem models based largely at a functional group level or whether a new generation of models is needed (this will then dictate what form of models are developed in later stages, whether they will be stand alone or nest within existing modelling frameworks).
- Identify different existing approaches to modelling biological adaptation; this will involve evaluating the different approaches - such as trait-based modelling (e.g. Norberg 2004, Merico et al. 2009), “systems of indefinite diversity” (Bruggeman and Kooijman 2007), and pattern-oriented modelling (e.g. Grimm et al. 2005) - in terms of functionality, effectiveness, computer efficiency and model complexity.
- Construction of sub-models for ecosystem models (or stand alone models depending on the outcome of objective 1), representing biodiversity in a variety of non-stationary ways.
- Use the models to consider biodiversity under changing conditions (potentially also identifying key related processes and their importance for biodiversity in the test ecosystems).
- Altogether this work will consolidate information on how to model ecosystem processes as a Complex Adaptive System.

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Impact of climate change on Australia's climate drivers and water resources

Supervision Team: A/Prof Neil Holbrook (UTAS), Prof Gary Meyers (UTAS), Dr Peter McIntosh (CSIRO)

Background

The response of climate variability to climate change forcing is one of the most important issues in climate research. This is particularly relevant for Australia where the climate is highly variable and characterized by severe extreme climate and weather events, being influenced by modes of variability such as El Nino - Southern Oscillation (ENSO), variability of Indian Ocean and Southern Ocean Sea Surface Temperature (SST). A change in the property of these modes may result in significant changes to the rainfall, moisture supply, and humidity. Further, climate change signals may project onto these modes, contributing to secular trends in these modes. Trends toward lower rainfall in some regions already observed (Queensland and Southwest Western Australia) and suggested by global climate models are likely to compound with rising temperatures and potential evaporation to exacerbate the strain on future water resources and the impact. Thus the likelihood of these exiting trends continuing and new drying trends emerging in other regions, and the extent of the impact await detailed investigations. This is highlighted by the severity of the 2002 drought.

Objectives

The potential for two PhD projects is outlined here. We will address the above issues by using the CSIRO Mark 3 climate model.

Research can include the following:

Provide a quantitative assessment of how well the model simulates the present day variability in the control climate simulation. In particular we will examine the model processes responsible for several unrealistic features in the Pacific Ocean, possibly including:

1. Cold tongue bias and equatorial confinement of the equatorial Pacific SST pattern
2. The linkage with overly biennial signals and other possible consequences of the above problems
3. The lack of multidecadal signals in the extra tropical Pacific

The objective is to contribute to the on-going effort of model improvement.

Identify natural, multidecadal variation of ENSO characteristics in the model, with focus on:

- 1 The relationship between Pacific heat content and Nino3.4 SST: the well-known asymmetry (per unit change of recharge generates a larger change in positive Nino3.4 index than per unit change of discharge for negative Nino3.4 index), and its relationship with tropical Pacific variations on multidecadal time scales (we know that tropical variability is reasonably simulated)
- 2 the relationship between Pacific heat flux (wind) and Nino3.4, and its fluctuations on multidecadal time scales The objective is to understand the mechanisms of natural decadal and multidecadal variability. Identify mechanisms of the response of climate variability to climate change.

The objective is to understand the mechanisms of natural decadal and multidecadal variability.

Identify mechanisms of the response of climate variability to climate change.

- 1 Are the responses consistent with results from multidecadal modulation in terms of mean state response and response of frequency and intensity?
- 2 How does the impact of ENSO may change? Do rainfall events become rarer but more intense as observed? What is the prospect of heat waves as a result of changes in ENSO properties.

The objective is to understand the dynamics of natural and human induced rainfall changes over Australia.

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Predictability of the interaction between El Nino Southern Oscillation and the tropical Indian Ocean

please note, this project is currently being modified due to a new supervisory team being appointed. If you are interested in this project please contact Neil Holbrook before submitting an application for the QMS PhD Program

Supervision Team: A/Prof Neil Holbrook (UTAS), Prof Gary Meyers (UTAS), Dr Peter McIntosh (CSIRO)

Background:

El Nino Southern Oscillation (ENSO) is a global, seasonal climate anomaly controlled by ocean-atmosphere interaction in the central and eastern equatorial Pacific Ocean. Climate anomalies in the monsoon systems of Australia, Asia and Africa are also modulated by ocean-atmosphere interaction in the tropical Indian Ocean, where the dominant pattern is the recently discovered Indian Ocean Dipole (IOD) or zonal mode. ENSO can influence IOD by an atmospheric tele-connection but IOD also is able to grow on its own. This study will assess the mechanisms that control IOD and its predictability.

Objectives:

- Compare the observed thermal and haline structure of IOD to the simulation of it by two dynamical climate prediction systems-COCA (CAR) and POAMA (BMRC).
- Assess the predictability of IOD using statistical and dynamical methods.

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Testing climate models and sea level rise projections using observations of ocean heat uptake

Chief investigator and contact person: Dr Susan Wjiffels (CSIRO)

Supervision Team: Prof Nathan Bindoff (UTAS), Dr Susan Wjiffels (CSIRO), Dr John Church (CSIRO), Dr Trevor McDougall (CSIRO), Dr Siobhan O'Farrell.

Ocean observations indicate that the ocean has warmed over the last 50 years. As a result of ocean thermal expansion sea level has risen. There has been a series of regional studies of ocean heat uptake but to date there has been only one global estimate of the amount of heat uptake by the ocean. We have initiated a new estimate of ocean heat uptake over the last 50 years and its contribution to sea level rise.

Aim

To compare observed ocean heat content increases with ocean only and coupled ocean/atmosphere models run under a variety of boundary conditions. Particular issues requiring attention include understanding the different rates of ocean heat uptake in models and the distribution of this heat uptake. The distribution implies an understanding of the regional distribution of sea level rise. The project may involve new numerical experiments or could focus on the analysis of existing model results.

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Determining and understanding changes in sea level over the last century

Supervision Team: Dr John Hunter (ACE CRC), Dr John Church (CSIRO)

Background

Global average sea level rose 10-20 cm over the past century and could rise as much as 80 cm during the present century, due primarily to global warming (from the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), 2001). While we are quite confident about the historic rate of rise of global sea level, we know little about the regional variation of that rise, especially in the Southern Hemisphere where there is a dearth of observational data. We also know little about changes in extreme sea level heights (e.g. due to storm surges) during the last century. It is, however, important that we understand what happened in the last century if we are to predict what will happen during the present century.

There exists, both in Australia and overseas, a large and relatively unexplored data set, originating from coastal tide gauges. However, many of these data sets are not presently referenced to standard vertical height datums, some contain errors (which are, in many cases, correctable), and a significant number are not yet in digital form. This represents a considerable problem of resource allocation, in the sense that there will probably never be sufficient resources to satisfactorily analyse all existing tide gauge records. We therefore have to select the most appropriate historic records (i.e. those that will provide useful data in a required region, and for which there is a reasonable chance that reliable datum information will be found).

Over the past decade, sea-level height has also been monitored by a number of orbiting satellites, using radar altimeters. The near-global coverage allows us to make good estimates of global sea-level rise, although the limited time-span precludes estimation of sea-level rise prior to about 1990. A recent analysis by researchers from the ACE CRC has used the satellite data to infer the spatial variability of sea level rise, and the tide gauge data to infer the time history. Such a combination of tide gauge and satellite data has yielded a reconstruction of sea level at high spatial resolution over the globe, covering much of the 20th century.

We are therefore gaining a quite good understanding of the way in which sea level varied during the 20th century. We do, however, have a significant problem in accounting for the observed rise in terms of the water budget and thermal expansion. For example, the IPCC Third Assessment Report could only account for around one half of the observed sea level rise. There is therefore a concerted international effort to improve our understanding of the various contributions to the observed sea level rise.

Objectives

The project would seek to both quantify and understand one or more of the aspects of historic sea level rise noted above. Possible projects would include:

- 1 The analysis of historic Australian and regional tide gauge records in order to improve the coverage of sea level data in this data-sparse part of the world.
- 2 The development of techniques to synthesise sea level records from different sources (e.g. tide gauge records from a number of locations and satellite observations) in order to generate global and regional reconstructions.
- 3 The analysis of tide gauge records in order to improve our understanding of extreme sea levels and of how, and why, they have changed during the past century.
- 4 The analysis of the results of numerical models of the ocean/atmosphere system in order to improve our understanding of various contributions to sea level rise.

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The signature of global warming in the Indian Ocean

please note, this project is currently being modified due to a new supervisory team being appointed. If you are interested in this project please contact Neil Holbrook before submitting an application for the QMS PhD Program

Supervision Team: A/Prof Neil Holbrook (UTAS), Prof Gary Meyers (UTAS)

Background:

Much of the global ocean shows a warming trend in sea surface temperature (SST) over the past several decades. The strongest SST warming occurs in the Indian Ocean. The SST trend is easily documented because there is a large volume of data collected as part of the weather observations made routinely by merchant ships since the 19th Century. Little is known about the signature of this trend below the sea surface and the oceanic mechanisms associated with the surface warming. This project will use available observations and results from climate models to document and understand the Indian Ocean trend. Two great surveys of the Indian Ocean are available for the periods 1960-1965 (The International Indian Ocean Expedition) and 1990-1995 (The World Ocean Circulation Experiment) as well as repeated bathythermographic lines and irregular research vessel cruises since 1950. Results from the simulation of global warming by the CSIRO and other climate models are also available for the study.

Objectives:

- Document the change in thermal and haline structure of the Indian Ocean since 1950 using observations and models.
- Validate the signature of global warming in the Indian Ocean in the CSIRO Mark 3 climate model against observations.
- Identify the mechanisms that control Indian Ocean warming in SST and below the surface.

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Remarkable near-surface eastward flows in the South Indian Ocean: Understanding the dynamical links between the Indian Ocean subtropical gyre, Indonesian Throughflow, Leeuwin Current and subduction south of Australia

Supervision Team: Dr Helen Phillips (UTAS), Prof Nathan Bindoff (UTAS), Dr Andreas Schiller (CSIRO)

Background

A remarkable aspect of the upper ocean circulation in the south Indian Ocean (SIO) is the presence of near-surface eastward flows across this basin. Parts of the eastward flow are concentrated into discrete bands and have been identified as the south Indian Counter current (SICC) and the Eastern Gyral Current (EGC). These features have been detected in observations, although details about their precise location, intensity and variability are still to be described. These currents have been simulated successfully by some numerical models, although their basic dynamics remain unclear. The most remarkable aspect of the eastward flows is that they are in the opposite direction to that predicted by both Ekman and Sverdrup theory. Recent advances have been made linking Australian and regional climate variability to variability in the Indian Ocean. Before we can further our understanding of the Indian Ocean's influence on Australian climate, we need to understand the first-order dynamics controlling its circulation and watermass variability.

Modelling studies have proposed three mechanisms for the cause of the eastward flow, which is compensated by subsurface westward flows. The first is the damping of Rossby waves, forced by the Indonesian Throughflow (ITF), away from the eastern boundary. The second is localised regions of downwelling, such as caused by convection south and southwest of Australia and at the West Australian coast in the Leeuwin Current. The third is the large decrease in steric height in the SIO due to the

meridional density gradient from light ITF and tropical waters to denser southern waters, giving rise to eastward flow. In support of the latter idea, when the ITF is shut off in numerical ocean models there is a reduced meridional density gradient and weaker eastward flows.

Ideas for why the eastward flow concentrates in bands (EGC and SICC) include 1) winds and/or buoyancy fluxes causing a convergence of the surface flow; and 2) Rossby waves emanating from regions of subduction south of Australia propagating west and being deflected north by the subtropical gyre. In support of the latter process, revealed in model simulations, the southern edges of the observed eastward flow all connect to the SW tip of Australia.

Project outline and objectives

The student will be part of a team that includes the supervisors, a postdoctoral research fellow, Dr Stuart Godfrey, and Drs Jay McCreary and Ryo Furue of the University of Hawai'i International Pacific Research Center.

The PhD project will focus on the role of subduction south of Australia in driving the near-surface eastward flows, and will link into the work of the team in answering the broader questions. The specific objectives for the project are

- Analyse observations from the Indian Ocean Thermal Archive and the CSIRO Atlas of Regional Seas to build a detailed picture of the location, intensity and variability of circulation pathways in the southeastern Indian Ocean, and potential Rossby wave paths emanating from south of Australia, in particular.
- Conduct a similar analysis using the high-resolution output from the BLUElink Ocean Forecast Australia Model (OFAM). The model's high spatial resolution and multi-year time series will allow a quantification of the year-round variability in SIO currents, and detailed mapping of the subduction regions in the SIO. It will also allow an exploration of the cross-correlations between the eastward flows, ITF, Leeuwin Current, subducted water flow, Rossby waves and atmospheric forcing.
- Investigate ocean processes that drive the near-surface eastward flows using a hierarchy of models less complex than OFAM including analytical, linear-continuously-stratified box models and general circulation models. This part of the work relies on close interaction with Drs McCreary and Furue and the Postdoctoral Research Fellow.

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Quantitative analyses the role of socio-economic integration and drastic environment change in quantification of multi-objective criterion

Supervision Team: Dr Des Fitzgerald (UTAS), Dr G Cui (CSIRO), Dr A.D. Smith (CSIRO)

Background

Management of marine resources in the context of ecosystem sustainability will ideally expect that the resource management participants select rational coordinative strategies to meet emergent objectives that integrate ecological, environmental and socio-economic considerations. The pursuit of multi-objective integration is a rational way of attempting to find coordinated solutions that attain the best results for the whole participants/group. However, difficulties arise due to the lack of functional relationships between objectives; especially, the role of socio-economic and environment impacts in relation to resource objectives is less well understood, and ultimately may be disregarded in implementation. This has been reflected in real life, in that the most common process is the striving for a dominant equilibrium (non-cooperative strategy), in which each participant seeks to maximise their own rewards regardless of the results for others or for the system as a whole.

This study will focus on develop a process using Game Theory for defining essential socio-economic and environment impact metrics and their role in the quantification of multi-objective criterion, eg., a cooperative relationship or non-cooperative relationship, competitive or mutual inferior, etc. The result of the study can be used as an essential tool providing information for resource management in addressing the right integration problem and in selecting methods for the evaluation of management strategies.

Objectives

- 1 Define socio-economic and environment variables and explore the relationship with marine resources such as fish species.
- 2 Analyse the significance of cooperative and non-cooperative integration
Apply OR methods such as Game Theory and multi-objective decision analysis to define feasible
- 3 multi-objective criterions and metrics.4: Test the method to set up criteria for simple multi-objective planing.

The project would suit a candidate with a background at good honours or MSc level in a field such as applied mathematics, statistics, operations research (or economic modelling). The candidate may also be required to undertake some course work on selected subjects.

The study has a clear focus on exploring the relationship of socio-economic and environmental objective integration with resource management using advanced OR methods. It has wide applicability for resource MSE study, which is part of CMR's strategic focus area.

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