THE UNIVERSITY OF QUEENSLAND
AUSTRALIA

CARM Report

March 2019 – February 2020

Centre for Applications in Natural Resource Mathematics

Solving most pressing natural resource and environmental problems

www.smp.uq.edu.au/CARM

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CENTRE FOR APPLICATIONS IN NATURAL RESOURCE MATHEMATICS (CARM)

Background and Recent Progress

Initiated by Queensland's Department of Agriculture, Fisheries and Forestry to support research in the quantitative fisheries science, the Centre for Applications in Natural Resource Mathematics (CARM) in the School of Mathematics and Physics at The University of Queensland was established in April 2010[1] to promote applications of mathematics and statistics in the important area of natural resource modelling.

Over the past decade the centre developed a special focus on modelling sustainable fisheries to ensure that our research outcomes are directed at problems that impact Australia and benefit end-users. Indeed, CARM has produced excellent results for Queensland by developing state-of-the-art statistical and mathematical modelling methodologies. These advances have been applied by DAF to inform their fisheries stock assessments and have also led to high-quality research outputs. The relationship with the Department of Agriculture and Fisheries (DAF) also ensures that CARM students have a pathway into careers in natural resource management in government. In 2019, CARM and UQ were acknowledged in the Australian Research Council's Engagement and Impact Assessment as having 'high' impact in the Mathematical Sciences. This success was a direct result of the DAF-CARM partnership.

Overall, 2019 has been a strong year for CARM. Three dynamic early career researchers **Drs Wen-Hsi Yang, Matthew Holden** and **Sabrina Streipert** ably supported **Professors Filar and Richardson** in advancing the centre's mission and were mentored by them, in the process. These young researchers have been critical to CARM's mission in view of our expanding portfolio of activities and external projects that have a measurable impact on sustainable management of natural resources both in Queensland and elsewhere. These included:

1. New, Fisheries Research Development Corporation (FRDC) project entitled "Modelling environmental changes and effects on wild-caught species in Queensland" was approved in November 2019. The project is led by CARM's **J.A. Filar**, joint with a team of collaborators from UQ, the Department of Agriculture and Fisheries and the Australian Institute of Marine Science. The project aims to identify and measure the effects of environmental drivers on several key Queensland fishery species – snapper, pearl perch, and spanner crab: https://www.uq.edu.au/news/article/2020/01/how-do-environmental-factors-impact-queensland%E2%80%99s-fisheries .
2. New, ARC Discovery project entitled "Partially Observable MDPs, Monte Carlo Methods, and Sustainable Fisheries" was approved in December 2019. The project is led by D. Kroese from the School of Mathematics and Physics in collaboration with **J.A. Filar**, N. Ye, H Kurniawati (ANU) and M. Bohner (MST, USA). This project aims to develop new efficient Monte Carlo algorithms to significantly advance the application of partially observable Markov decision processes to real-world decision problems. Both theoretical and algorithmic approaches will be applied to sustainable fishery management --- an important problem for Australia.
3. Continuing, 2019-2021 ARC Discovery project entitled "Future fisheries under climate change: the missing role of zooplankton" led by CARM's **A.J. Richardson,** joint with a team of collaborators**.** This project aims to develop the first global ecosystem model with a more realistic representation of zooplankton. Fish are the main source of protein for 3 billion people, yet fish catches are declining. Current models of future fish biomass under climate

[1] The vision for CARM was conceived by the department and Professors Hugh Possingham and Anthony Richardson some two years before Professor You-Gan Wang became the Foundation Director in 2010.

change do not consider the complex role that zooplankton play in transferring energy from phytoplankton to fish. By resolving the link between phytoplankton and fish, this project will vastly improve estimates of future global fisheries production and regional variation. Such knowledge is vital for future food security in Australia and globally, and also for understanding the role of zooplankton in carbon export in the ocean.

4. Continuing, 2019-2021 ARC DECRA project entitled "The value of model complexity for fisheries management" by CARM's **M. Holden.** This project aims to quantify the benefits of using dynamic multi-species models for harvest decisions. Expected outcomes of the project include: 1) guidance for fisheries scientists on when to use multi-species models for management, 2) improved decision making to reduce the risk of fishery collapse, 3) a new method for dynamic model validation in the face of limited data, and 4) enhanced collaboration between modellers and applied agencies.
5. Completed, Fisheries Research Development Corporation (FRDC) Project titled, "Stock predictions and spatial population indicators for Australia's east coast saucer scallop fishery" joint with M.F. O'Neill, A.J. Courtney, G. Leigh., M.J. Campbell (DAF) **W-H, Yang, J. Filar** (CARM). This project improved spatial indicators and stock model predictions to estimate the current population size of saucer scallops and develop management procedures.
6. Completed, Australian Fisheries Management Authority (AFMA) funded project led by CSIRO titled, "Harvest strategies for the Torres Strait Finfish fishery". Joint with T. Hutton (CSIRO); M.F. O'Neill, G. Leigh (DAF); A. Tobin (Tobin Fish Tales); **K. Basford, J. Filar** and **M. Holden** (CARM). The project contributed to defensible and robust management decisions including the potential mechanisms for fishery expansion. This will assist in a development of a sustainable harvest strategy that is ratified by management agencies and Islanders**. Dr Holden** had a key quantitative modelling role in this project.
7. Continuing, 2018-2020 ARC Discovery project entitled "Time consistency, risk mitigations and partially observable systems" will involve **J. Filar's** collaboration with SMP colleagues and distinguished international partner investigators. This theoretical investigation is inspired by the problem arising in sustainable management of fisheries: design harvest policies that, consistently, minimize the risk of fishery collapse. Research Fellow **M. Jansen** who recently received his PhD from the University of Amsterdam has joined the research team.
8. **S. Streipert** was the lead author of DAF's most recent stock assessment model for Barramundi, an iconic Queensland species that is a target of both commercial and recreational fishers; see http://era.daf.qld.gov.au/id/eprint/7003/ . She was also involved in theoretical investigations of dynamical systems and risk analysis.
9. The Introduction to R workshop was held on 5th February 2019 with Professor **Anthony Richardson**, Associate Professor Chris Brown and Professor Dave Schoeman. The trio then held the Intermediate to R Workshop from the 6th – 7th February 2019 and a new workshop ggplot/spatial analysis with R Workshop. The focus throughout was on ecological applications and particularly marine habitats. Dr Bill Venables conducted the Advanced R Workshop from 5th – 7th February 2019.
10. CARM hosted the Satellite Workshop Applied^2 Probability at St Lucia on the 2nd July, 2019. The Organizing Committee consisted of Ivo Adan, Konstanin Avrachenkov, John Boland, Mark Fackrell, **Jerzy Filar**, David Goldberg, **Matthew Holden, Roxanne Jemison**, Ross McVinish and Joshua Ross.
    Professor Jenny Seddon, Associate Dean Research & Deputy Executive Dean, Faculty of Science, The University of Queensland opened this workshop themed, "Uncertainty quantification applications" to an interested crowd of 90 attendees. The survey feedback was positive and attendees particularly liked the diversity of sessions and talks.
11. Two of CARM's PhD students graduated in 2019. **Ryan Heneghan** who was supervised by **A.J. Richardson** took up an International Postdoctoral Fellowship at the Autonomous University of Barcelona, Spain. **Maria Kleshnina,** who was supervised by **J. Filar**, took up a

prestigious IST plus Postdoctoral Research Fellowship at the Institute of Science and Technology in Vienna, Austria. This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement No 754411.

Growing national and international recognition in applications of natural resources mathematics.

CARM's researchers continued to disseminate their results in high quality international journals. In 2019/20, CARM's output of 7 book chapters, 2 edited books, 26 journal articles and 1 conference paper included many high-impact publications, focusing on the impact of climate change on biodiversity and the role of protected areas as well as on some more foundational problems of mathematical sciences. The latter included papers in Science, Nature Ecology & Evolution, Journal of Mathematical Biology and Journal of Mathematical Analysis and Applications. Importantly, CARM researchers co-authored 4 significant technical reports with our industry partners. These address important practical issues in Queensland's fisheries. A complete list is supplied at the end of this report.

In addition we highlight a few less tangible but also significant developments that are serving to further raise CARM's national and international profile. These include:

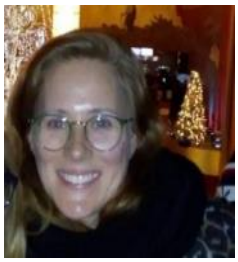
- In 2019, CARM and UQ were acknowledged in the 2018 ARC Engagement and Impact Assessment as having 'high' impact in the Mathematical Sciences. UQ was one of only five institutions to receive a rating of 'high' impact in this FOR code, and one of only two Go8 institutions. The impact study document was prepared by **J.Filar** and **R. Jemison**.
- **Jerzy Filar** was a plenary speaker at the 2019 World Conference on Natural Resource Modelling held in Montreal, Canada, May 22-24, 2019.
- **Sabrina Streipert** and **Matthew Holden** presented talks titled respectively, "An age-structured population model for lates calcarifer" and "Probability of misidentifying population declines and recoveries using linear models" at the 2019 World Conference on Natural Resource Modelling, Montreal, Canada, May 22-24, 2019.
- **Matthew Holden** was invited to speak at the Universitas 21 Early Career Researcher Workshop in Shanghai, China and presented, "The benefit of demand reduction campaigns to reduce poaching". As an indication of Matthew's growing reputation, in 2018, Fellow of the Royal Society, Professor Andrew Balmford, at Cambridge University, sought out Dr Holden and has started an active collaboration with him.
- CARM houses the editorial office of Springer's Environmental Modeling and Assessment, where **J. Filar** serves as editor-in-chief. Serendipitously, a member of the journal's editorial board, Professor W.D. Nordhaus, received the 2018 Nobel Prize in Economics for his fundamental work on climate change.

Current Staff

Jerzy Filar: Director (December 2016-present)
Professor Filar is a Professor of Applied Mathematics in the School of Mathematics and Physics at UQ. Prior to joining UQ he was Strategic Professor of Mathematics and Director of Flinders Mathematical Sciences Laboratory. A Fellow of the Australian Mathematical Society, Jerzy is a broadly trained applied mathematician with research interests spanning a wide spectrum of both theoretical and applied topics in Operations Research, Applied Probability, Environmental Modelling, Optimisation, Game Theory and Perturbation Analysis. He spent the first thirteen years of his academic career in the US, which included long-term consulting for the Environmental Protection Agency in Washington. He is the editor-in-chief of Springer's Environmental Modelling and Assessment.

Anthony Richardson: Deputy Director (2010 - present)
Professor Richardson is a mathematical ecologist with a joint position between UQ and CSIRO Oceans and Atmosphere. Anthony has research interests in understanding human impacts on marine systems and how we can improve their management and conservation. He uses statistical and mechanistic ecosystem models to understand marine systems currently, and then projects these models into the future under different climate change and fishing scenarios. He has made significant contributions to describing how marine species are responding to climate change and was the first to show changes in the timing of marine species. His current research focus is on how climate change could affect the movement of biodiversity and functioning of marine systems, and where we might best place protected areas, fish differently, or use other approaches to conserve ecosystems.

Matthew Holden: Research Fellow (June 2017 – present)
Matthew's research program integrates the fields of mathematics, theoretical ecology, fisheries management, and conservation. Matthew uses dynamic models and decision theory to improve conservation planning when conservation benefits depend on how humans modify their behaviour in response to policy. He earned his PhD in Applied mathematics at Cornell University, winning a National Science Foundation Graduate Research fellowship to work on optimization problems in fisheries management, invasive species control, and sustainable agriculture. He received his bachelor's degree from the University of California, Davis, where he won the University Medal, working on the effect of habitat fragmentation on species persistence.



Sabrina Streipert: Research Fellow (October 2017 – October 2019)
Sabrina received a Diplom (Master) in Mathematical Economics from the University of Ulm and a Master of Applied Mathematics from the Missouri University of Science and Technology (MST). Her PhD research at MST focused on the analysis of dynamical systems on time scales with applications in population dynamics and epidemiology. After receiving her PhD in Applied Mathematics in 2015, she became a Research Associate in the Department of Psychiatry at the University of Wisconsin-Madison, working on the mathematical theory of Consciousness.

Wen-Hsi Yang: Research Fellow (June 2016 – present)
Dr Wen-Hsi Yang is a CARM Research Fellow with previously held positions in CSIRO, U.S. Geological Survey, Institute of Space Science, National Central University. Wen-Hsi received his bachelor's degree and Master's degree at the National Central University, Taiwan and earned his PhD in statistics at the University of Missouri. Wen-Hsi has research interests in statistical analysis, modelling and theory for spatial, temporal and spatio-temporal data, in particular for fisheries data.

Marijn Jansen: Research Fellow (July 2018 – present)
Marijn studied mathematics at VU University in Amsterdam. After that, was a PhD student in applied probability, jointly at Ghent University and the University of Amsterdam. Marijn joined CARM as a postdoctoral researcher and works on partially observable systems.

Jason Everett: Senior Research Fellow (June 2019 – present)
Jason is a biological oceanographer, with an interest in how oceanographic processes structure planktonic ecosystems. His research has focused on how flow regimes, boundary currents, eddies and upwelling events drive changes in the biomass, species distribution and size structure of zooplankton communities. In addition, he has extensive experience working with satellite data and numerical model output.

Roxanne Jemison: Centre Administrator (March 2017 – present)
Roxanne has held positions throughout UQ in the Schools of Medicine, Economics and the Biomedical Sciences and completed her MBA in 2019. Roxanne has interests in preserving our natural resources for future generations.

Kaye Basford: Interim Director (October 2015 – November 2016)
Professor Basford is a Professor of Biometry in the School of Agriculture and Food Sciences at UQ and holds directorships with the Australian Academy of Technological Sciences and Engineering, Crawford Fund Limited, and Grains Research Foundation Limited.

Alexander Campbell: Adjunct Senior Lecturer (2016 - present)
Dr Alexander Campbell is a computer scientist and applied mathematician with ten years experience in fisheries stock assessment. He specialises in continuum approaches to population modelling (i.e. partial differential equations) and dynamical systems approaches to uncertainty characterisation (e.g. shadowing).

Roger Cropp: Adjunct Associate Professor (2019 - present)
Dr Roger Cropp was a member of the School of Environment at Griffith University where he taught into the Marine Science program. Roger's primary research interests are in theoretical ecology, in particular the development and deployment of a resource-based approach to modelling population interactions. This theory has applications in the dynamics of persistent organic pollutants in marine ecosystems and marine mammals, the role of marine plankton ecosystems in the production of climatically important gases, and understanding how populations adapt and ecosystems change.

PhD Completions

Tina Berry (with Curtin University)
Molecular genetics of zooplankton
(Curtin University: approved September 2019)

Ryan Heneghan
Resolving the role of zooplankton in the marine ecosystem with functional size spectra
(University of Queensland; approved February 2019)

Maria Kleshnina
Incompetence and evolutionary dynamics
(University of Queensland; approved February 2019)

Honours Completions

Jakeb Lockyer

A dynamical systems approach to modelling management and enforcement to reduce elephant poaching for ivory (University of Queensland; approved November 2019)

Samuel Nolan

Optimal harvest of populations governed by stochastic difference equations (University of Queensland; approved November 2019)

Current PhD Students

Amelia Armstrong
Population genetics and movement of manta rays in Eastern Australia and the South Pacific

Asia Haines (Armstrong)
Ecology of Reef Manta Rays *Mobula alfredi*: Habitat Use, Threats and Connectivity

Manuela Mendiolar
Fishery dependent monitoring of Queensland fisheries

Jacob Rogers
Developing models of intermediate complexity for ecosystem assessment (MICE) for Australian marine ecosystems: Managing fisheries and climate change

Philip Dyer
Global biodiversity, climate change and marine protected areas

Sarah Pausina
Resilience of Moreton Bay to climate change: Links between nutrient inputs and plankton dynamics

Patrick Sykes
Using size spectrum models to understand fisheries productivity in the ocean now and in the future

Chris Lawson
Bioenergetic of elasmobranchs

Jody McKerral (with Flinders University)
Universal laws in ecological systems

Isaac Brito Morales
Climate velocity and the effects on marine protected areas

Zhihao Qiao
The impact of climate change and geoengineering on marine biodiversity

Anura Ratnasiri
Surveillance of low birthweight, preterm deliveries and infant mortality in California, 2006-2013: Application of multivariable statistics to explore socioeconomic status by maternal morbidity interactions

Current MPhil Student

Rosemary O'Connor (MPhil)
The impact of climate change and geoengineering on marine biodiversity

Current Honours Students

Erin Medland

Improving the stability of a system of non-linear PDEs

Nick Outram

Maximum economic versus sustainable yield in multiplicative harvest models

Bryce Stansfield

Numerical solutions of a system of non-linear PDEs

Research Grants

(includes grants initiated outside of CARM that involve CARM co-investigators).

ARC – DECRA

M. Holden. (2019 – 2021). *The value of model complexity for fisheries management. ARC DECRA $329,538*

ARC – Discovery

D.Kroese, **Filar, J.,** Ye, N., Kurniawati, H., Bohner, M. (2020-2022).
Partially observable MDP's, Monte Carlo methods, and sustainable fisheries. ARC Discovery: $365,000.

A.Richardson., J. Blanchard., D. Schoeman., R. Watson., I. Suthers., D. Tittensor., A. Lenton. (2019 – 2022).
Future fisheries under climate change: the missing role of zooplankton. ARC Discovery: $493,000.

J.A. Filar, Y. Nazarathy, T. Taimre, V.Borkar, M. Mandjes*. (2018-2021). Time consistency, risk-mitigation and partially observable systems*. ARC Discovery: $386,828.

ARC – Linkage

Bennett, M., Ovenden, J., **Richardson, A.J.**, Townsend, K., Dudgeon, C., van Keulen, M., McGregor, K., Nichols, C., Carter, D. (2016-2020). *Distribution, connectivity and sustainability of manta ray populations: Species of national ecotourism value and conflicting international pressures.* ARC Linkage: $510,000.

Other

Filar, J., Courtney, A., Campbell, M., Leahy, S., **Yang, W-H**., Robson, B., Steinberg, C., Williams, S., Ye, N. (2019 - 2021). Modelling environmental changes and effects on wild-caught species in Queensland. FRDC $298,704.

Richardson, A. (2019-2021). The effect of blue water marine protected areas on pelagic ecosystems. The Nature Conservancy Limited. $246,957.

Teaching and Supervision

Collectively, CARM staff have a wealth of specialised knowledge and skills in research areas in which there is a recognised skills shortage both nationally and internationally. We were invited and pleased to contribute to teaching established undergraduate courses in the School of Mathematics and Physics.

We have also expanded student learning opportunities through the introduction of new courses such as our "flagship" course in Natural Resource Mathematics, a special topic in longitudinal data analysis, and a reading course in Bayesian statistics which was run in response to student demand. CARM is also contributing to the teaching of a large "Theory & Practice in Science" undergraduate course. This foundation course in science introduces students to the broad range of mathematical, analytical, conceptual and computational tools employed by scientists to develop, analyse and interpret models of scientific processes. These courses help to bridge a crucial gap in students' training, that is, the gap between mathematical theory and the ability to apply it in real world or workplace settings.

As well as undergraduate teaching, we also provide expert supervision to research students (from mathematics and other disciplines) who may not otherwise have been able to access this knowledge. For example, CARM staff have provided training in the highly specialised area of state-space modelling to UQ research students. This methodology was applied to the significant problems of modelling Queensland fish movements and building Bayesian economics models, and was achieved through CARM's collaboration with students working in environmental sciences and economics, respectively.

Mathematical skills will be in even more demand in the future as technology advances rapidly and pressure on natural resources increases. In this way, CARM's active and enthusiastic role in helping to train new generations of scientists in these fields not only brings value to this leading institution, but also strengthens the key capacities that will ensure that our graduates will continue to make Australian scientists internationally competitive into the future.

Natural Resource Mathematics – CARM Flagship Course

MATH3070 Natural Resource Mathematics. Semester 2 (since 2017). **Filar, J., Holden, M., Leigh, G., Richardson, A. Streipert, S**. Students taking this course learn to: apply modern mathematical and statistical methods for dynamic systems; model populations and investigate impacts of climate change, overfishing, pollution and habitat destruction; and communicate their work to scientists and decision makers. All practicals are delivered in MATLAB. CARM members have designed the course so students will be employable in a number of growing fields of natural resource management and conservation, especially with State and Federal Governments, universities and NGOs

Other Courses

SCIE1000 Theory and Practice in Science. Semesters 1 and 2 (since 2014). Adams, P., O'Donoghue. P. and **Richardson, A.J.** This is a strongly recommended first year course for all science students.

MARS3012 Physical-Biological Oceanography. Semester 1 (since 2012). **Richardson, A.J.** and Weeks, S. This is an Introduction to Oceanography course that covers physical, chemical and biological oceanography, including remote sensing.

Potential PhD, Masters and Honours Projects

CARM has a diverse suite of potential higher degree research projects on offer. Depending on the background and interests of candidates, the scope of many of these projects could be tailored to correspond to PhD, Masters and Honours level theses. In most cases the ensuing investigations will involve teamwork and collaboration with researchers from other organisations, especially from our industry partner Department of Agriculture and Fisheries.

Could geoengineering the atmosphere to minimize global warming compromise global fisheries?
Supervisor: Professor Anthony Richardson

With global warming accelerating, scientists are exploring mitigation options including geoengineering. One approach is to pump small particles of sulphur dioxide into the upper atmosphere to reflect the sun's energy back into space. This will cool the planet but the shading of the planet could reduce marine productivity and thus global fisheries. We are looking for a mathematics student interesting in learning to model marine ecosystems using partial differential equations. This is part of an Australian Research Council Discovery Project, and travel to a national and international conference or workshop will be supported as part of the project.

Fishery-dependent monitoring of Queensland's fisheries
Supervisor: Professor Jerzy Filar

Review and evaluate efficient sampling programs: Is the right amount of sampling occurring for each species? Are there any significant biases in the sampling programs for each species? Assess whether routine analyses are being carried out correctly and develop new analyses for fisheries management. Project components include developing: Quantitative analyses to optimise fishery-dependent sampling across multiple species and regions. Routine methods for assessing precision of current sampling of fish length and age. New methods for turning fish length and age data into advice (indicators) about fishing pressure and the status of fish stocks. Develop corresponding harvest strategies and reference points for judging the performance of the indicators.

Forecasting future global fisheries production under climate change using systems of differential equations
Supervisor: Professor Anthony Richardson

The student will develop state-of-the-art size spectrum models – based on systems of DEs – for the plankton and fish in the global ocean. These will be solved by using ode solvers in R. The models will then be forced by climate change scenarios to see how many fish are likely to be in the ocean in the future, how their distributions could change, and how this would affect the fish catch in nations of the world. As wild fisheries and aquaculture provide >3 billion people with 20% of their protein intake, forecasting future global fisheries is a real-world and pressing problem.

Generalised linear and additive modelling of impacts of climate change
Supervisor: Professor Anthony Richardson

This applied statistical PhD involves advanced multivariate statistical techniques applied to global marine datasets. The aim is to estimate the current and future distribution of marine life under a changing climate. The student needs a background in applied statistics and an interest in the natural world. The project will support travel to an international conference during the PhD.

How can we conserve marine biodiversity at different depths in the ocean under a warming climate?
Supervisor: Professor Anthony Richardson

With biodiversity globally in decline, and a strong international push to increase the area of the ocean protected to 30% by 2030, more large blue-water (far from the coast) Marine Protected Areas (MPAs) are being declared. However, there is still little consideration of climate change when MPAs are declared and where they are located. We know that global warming will alter the distribution of species, but at different speeds and directions at different depths in the ocean, complicating the designation of MPAs. This PhD involves using multivariate statistical techniques applied to model global marine species distributions in 3D. The aim is to estimate the current and future distribution of marine life under a changing climate and how best to protect it. The student needs a background in statistics or quantitative ecology and an interest in the natural world. The project will support travel to an international conference during the PhD.

How could marine heatwaves impact marine biodiversity in the future?
Supervisor: Professor Anthony Richardson

The common perception is that climate change is gradual and that its impact on natural and human systems is similarly incremental. However, there is increasing evidence that climate change is increasing the severity and frequency of extreme climate events, including heatwaves, such as coral bleaching on the Great Barrier Reef. This project will explore how the frequency and intensity of marine heatwaves will change in the future and the implications for marine life. The student will use state-of-the-art CMIP6 General Circulation Models (GCMs) that have daily estimates of temperature from the present to the year 2300. The student will need to develop statistical and/or differential equation models to describe impacts of heatwaves on marine life, and drive these using GCM output. GCMs are advanced Earth System Models and experience with these models will set up the student for future work in research, Government agencies and the private sector. We are looking for a student with solid mathematical and/or statistical expertise.

Queensland state-wide estimation of recreational fish catches
Supervisor: Professor Jerzy Filar

Improved estimation of state-wide recreational harvests, including resampling, bootstrap and MCMC techniques. Quantify changes in survey angler avidity and recall bias between survey years and methodologies; adjust previous survey data to obtain improved estimates. Evaluating sampling frames - develop methods to generate state-wide harvest estimates (and associated measures of uncertainty) from several synchronous samples taken from different sampling frames (e.g. a licence frame and a residential telephone number list). Develop hierarchical and conditional mixed models for estimation of recreational fish catch and catch rates. Investigate the statistical modelling of recreational survey data collected from multiple survey methods. From survey to analysis: dealing with differences in the scale at which survey data are collected and the scale at which data are analysed. Examine appropriate estimation methods for different fish species. Develop statistical methods for low fish abundance or recreational species caught by ‘hard-to-reach’ fishers. Develop methods to engage and retain recreational fishers in volunteer data contribution programs.

Risk and uncertainty quantification in environmental modelling
Supervisor: Professor Jerzy Filar

Mathematical models of environmental problems often demand understanding of complex dynamics and interactions between many physical and biological variables on the one hand, and human inputs on the other. Uncertainties accompanying such models stem from multiple sources. Sometimes they manifest themselves as cascading errors and at other times they involve the risk of key variables crossing undesirable thresholds. In both cases they undermine confidence in either the model or, worse still, the underlying science.

The accompanying mathematical problems can be studied using a wide range of approaches including (but not limited to) perturbation theory, stochastic processes, partially observable Markov decision processes, statistical methods, dynamical systems and simulation. They can also be applied in several important contexts including (but not limited to) conservation of natural resources, optimizing harvests of fish subject to sustainability constraints or generating warning signals for species whose abundance drops to low levels. One particularly challenging problem is that of designing controls that minimize the probability of a catastrophe, consistently over time, while achieving satisfactory and sustainable resource consumption. A related problem, also stemming from fishery science applications, is that of devising a “balanced harvest” strategy that ultimately restores the proportions of age cohorts of the harvested species to those that are natural for that species.

Size spectrum modelling in the ocean using systems of differential equations
Supervisor: Professor Anthony Richardson

This applied mathematics PhD involves modelling the marine ecosystem from bacteria to whales using systems of ordinary differential equations and numerical techniques to solve them. The aim is to estimate the number of fish in the oceans and how much can be harvested. The student needs a background in applied mathematics and an interest in the natural world. The project will support travel to an international conference during the PhD.

Stability analysis of a complex ecosystem model
Supervisor: Professor Anthony Richardson

Size spectrum models represent marine ecosystems from plankton to fish and include processes such as climate change and fishing. They are based on systems of partial differential equations and are often unstable, with waves propagating through the model. We are looking for a strong applied or theoretical mathematics student to perform a stability analysis on a size spectrum model, finding the parameter space where the model is stable, and reconfiguring the model to improve stability. This is part of an Australian Research Council Discovery Project, and travel to a conference in Australia will be supported as part of the project.

Statistical modelling of biodiversity in the ocean
Supervisor: Professor Anthony Richardson

This applied statistical PhD involves advanced multivariate statistical techniques applied to global marine datasets. The aim is to estimate the current and future distribution of marine life under a changing climate. The student needs a background in applied statistics and an interest in the natural world. The project will support travel to an international conference during the PhD.

Time-series analysis of suspended solids and nutrients entering the Great Barrier Reef
Supervisor: Dr Alan Huang

The Australian and Queensland governments commenced the Reef Water Quality Improvement Plan in 2003 with the aim of decreasing the annual loads (total mass) of suspended solids and nutrients entering the lagoon of the GBR. While there has been extensive monitoring of these pollutants at up to 38 sites for up to 13 years, progress in reducing loads has been based on modelling. This project will use time-series methods to analyse water quality monitoring data to determine if loads have remained static, have improved or got worse. Opportunities for new

methodological advances in multivariate time-series analysis with varying sampling frequencies will be key to this project. The findings of this work will be of great interest to the Australian and Queensland governments, researchers in general and will feed into on-going development of policy. We expect that the results would be published in a scientific journal. This honours project is available to start in first semester, 2020. A stipend of $5 000 will be paid to the successful candidate who undertakes this project.

Using systems of partial differential equations to understand changes in tuna fisheries in response to climate change
Supervisor: Professor Anthony Richardson

Tuna fisheries are some of the biggest, most valuable and iconic globally, but are found in the marine equivalent of deserts on land. How the marine food web supports these productive fisheries is an open question, as is how these fisheries will respond to climate change. This project will answer these questions by modelling the global marine ecosystem from bacteria to whales using size spectrum models, based on systems of partial differential equations. The successful student needs a background in applied mathematics and an interest in the natural world.

The successful student will be part of the Mathematical Marine Ecology research lab at the University of Queensland. This project comes with a tuition scholarship and a living stipend of $27,596 per annum tax-free (2019 rate), indexed annually. The scholarship is for 3 years with the possibility of two 6-month extensions. Domestic and international students are welcome to apply. The project will support travel to an international conference during the PhD.

Workshops and Conference Presentations

CARM staff have presented their research results at national and international conferences.

- **Matthew Holden** session chair, ANZIAM Conference, New Zealand, 4th February, 2019.
- **Matthew Holden** presented a talk titled, “Can population dynamic models improve species occurrence predictions?” ANZIAM Conference, New Zealand, 7th February, 2019.
- **Sabrina Streipert** presented a talk titled, “An age-structured population model for lates calcarifer.” 2019 World Conference on Natural Resource Modelling, Montreal, Canada, 22nd May, 2019.
- **Sabrina Streipert** session chair, 2019 World Conference on Natural Resource Modelling, Montreal, Canada, 23rd May, 2019.
- **Matthew Holden** presented a talk titled, “Probability of misidentifying population declines and recoveries using linear models.” 2019 World Conference on Natural Resource Modelling, Montreal, Canada, 23rd May, 2019.
- **Jerzy Filar** presented a plenary lecture titled, “Threshold risk and uncertainty quantification in environmental modelling.” 2019 World Conference on Natural Resource Modelling, Montreal, Canada, 24th May, 2019.
- **Jerzy Filar** presented an invited talk titled, “Threshold risk and uncertainty quantification in environmental modelling.” AMSI OPTIMISE, Perth, Australia, 19th June, 2019.
- **Jerzy Filar** presented a talk titled, “Threshold risk and uncertainty quantification in environmental modelling.” Queues, Modelling, and Markov Chains: A Workshop Honouring Professor Peter Taylor, Mount Tamborine, Brisbane, Australia, 29th June, 2019.
- **Matthew Holden** session chair, Satellite Workshop Applied^2 Probability, Brisbane, Australia 2nd July, 2019.
- **Matthew Holden** presented a talk titled, “Predicting the outcomes and cost-efficacy of anti-poaching interventions under extreme uncertainty.” Satellite Workshop Applied^2 Probability, Brisbane, Australia 2nd July, 2019.
- **Jerzy Filar** session chair, Satellite Workshop Applied^2 Probability, Brisbane, Australia 2nd July, 2019.
- **Wen-Hsi Yang** session chair, Satellite Workshop Applied^2 Probability, Brisbane, Australia 2nd July, 2019.
- **George Leigh** session chair, Satellite Workshop Applied^2 Probability, Brisbane, Australia 2nd July, 2019.

- **Jerzy Filar** presented a talk titled, ”Uncertainties in an age-structured population model for Barramundi.” Satellite Workshop Applied^2 Probability, Brisbane, Australia 2nd July, 2019.
- **Wen-Hsi Yang** presented a talk titled, “Spatially and environmentally based quantitative assessment of the Queensland Saucer Scallop Fishery.” Satellite Workshop Applied^2 Probability, Brisbane, Australia 2nd July, 2019.
- **George Leigh** presented a talk titled, “How do we know whether a fishery is sustainable when the main action took place before the records began?” Satellite Workshop Applied^2 Probability, Brisbane, Australia 2nd July, 2019
- **Marijn Jansen** presented a talk titled, “The asymptotic behavior of the time-varying supermarket model.” INFORMS APS 2019, 4th Brisbane, Australia, July, 2019
- **Jerzy Filar** presented a talk titled,”Taxonomy of Uncertainties in Mathematical Models of the Environment.” INFORMS APS 2019, Brisbane, Australia 4th July, 2019
- **Matthew Holden** presented a talk, “Predicting the outcomes and cost-efficacy of anti-poaching interventions.” International Congress on Conservation Biology, Kuala Lumpur, Malaysia, 24th July, 2019.
- **Jerzy Filar** presented an invited talk, “Threshold risk and uncertainty quantification in environmental modelling.” Monash Centre for Modelling of Stochastic Systems, Monash University, Melbourne, 19th September, 2019.
- **Matthew Holden** presented an invited talk, “The dynamics of wildlife crime.” Applied Mathematics Seminar, University of Sydney, 23rd October, 2019.
- **Wen-Hsi Yang**, presented a talk titled, “Doing Stock Assessment Using ADMB, Stock Synthesis or TMB? A Case Study on the Queensland Saucer Scallop.” CAPAM Next Generation General Stock Assessment Model Workshop, Wellington, New Zealand, 4th November, 2019.
- **Marijn Jansen**, presented a talk titled, “The asymptotic behavior of the time-varying supermarket model.” 63nd Annual Meeting of the Australian Mathematical Society, Melbourne, Australia, 6th December, 2019.
- **Zhihao Qiao** presented a talk titled, “POMDP’s for sustainable fishery management.” MODSIM2019, Canberra, Australia, 3rd December 2019.

Seminar Series

To better engage with staff in the School of Mathematics and Physical Sciences, CARM has been running research seminars jointly with the Statistics, Modelling and Operations Research (SMOR) groups.

During the last 12 months our seminars included the following:

- **Dr Chanjuan Liu,** School of Economics and Management, Shanghai Maritime University (13 August, 2019), Natural mortality estimation using tree-based ensemble learning methods.
- **Philip Dyer,** The University of Queensland (8 October, 2019). Modelling biodiversity in the oceans for conservation and management.
- **Dr Nan Ye,** The University of Queensland (14 October, 2019), The wisdom of the crowd: ensemble learning and multi-modal imitation learning. Maths Colloquium
- **Distinguished Professor Noel Cressie,** University of Wollongong (18 November, 2019). Atmospheric carbon and the statistical science of measuring, mapping, and uncertainty quantification. Maths Colloquium

Major Collaborations

With DAF

Modelling environmental changes and effects on wild-caught species in Queensland
Objective: The project has three key objectives: (1) Find indices of association between measures of abundance and key environmental drivers; (2) Use these indices to enhance the existing stock assessment model for each species; and (3) Enable forecasting of environmentally driven fluctuations in targeted species' abundance, including enhancing Management Strategy Evaluations (MSEs).

Stock predictions and spatial population indicators for Australia's east coast saucer scallop fishery
Objective: This FRDC funded project aims to improve mortality rate estimates for management of the Queensland saucer scallop fishery.

Harvest strategies for the Torres Strait Finfish fishery
Objective: The CSIRO led project, funded by AFMA, will contribute to defensible and robust management decisions including the potential mechanisms for fishery expansion. It will assist in a development of a sustainable harvest strategy that is ratified by management agencies and Islanders.

Assessments of the status of Queensland's east coast and Gulf of Carpentaria shark fisheries
Objectives: (i) Develop standardised indices of abundance for the major species/taxa; (ii) Reviewing monitoring strategies and developing assessment modelling tools; (iii) Reviewing the status of the "stock" in relation to the commercial catch quota; (iv) Develop empirical management procedures.

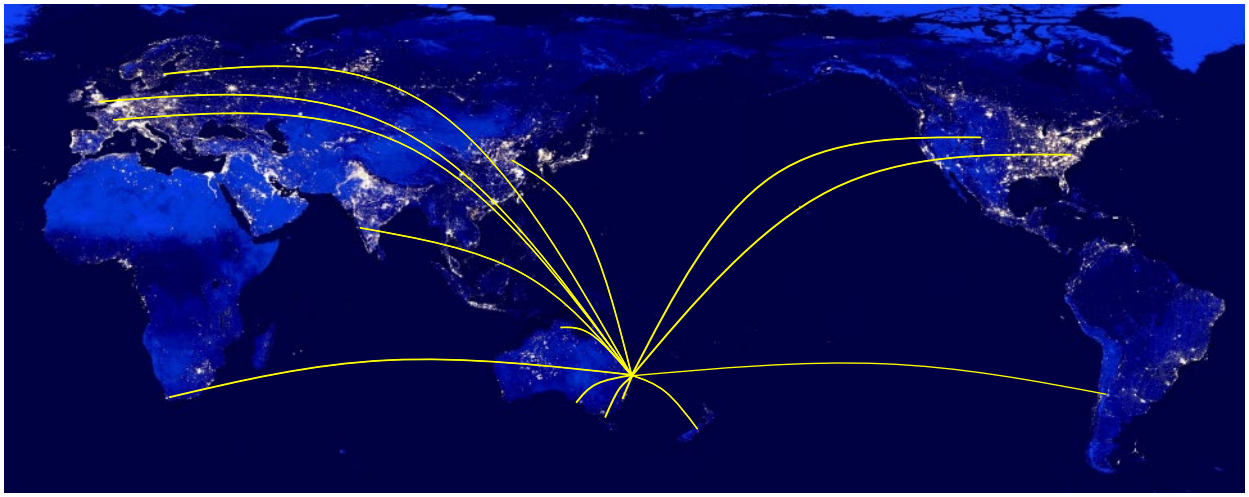
Estimation of recreational fish catches
Objectives: (i) Develop hierarchical and conditional mixed models for estimation of recreational fish catch and catch rates; (ii) Investigate the standardisation of recreational survey data collected from multiple survey methods; (iii) From survey to analysis: dealing with differences in the scale survey data are collected at and the scale data are analysed at, (iv) Assess changes in angler avidity and recall bias between survey years and methodologies; (v) Examine appropriate estimation methods for different species; (vi) Develop methods for low abundance or recreational species caught by 'hard-to-reach' fishers.

Fishery-dependent monitoring of Queensland's fisheries: Reviewing routine collection of length and age data, and routine analysis
Objectives: Review and evaluate efficient sampling programs: Is the right amount of sampling occurring for each species? Are there any significant biases in the sampling programs for each species? Assess whether routine analyses are being carried out correctly, and to develop new analyses for fisheries management.

Physical oceanographic influences on Queensland reef fish and scallops
Objectives: (i) review recent advances in the study of physical oceanographic influences on fisheries catch data and describe the major potential influences on Queensland reef fish and saucer scallops; (ii) collate Queensland's physical oceanographic and fisheries data; (iii) develop stochastic population dynamics models for reef fish and saucer scallops, which can link environmental influences (e.g. sea surface temperature) to catch rates, biological parameters (e.g., growth, reproduction, natural mortality) and ecological aspects (e.g., spatial distribution); (iv) forecast the dispersion of reef fish and scallop larvae in the southern GBR region.

East Queensland grey mackerel stock assessment
Objective: Develop a regional, sex- and age-structured population model for the east Queensland grey mackerel; estimate east coast wide and regional quota levels; suggest regional management responses.

Other External Collaborations



Australia

- CSIRO
- Institute of Geography and Limnology, Charles Darwin University
- University of New England
- University of Adelaide
- University of Melbourne
- Queensland University of Technology
- University of Sydney
- University of the Sunshine Coast
- Flinders University
- Queensland Department of Agriculture and Fisheries

Overseas

- Chinese Academy of Sciences, China
- Harvard University, USA
- Landcare Research, New Zealand
- AgResearch, New Zealand
- Swedish University of Agricultural Sciences, Sweden
- University of Glasgow, UK
- University of the Western Cape, South Africa
- University of Cape Town, South Africa
- Sir Alister Hardy Foundation for Ocean Science, UK
- University of Alberta, Canada
- UC Santa Cruz and NOAA
- INRIA, Sophia-Antipolis, France
- IIT, Mumbai, India
- Universiteit van Amsterdam, The Netherlands
- Center for Mathematical Modeling (CMM), Chile
- National Institute for Mathematical and Biological Synthesis, USA
- MIRA Research Group, France

Within UQ

School of Mathematics and Physics
Joint supervision of PhD and honours students, joint research projects, lectures

School of Geography Planning and Environmental Management
Joint supervision of PhD and honours students, lectures

School of Biological Sciences
Joint supervision of PhD and Honours students, lectures and joint UQ FirstLink Genetic stock assessment of Queensland and New South Wales snapper (Pagrus auratus) fishery

School of Agriculture and Food Sciences
Joint supervision of PhD students and AFMA funded project, "Harvest strategies for the Torres Strait Finfish fishery".

ARC Centre of Excellence for Environmental Decisions (CEED)
Research collaborations and joint supervision of PhD and Honours students

External Service, Engagement and Awards

Jerzy Filar

- Editor-in-Chief: Environmental Modeling and Assessment, Springer.
- Associate Editor: Journal of Mathematical Analysis and Applications, Elsevier.
- Associate Editor: Dynamic Games and Applications, Springer.
- Associate Editor: Applicationes Mathematicae, Polish Academy of Sciences.
- Associate Editor: International Game Theory Reviews, World Scientific.
- Served as Chair of the Awards and Medals Selection Committee of ASOR (Australian Society of Operations Research).

Kaye Basford FTSE, FAICD, FIS, FQA

- Deputy Chair, Board of Trustees of the International Rice Research Institute (IRRI)
- Vice President, Australian Academy of Technological Sciences and Engineering (ATSE)
- Director, Crawford Fund Limited (and Chair of the Queensland Committee)
- Member, UQ Union College Board
- Associate Editor, *Crop and Pasture Science*
- Life member, International Biometric Society
- Life member, Statistical Society of Australia Incorporated

Anthony Richardson

- Editorial Board: Journal of Plankton Research
- Head , Australian Continuous Plankton Recorder Survey
- 2018 Global Highly Cited Researcher list. This list recognizes researchers who have produced highly cited papers that rank in the top 1% for their field in 2018

Matthew Holden

- Selected by the Australian Society of Operations Research to attend Science Meets Parliament, Canberra
- Elected Treasurer of the Queensland Branch of the Australian Society for operations Research (ASOR)
- Nominated for the UQ, Faculty of Science, Rising Star Academic Award

Visitors

Jody Fisher, Flinders University (23 – 26 May 2019)
Professor Michel Mandjes, University of Amsterdam (23 June – 10 July, 2019)
Krzysztof Bisewski, Centrum Wiskunde & Informatica, The Netherlands (8 July – 7 August, 2019)
Femke van der Schoot, Eindhoven University of Technology, The Netherlands (1 August – 1 December, 2019)
Philip Erm, University of Melbourne (20 August – 24 August, 2019)
Noel Cressie, The University of Wollongong (19-20 November, 2019)

Publications
Book Chapters

1. Borkar, V.S., **Filar, J.A**. (2019). Postponing collapse: Ergodic control with a probabilistic constraint. In: Modeling, stochastic control, optimization, and applications. Edited by Yin G, Zhang Q. The IMA Volumes in Mathematics and its Applications, 164. Springer Nature Switzerland. 57-65
2. Dudgeon, C.L., Kilpatrick, C., **Armstrong, A., Armstrong, A**., Bennett, M.B., Bowden, D., **Richardson, A.J**., Townsend, K.A., Hawkins, E. (2019). Chapter 6. Citizen science photographic identification of marine megafauna populations in the Moreton Bay Marine Park. In Tibbetts.I.R., Rothlisberg, P.C., Neil, D.T., Homburg, T.A. (Editors). Moreton Bay *Quandamooka* & Catchment: *Past, present, and future*. The Moreton Bay Foundation. Brisbane, Australia
3. **Pausina, S**., Greenwood, J., Pitt, K., Rissik, D., Rochester, W., Skerratt, J., Uribe-Palomino, J., **Richardson, A.J**. (2019). Zooplankton of Moreton Bay. In Tibbetts, I.R., Rothisberg, P.C. Neil.D.T., Homburg, T.A., Brewer, D.T., & Arthington, A.H. (Editors). Moreton Bay *Quandamooka* & Catchment: *Past, present, and future*. The Moreton Bay Foundation. Brisbane, Australia
4. **Richardson, A.J**., Uribe-Palomino, J., Slotwinski, A., Coman, F., Miskiewicz, A.G., Rothlisberg, P.C., Young, J.W., Suthers, I.M. (2019). Chapter 8. Coastal and marine zooplankton: identification, biology and ecology. In *Plankton: A Guide to Their Ecology and Monitoring for Water Quality*. Edited by Suthers I, Rissik D, Richardson AJ. 2nd edition. CSIRO Publishing. 141-208
5. Rissik, D., Ajani, P., Bowling, L., Gibbs, M., Kobayashi, T., Pitt, K., **Richardson, A.J**., Suthers, I. (2019). Chapter 3. Use of plankton for management. In Plankton: A Guide to Their Ecology and Monitoring for Water Quality. Edited by Suthers I, Rissik D, **Richardson AJ.** 2nd edition. CSIRO Publishing. 37-61
6. Roe, T., **Richardson, A.J**., Suthers, I. (2019). Chapter 9. Educating with Plankton. In *Plankton: A Guide to Their Ecology and Monitoring for Water Quality*. Edited by Suthers I, Rissik D, Richardson AJ. 2nd edition. CSIRO Publishing. 209-222
7. Suthers, I., **Richardson, A.J**., Rissik, D. (2019). Chapter 1. The importance of plankton. In Plankton: A Guide to Their Ecology and Monitoring for Water Quality. Edited by Suthers, I., Rissik, D., **Richardson, A.J.** 2nd edition. CSIRO Publishing

Edited Books

8. **Holden, M., Lee, S.X., Yang, W-H.** Editors. (2019). WANRM special issue. Environmental Modeling & Assessment, 24, 4: 365 – 456
9. Suthers, I., Rissik, D., **Richardson, A.J.** (2019). Editors of *Plankton: A Guide to Their Ecology and Monitoring for Water Quality*. Edited by Suthers I, Rissik D, Richardson AJ. 2nd edition. CSIRO Publishing. 230

Journals

10. Adams, M.P., Sisson, S.A., Helmstedt, K.J., Baker, C.M., **Holden, M.H**., Plein, M., Holloway, J., Mengersen, K.L., McDonald-Madden, E. (2020). Informing management decisions for ecological networks, using dynamic models calibrated to noisy time-series data, Ecology Letters, doi: 10.1111/ele.13465
11. **Armstrong, A.J., Armstrong, A.O.,** Bennett, M.B., McGregor, F., Abrantes, K.G., Barnett, A., **Richardson, A.J.**, Townsend, K.A., Dudgeon, C.L. (2020). The geographic distribution of reef and oceanic manta rays (*Mobula alfredi* and *Mobula birostris*) in Australian coastal waters, Journal of Fish Biology: 1-6
12. **Armstrong, A.O., Armstrong, A.J.,** Bennett, M.B., **Richardson, A.J**., Townsend, K.A., Dudgeon, C.L. (2019). Photographic identification and citizen science combine to reveal long distance movements of individual reef manta rays Mobula alfredi along Australia's east coast. Marine Biodiversity Records, 12:14
13. Avrachenkov, K., Ejov, V., **Filar, J.A.,** Moghaddam, A. (2019) Zero-sum stochastic games over the field of real algebraic numbers. Dynamic Games and Applications. 9(4):1026-1041
14. Babcock, R. C., Bustamante, R.H., Fulton, E.A., Fulton, D.J., Haywood, M.D., Hobday, A.J., Kenyon, R., Matear, R.J., Plaganyi, E.E., **Richardson, A.J**., Vanderklift, M.A. (2019). Severe continental-scale impacts of climate change are happening now: Extreme climate events impact marine habitat forming communities along 45% of Australia's coast. frontiers in Marine Science, 6: 411
15. Bates, M.L., Hawker, D.W., **Cropp, R.** (2019). Spatio-temporal variations in hexachlorobenzene partitioning in a near shore Antarctic marine environment from a one-dimensional coupled eco-system-chemical model, Journal of Marine Systems, 196:65-76
16. Batten, S.D., Abu-Alhaija, R., Chiba, S., Edwards, M., Grahams, G., Jyothibabu, R., Kitchener, J.A., Koubbis, P., McQuatters-Gollop, A., Muxagata, E., Ostle, C., **Richardson, A.J.,** Robinson, K.V., Takahashi, K.T., Verheye, H.M., Wilson, W. (2019). A Global Plankton Diversity Monitoring Program, frontiers in Marine Science, 6, Article 321
17. **Berry, T**., Saunders, B., Coghlan, M., Stat, M., Jarman, S., **Richardson, A**., Davies, C., Berry, O., Harvey, E., Bunce, M. (2019). Marine environmental DNA biomonitoring reveals seasonal patterns in biodiversity and identifies ecosystem responses to anomalous climatic events, PLOS Genet, 15 (2):e1007943

18. Bessey, C., Jarman, S., Stat, M., Rohner, C., Bunce, M., Koziol, A., Power, M., Rambahiniarison, J., Ponzo, A., **Richardson, A.J.,** Berry, O. (2019). DNA metabarcoding assays reveal a diverse prey assemblage for Mobula rays in the Bohol Sea, Philippines, Ecology and Evolution, 2019: 1-16
19. Bohner, M., Torres, D, **Streipert, S.** (2019). Exact solution to a dynamic SIR model, Nonlinear Anal. Hybrid Syst, 32: 228 - 238
20. Briscoe, N.J., Elith, J., Salguero-Gomez, R., Lahoz-Monfort, J.J., Camac, J.S., Giljohann, K.M., **Holden, M,** H., Hradsky, B.A., Kearney, M.R., McMahon, S.M., Phillips, B.L., Regan, T.J., Rhodes, J.R., Vesk, P.A., Wintle, B.A., Yen, J.D.I., Guillera-Arroita, G. (2019). Forecasting species range dynamics with process-explicit models: matching methods to applications. Ecology Letters, 22:1940-1956
21. Derkley, T., Biggs, D., **Holden, M**., Phillips, C. (2019). A framework to evaluate animal welfare implications of policies on rhino horn trade. Biological Conservation, 235: 236-249
22. Eriksen, R., Davies, C., Bonham, P., Coman, F., Edgar, S., McEnnulty, F., McLeod, Miller, M., Rochester, W., Slotwinski, A., Tonks, M., Uribe-Palomino, J., **Richardson, A.** (2019). Australia's long-term plankton observations: the Integrated Marine Observing System National Reference Station network, frontiers in Marine Science, 6:161
23. **Filar, J.A., Qiao, Z., Streipert, S**. (2020). Risk sensitivity in Beverton-Holt fishery with multiplicative harvest, Natural Resource Modeling: e12257
24. **Jansen, H.M**., Mandjes, M., De Turck, K., Wittevrongel, S. (2019). Diffusion limits for networks of Markov-modulated infinite-server queues, Performance Evaluation, 135: 102039
25. Lawson, C.L., Halsey, L.G., Hays, G.C., Dudgeon, C.L., Payne, N.L., Bennett, M.B., White, C.R., **Richardson, A.J**. (2019). Powering ocean giants: The energetics of shark and ray megafauna. TREE, 34(11): 1009-1021
26. McGregor, F., **Richardson, A., Armstrong, A., Armstrong, A**., Dudgeon, C. (2019). Rapid wound healing in a reef manta ray masks the extent of vessel strike. PLoS One, 14(12):e0225681
27. Mills, M., Bode, M., Mascia, M., Weeks, R., Gelcich, S., Dudley, N., Govan, H., Archibald, C., Romero-de-Diego, C., **Holden, M.,** Biggs, D., Glew, L., Naidoo, R., Possingham, H, P. (2019). How conservation initiatives go to scale. Nature Sustainability, 2: 935-940
28. O'Bryan, C., Allan, J., **Holden, M.,** Sanderson, C., Venter, O., Di Marco, M., McDonald-Madden, E., Watson, J. (2020). Intense human pressure is widespread across terrestrial vertebrate ranges. Global Ecology and Conservation, 21: e00882
29. O'Bryan, C., **Holden, M**., Watson, J. (2019). The mesoscavenger release hypothesis and implications for ecosystem and human well-being. Ecology Letters, 22:1340-1348
30. Pascoe, S., Cannard, T., Dowling, N., Dichmont, C., Breen, S., Roberts, T., Pears, R., **Leigh, G**. (2019). Developing harvest strategies to achieve ecological, economic and social sustainability in multi-sector fisheries, Sustainability, 11: 644
31. **Richardson, A.J**, Schoeman, D.S. (2019). Sea animals are more vulnerable to warming than are land ones, Nature, 569; 50-51
32. Skerratt, J.H., Mongin, M., Baird, M., Wild-Allen, K.A., Robson, B.J., Schaffelke, B., Davies, C.H., **Richardson, A**., Margvelashvili, N., Soja-Wozniak, M., Steven, A.D.L. (2019). Simulated nutrient and plankton dynamics in the Great Barrier Reef (2011 - 2016), Journal of Marine Systems, 51-74
33. Tulloch, V. J.D., Plaganyi, E. E., Brown, C., **Richardson, A. J**., Matear, R. (2019). Future recovery of baleen whales could be hampered by climate change, Global Change Biology, 1-19
34. Uribe-Palomino, J., Lopez, R., Gibbons, M.J., Gusmao, F., **Richardson, A.J.** (2019). Siphonophores from surface waters of the Colombian Pacific Ocean, J Marine Biological Association of the United Kingdom, 99(1): 67-80
35. Wang, N., Courtney, A.J., Campbell, M.J., **Yang, W-H.** (2019). Quantifying long-term discards from Queensland's (Australia) east Coast otter trawl fishery, ICES Journal of Marine Science, fsz205

Conference Paper

36. **Filar, J.A., Qiao, Z**., Ye, N. (2019). POMDPs for sustainable fishery management, 23rd International Congress on Modelling and Simulation, Canberra, ACT, Australia, 1 to 6 December 2019, mssanz.org.au/modsim2019

Technical Reports with Industry Partners

37. Hutton, T., O'Neill, Leigh, G., **Holden, M**., Deng, R., Plaganyi, E. (2019). Harvest strategies for Torres Strait Finfish fishery. Project Report No. 2016/0824, Australian Government, Australian Fisheries Management Authority
38. Leigh, G.M., **Yang, W.H**., O'Neill, M.F., McGilvray, J.G., Wortmann, J. (2019). Stock assessments of bream, whiting and flathead (Acanthopagrus, Sillago cillaga and Platycephalus fuscus) in South East Queensland. Technical Report. State of Queensland
39. O'Neill, M. F. Lovett, R, Bessell-Browne, P., **Streipert, S**., Leigh, G., Campbell, A. Northrop, A., Wortmann, J., Helidoniotis, F., **Yang, W-H**., **Holden, M**., and French, S. (2020). Custom training and technical support for the fishery stock assessment software 'stock synthesis' , FRDC Project No. 2018-168, Fisheries Research and Development Corporation
40. **Streipert, S., Filar, J.,** Robins, J.B., O'Neill, M.F., Whybird, O.J. (2019). Assessment of the barramundi (Lates calcarifer) fishery in Queensland, Australia. Department of Agriculture and Fisheries, Queensland Government. Centre for Applications in Natural Resource Mathematics, University of Queensland. 60p. This publication has been compiled by **S. Streipert** and **J. Filar** of the Centre for Applications in Natural Resource Mathematics, The University of Queensland and J. B. Robins, M. F. O'Neill and O. Whybird of the Department of Agriculture and Fisheries.

Other

41. Tulloch, A. I.T, Auerbach, N., Avery-Gomm, S., Dickman, C. R, Fisher, D. O, Grantham, H., **Holden, M. H**., Lavery, T. H, Leseberg, N. P, O'Connor, J., Robertson, L., Smyth, A. K, Stone, Z., **Tulloch, V.,** Turak, E., Watson, J. E.M., Wardle, G. M. (2019). Reply to "Consider species specialism when publishing datasets' and "Decision trees for data publishing may exacerbate conservation conflict", Nature Ecology & Evolution, 3(3): 320-321