The 14th Annual

# New Zealand Ocean Acidification Conference

11th and 12th February | 2021

Dunedin

University of Otago
Te Whare Wānanga o Otāgo
New Zealand

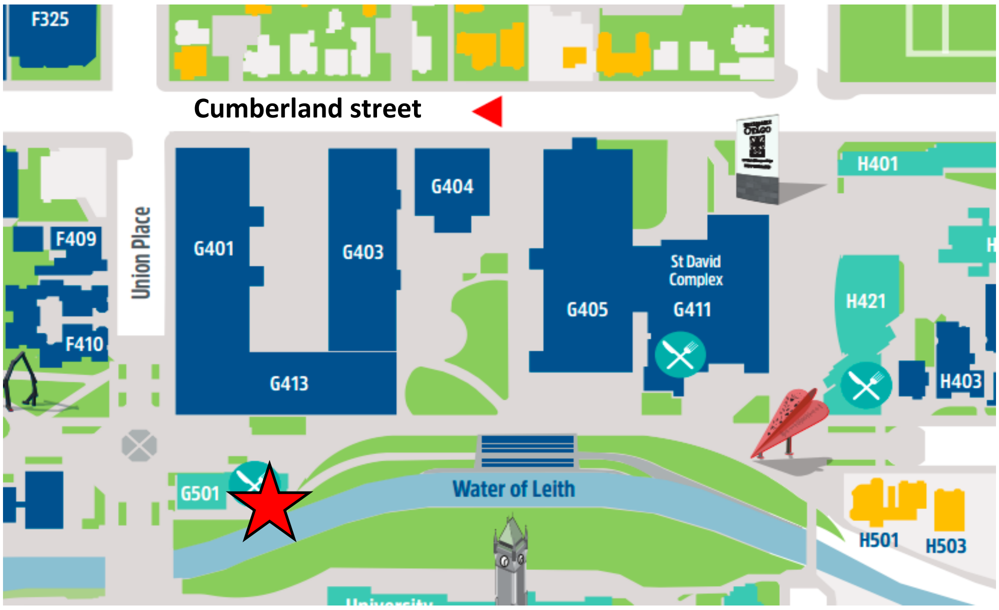
Future Ocean Research Theme

NZOAC

# General Information

## Conference location

The conference will be held in room 215 the Mellor Laboratory Building, which is building G401 in the image below.




## Registration:

Registration for the workshop will be available from 8:45 am Thursday February 11th, in room 209 the Mellor Laboratory Building.

## Conference dinner:

The wine tasting (6:00 – 7:30pm) and dinner (7:30 pm) will be at Carrington College (57 Heriot Row, North Dunedin, Dunedin 9016) on Thursday 11 February. Preregistration required.

# Programme Overview

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|---|---|---|
| Thursday 11 February | 8:45 - 9:20 | Registration and welcome coffee, Mellor 209 |
| | 9:20 - 9:30 | Welcome, Mellor 215 |
| | 10:45 - 11:15 | Morning tea, Mellor 209 |
| | 11:15 - 1:10 | Session 1a: The devil is in the details |
| | 1:10 - 2:30 | Lunch |
| | 2:30 - 3:45 | Session 1b: The devil is in the details |
| | 3:45 - 5:00 | Poster session and afternoon tea, Mellor 209 |
| | 6:00 - 7:30 | Wine tasting, Carrington College |
| | 7:30 | Conference dinner, Carrington College |
| Friday 12 February | 8:30 - 9:00 | Welcome coffee |
| | 9:00 - 9:10 | Welcome |
| | 9:10 - 10:40 | Session 2: Healthy oceans, healthy people |
| | 10:40 - 11:00 | Morning tea, Mellor 209 |
| | 11:00 - 12:00 | Breakout session |
| | 12:00 - 12:25 | Report back, wrap up |
| | 12:30 - 1:30 | Lunch, Staff Club, Gallery Room |
| | 1:30 - 3:15 | Session 3: Research frontiers |
| | 3:15 - 3:40 | Conference close |

## Scientific Programme

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|---|---|---|
| | **Thursday, February 11th 2021** | |
| 8:45 - 9:20 | Registration and welcome coffee, Mellor 209 | |
| 9:20 - 9:30 | Welcome | |
| 9:30 - 10:00 | Kirsten Isensee | Acidification Research for Sustainability - Providing society with the observational and scientific evidence needed to sustainably identify, monitor, mitigate and adapt to ocean acidification; from local to global scales (virtual) |
| 10:00 - 10:20 | Kim Currie | Discussion: How can NZ align with the Decade |
| 10:20 - 10:45 | Rebecca Zitoun | Scientific and institutional capacity challenges of Small Island Developing States |
| | | |
| 10:45 - 11:15 | Morning tea, Mellor 209 | |
| | | |
| 11:15 - 1:10 | **Session 1a: The devil is in the details** | |
| 11:15 - 11:55 | Philip Munday | Methods matter in repeating ocean acidification studies (virtual) |
| 11:55 - 12:20 | Wayne Dillon | The calcium-salinity relationship: an underappreciated detail in coastal ocean acidification monitoring and data quality |
| 12:20 - 12:45 | Christopher Cornwall | Coralline algal responses to ocean acidification: synthesis and meta-analysis |
| 12:45 - 1:10 | Sam Dupont | Do you (really) know your multiple stressors? (virtual) |
| | | |
| 1:10 - 2:30 | Lunch, on your own | |
| | | |
| 2:30 - 3:45 | **Session 1b: The devil is in the details** | |
| 2:30 - 2:55 | Abby Smith | It hasn't always been this way: a geological perspective on $CO_2$ and OA |
| 2:55 - 3:20 | Peter Dillingham | Multi-driver experiments with different scales of replication |
| 3:20 - 3:45 | Jesse Vance | Don't miss a beat: Imputing ocean carbon time series data gaps |

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|---|---|---|
| 3:45 - 5:00 | Poster session and afternoon tea, Mellor 209 | |
| | Jacquie L. Bown | The effects of ocean acidification on the establishment and maintenance of cnidarian-dinoflagellate symbioses |
| | Wan-Har Chen | Optical fiber pH sensor for marine microenvironments |
| | Theodore J.E. Christensen | Redefining $K_{sp}$ for calcite and aragonite with lower uncertainty in artificial seawater |
| | Grace T Cowley | Environmental Science in Civic Society and Policy: Outreach for a better world today |
| | Lea K. Muetzel | NZOA monitoring program unaffected by [$Ca^{2+}$]-salinity variability |
| | Alexia D. Saint-Macary | The influence of ocean acidification and warming on DMSP & DMS in New Zealand coastal water |
| 6:00 - 7:30 | Wine tasting, Carrington College | |
| 7:30 | Conference dinner, Carrington College | |

| Friday, February 12th 2021 | | |
|---|---|---|
| 8:30 - 9:00 | Welcome coffee | |
| 9:00 - 9:10 | Welcome | |
| | | |
| 9:10 - 10:40 | **Session 2: Healthy oceans, healthy people** | |
| 9:10 - 9:40 | Anne-Marie Jackson and Chris Hepburn | Coastal People: Southern Skies. An overview |
| 9:40 - 10:00 | Kim Currie | DOC and NZOA-ON join forces to expand ocean acidification monitoring in Aotearoa New Zealand |
| 10:00 - 10:20 | Sally Carson | OA in the science curriculum, value of hands-on learning |
| 10:20 - 10:30 | Grace Cowley | Getting evidence through to policymakers: the importance of submissions |
| 10:30 - 10:40 | Linn Hoffmann and Grace Cowley | Outreach in the Decade of Ocean Science for Sustainable Development |
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| 10:40 - 11:00 | Morning tea, Mellor 209 | |
| | | |
| 11:00 - 12:00 | Breakout session | |
| 12:00 - 12:25 | Report back, wrap up | |
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| 12:30 - 1:30 | Lunch, Staff Club, Gallery Room | |
| | | |
| 1:30 - 3:15 | **Session 3: Research frontiers** | |
| 1:30 - 2:00 | Lennart Bach | Ocean acidification impacts on phytoplankton: From microscales to climate change mitigation |
| 2:00 - 2:25 | Erik Krieger | Physiological Traits underpinning Resistance of Coralline Algae to Ocean Acidification |
| 2:25 - 2:50 | Mary Sewell | Near-future oceanic $CO_2$ delays development and growth in early-stage larvae of the endemic New Zealand sea urchin, Evechinus chloroticus |
| 2:50 - 3:15 | Miles Lamare | Diffusive Boundary Layers and Ocean Acidification: Implications for Sea Urchin Settlement and Growth |
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| 3:15 - 3:40 | Conference close | |

# Abstracts

## Acidification Research for Sustainability - Providing society with the observational and scientific evidence needed to sustainably identify, monitor, mitigate and adapt to ocean acidification; from local to global scales

Kirsten Isensee[1*]

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The science we need for the ocean we want: We want a more resilient ocean where ecosystems can thrive and resources can be used and managed sustainably. This cannot happen without understanding one of the main threats facing our oceans, now and in the future: ocean acidification. The UN Decade of Ocean Science for Sustainable Development from 2021-2030 offers new possibilities to foster the development of the science of ocean acidification including the impacts on marine life and sustainability of marine ecosystems in estuarine-coastal-open ocean environments.  As outlined in the SDG target 14.3 there is a need to ‘Minimize and address the impacts of Ocean Acidification (OA), including through enhanced scientific cooperation at all levels. Key components of ocean acidification research for the next ten year must include: 1) enhancing regional collaborative efforts, 2) coordination of capacity building in science, 3) codesign and implement observation and research to address the threat of ocean acidification, and 4) communication and delivery of the outputs to policy makers and communities.

New research and observations will aim to provide systematic evidence of the impacts of ocean acidification on the sustainability of marine ecosystems, enhance the communication to policy makers and communities and to facilitate the development and evaluation of strategies to offset future impacts.

## Scientific and institutional capacity challenges of Small Island Developing States

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The success of the UN SDG 14 and the upcoming Decade of Ocean Science for Sustainable Development is critically dependent on global capacity building efforts and resource sharing between developed and developing countries. Especially the support of capacity building efforts in Small Island Developing States (SIDS) is indispensable for the achievement of both individual and collective ocean-related 2030 agenda priorities for sustainable development. To put effective capacity development responses in SIDS in place, addressing their nationally identified priorities and fulfilling their obligations in the framework of global conventions, knowledge of their individual capacity building and research infrastructure requirements is necessary. Here, we present a capacity assessment, summarizing the existing key research capacities in SIDS UN Member States, to help formulate and implement durable, relevant, and effective capacity development responses to the most urgent marine issues of concern for SIDS. The assessment highlighted that there is only limited, if any, up-to-date information publicly available on human resources and research capacities in SIDS. A reasonable course of action in the future should, therefore, be the collection and compilation of data on educational, institutional, and human resources, as well as research capacities and infrastructures in SIDS into a publicly available database. This ocean-related database, supported by continued, long-term international, national, and regional collaborations, will lay the foundation to provide accurate and up-to-date information on scientific capacities, gaps, and requirements in SIDS and thereby inform strategic science and policy targets towards achieving SDG 14 within the next decade.

# Session 1a: The devil is in the details

## Methods matter in repeating ocean acidification studies

Philip L Munday

ARC Centre of Excellence for Coral Reef Studies, James Cook University, Townsville, QLD 4814, Australia
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It is a little over a decade since research commenced into the effects of anthropogenic ocean acidification on marine fishes. In that time, we have learned that projected end-of-century $CO_2$ levels can affect the physiology, growth and survival of some species, but not others. There are also wide-ranging effects on behaviour that could alter the performance and survivorship of some species. However, these effects are context and species specific, and the results depend on how experiments are done. In a provocative article published in Nature, Clark et al. claimed that ocean acidification does not impair the behaviour of coral reef fishes and that previous studies are not repeatable. In this talk I outline the overwhelming evidence from a decade of research showing that elevated $CO_2$ can affect the behaviour of a wide variety of fishes, including coral reef fishes, and I describe how methodological differences explain why different studies yield different results.

## The calcium-salinity relationship: an underappreciated detail in coastal ocean acidification monitoring and data quality

Wayne D.N. Dillon[1*], Peter W. Dillingham[2], Kim I. Currie[3], Christina M. McGraw[1]

[1] Department of Chemistry, NIWA/University of Otago Research Centre for Oceanography, University of Otago, Dunedin, 9016, New Zealand
[2] Department of Mathematics and Statistics, University of Otago, Dunedin, 9016, New Zealand
[3] National Institute of Water and Atmospheric Research, Dunedin, 9016 New Zealand
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The Global Ocean Acidification Observing Network (GOA-ON) endeavours to understand the global effects of Ocean Acidification (OA) through regionally dispersed monitoring programs. Two standards are defined for separate goals: the *Weather* goal is aimed at identifying relative spatial patterns and short–term localised variation, while the more stringent *Climate* goal sets the standards for assessing long term trends. The standard of data collected by member programs is assessed based on the computed propagated uncertainties of carbonate ion concentration ($[CO_3^{2-}]$), and therefore the $CaCO_3$ saturation state (Ω), in carbonate system characterisation. While the effects of measured carbonate parameter uncertainty on the propagated uncertainty of $[CO_3^{2-}]$ determination are well characterised, the relative impacts of uncertainty in salinity measurement and calcium ion concentration ($[Ca^{2+}]$) are poorly understood. In this study, the uncertainty propagation methods in the *R*-based marine carbonate chemistry software package *seacarb* were extended to include uncertainty in $[Ca^{2+}]$. The updated script was subsequently employed to examine the effects of anticipated levels of uncertainty in salinity and $[Ca^{2+}]$ on carbonate system calculations. Our findings indicate that uncertainty in $[Ca^{2+}]$ is of primary concern, where relatively small (<4%) deviations from the global $[Ca^{2+}]$-salinity relationship leads to GOA-ON's quality standards being exceeded. In contrast, the uncertainty in salinity has a relatively minor impact on uncertainty in $[CO_3^{2-}]$ and Ω. Given the importance of Ω and its sensitivity to $[Ca^{2+}]$, coastal OA monitoring programs should consider whether their region conforms with the global $[Ca^{2+}]$-salinity relationship, and if necessary, directly measure $[Ca^{2+}]$ when calculating Ω.

## Coralline algal responses to ocean acidification: synthesis and meta-analysis

Christopher E. Cornwall,[1*] Steeve Comeau[2], Daniel L. Cornwall[1], Ben Harvey[3], Lucia Porzio[3]

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[2] Sorbonne Université, CNRS-INSU, Laboratoire d'Océanographie de Villefranche, 181 chemin du Lazaret, F–06230 Villefranche-sur-mer, France.
[3] Shimoda Marine Research Center, University of Tsukuba, Japan
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Ocean acidification is a major threat to the persistence of biogenic reefs throughout the world's oceans. Coralline algae are comprised of high magnesium calcite, and have long been considered one of the most susceptible taxa to the negative impacts of ocean acidification. However, there is considerably variability in the responses of different species of coralline algae to ocean acidification, even though the majority display reduced calcification rates, recruitment rates/sizes in laboratory experiments and reduced abundance and recruitment at naturally elevated $CO_2$ sites. Here we explore potential causes of variability in coralline algal responses: geography, phylogeny, and physiology using a meta-analytical and extensive review approach. We find that both geography and phylogeny impact the magnitude of species' responses. However, with advances in experimental design and methodological techniques, we now understand that the physiology of coralline algae largely dictates their responses to ocean acidification. While the number of studies assessing the impacts of ocean acidification on coralline algae has grown remarkably over the last 15 years, significant challenges remain in better predicting generalisations in their responses to ocean acidification. These challenges revolve around differences in experimental methodologies that make study-to-study comparisons difficult, an inability to accurately understand species identity given the expense/difficulty of molecular methods, and a lack of holistic studies that assess meaningful physiological responses of coralline algae to ocean acidification.

## Do you (really) know your multiple stressors?

Sam Dupont,[1*] Christopher Cornwall,[2] Christina McGraw[3]

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[2] School of Biological Sciences, Victoria University of Wellington, Kelburn 6140, Wellington, New Zealand
[3] Department of Chemistry, NIWA/University of Otago Research Centre for Oceanography, University of Otago, Dunedin, 9016, New Zealand

[*]Presenting author. Email: sam.dupont@bioenv.gu.se

Resolving the biological impacts of ocean acidification within the mist of multiple stressors is one of the most pressing challenges of our time. Laboratory experimentation is one of the available tools at our disposal but designing and interpreting a relevant multiple stressors experiment is challenging. This interactive talk will explore concepts and common misconceptions when interpreting data from multiple driver studies and provide some keys on how to design a meaningful strategy to resolve impacts of multiple stressors.

## Session 1b: The devil is in the details

### It hasn't always been this way: a geological perspective on $CO_2$ and OA

Abigail M Smith[1*]

[1] Department of Marine Science, University of Otago
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It is natural for humans to concentrate on changes that occur on timescales similar to or less than our lifetimes. In a pinch, we are willing to consider timescales relative to human evolution, say 100,000 years. Geologists, however, learn to think in terms of millions of years, and have developed secular records for the Phanerozoic (the last 542 million years – the period for which there are common fossils), for a variety of atmospheric, climatic and marine parameters, including temperature, Mg:Ca, $CO_2$ and pH. Comparing some of these curves to each other is instructive and can lead to interesting hypotheses, but a clear understanding of their lack of precision is also needed for interpretation.

## Multi-driver experiments with different scales of replication

Peter W Dillingham,[1,*] Chuen Yen Hong,[1] Christopher E Cornwall,[2] David Fletcher,[1] Christina M McGraw,[3] and Jiaxu Zeng[4]

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[4] Department of Preventive and Social Medicine, University of Otago
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Multi-driver experiments often manipulate and replicate factors at different levels (Figure 1), e.g. using split-plot or related designs, usually due to logistical constraints such as the number of available fields in an agricultural experiment or header tanks available for an ocean global change experiment (Figure 1). The standard correct analyses of these experiments recognizes that small scale or subplot replicates within each large scale or whole-plot replicate are likely to be correlated, and adjusts standard errors and degrees of freedom accordingly. However, the split-plot nature of experiments is commonly ignored, leading to incorrect analyses and charges of pseudoreplication.

We recently developed a new analysis approach for split-plot experiments, employing frequentist model-averaging between 'correct' and 'incorrect' analyses. In certain settings, our approach provides increased precision for treatment comparisons while maintaining protection against false discovery near the desired level. In other settings, it reduces to the classical analysis. Here, we explain why many global ocean change experiments may benefit from this new analysis approach.

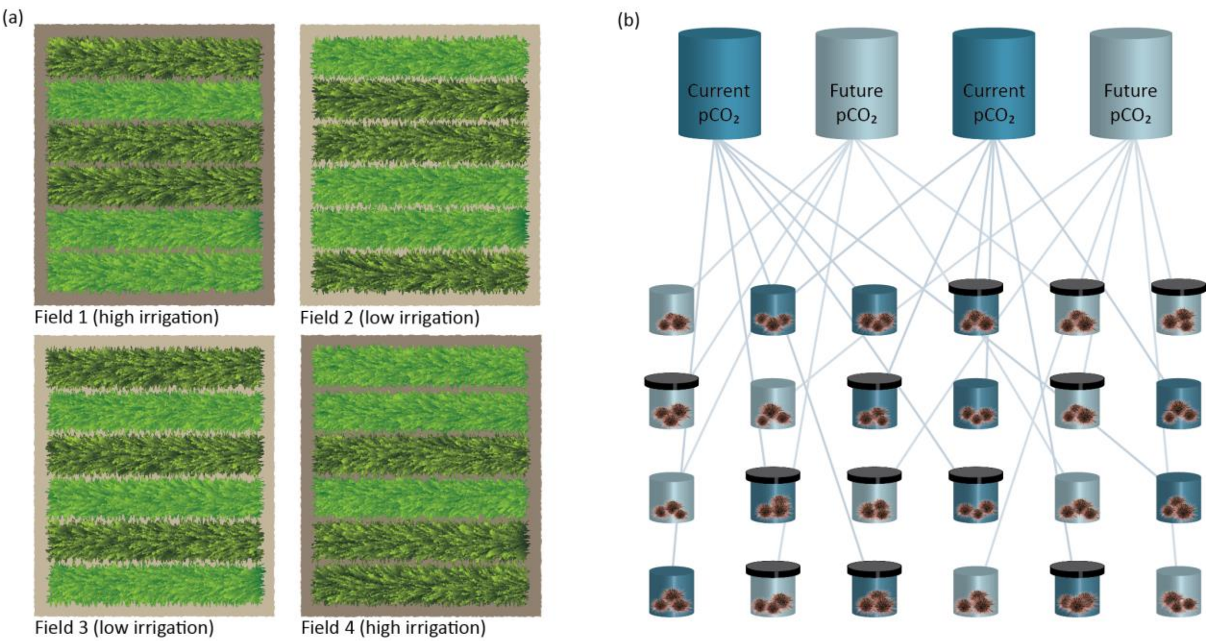


Figure 1. An example split-plot design with two whole-plot replicates and 12 subplot replicates for (a) a field-based agricultural experiment measuring crop yield versus irrigation and plant variety and (b) a laboratory-based ocean global change experiment measuring organism growth versus $pCO_2$ and light. In (a), we expect to see substantial variation between whole-plot replicates while in (b) we expect much less variation.

## Don’t miss a beat: Imputing ocean carbon time series data gaps

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Sustained timeseries observations of ocean carbon is essential to characterizing biogeochemical cycles, natural variability, regime shifts and long-term changes, such ocean acidification. Whether from equipment failure, cancelled voyages, budget cuts or a global pandemic, data gaps are ubiquitous in monitoring programmes. Calculations for evaluating seasonal processes, trends and fluxes over various time scales relies on continuous timeseries and so data gaps must be filled appropriately. Here we present the performance of 8 imputation methods, including a novel empirical multiple linear regression (MLR) approach used to estimate dissolved inorganic carbon (DIC) from remotely sensed chlorophyll, temperature and salinity, which was validated over 7 sites. The MLR model performed as well or better than previous empirical models for DIC. While most imputation methods performed similarly well over single gaps in monthly timeseries, the MLR, multiple imputation by chained equation (MICE) and mean imputation methods performed significantly better at higher rates of data missingness and sustained gaps. When testing these imputation methods using synthetic gaps, our results indicated that performance did not vary significantly for bimonthly timeseries, but model choice had a significant impact at 3-month and 6-month gaps for both retaining seasonal dynamics and accuracy of annual $CO_2$fluxes. The developed MLR model was also applied to the Munida Time Series to evaluate interannual variability and long-term changes in $CO_2$ flux, suggesting the subantarctic waters along the Southland Current Front have become a stronger sink for atmospheric $CO_2$ by 74 mmol C $m^{-2}$ $y^{-1}$ per year over the last 2 decades.

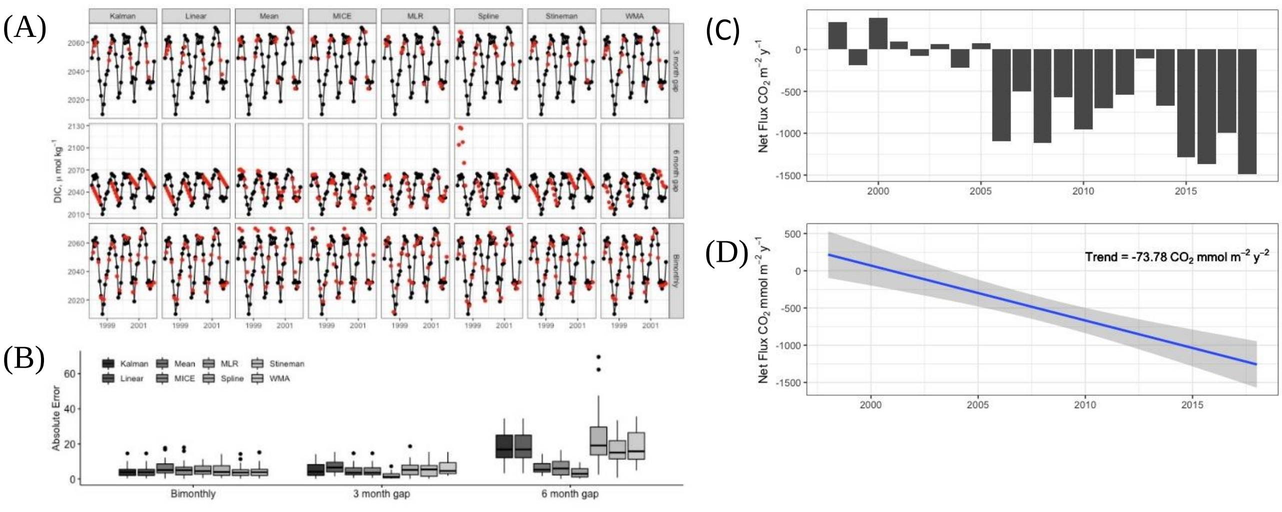


*Figure 1 (A) Timeseries of DIC measurements at Bermuda Atlantic Time Series (black) with artificial gaps representing bimonthly sampling, 3-month and 6-month sequential gaps. Predicted DIC values for each artificial gap regime are shown (red) for each imputation model. (B) Boxplots of absolute imputation error for each time series.(C) Net $CO_2$ flux at Munida Time Series and (D) apparent trend 1998 – 2019.*

# Session 2: Healthy oceans, healthy people

## Coastal People: Southern Skies. An overview

Anne-Marie Jackson[1*], Chris Hepburn [1]

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The vision of Coastal People: Southern Skies is flourishing wellness (mauri ora) of coastal communities. Our mission is to connect, understand and restore coastal ecosystems of New Zealand and the Pacific through transformative research, local action and by unlocking potential through new opportunities and pathways to learning. Our goals are Mana whenua (Our Pūtea/Economy): to build a generation of end user focused researchers of international standing who can apply cross-cultural and multi-disciplinary methodology to support coastal economies. Mana atua (Our Community): Deliver projects in partnership with coastal communities that provides knowledge and capacity to support informed decision making and action to address social, economic and environmental issues in coastal areas of NZ and the Pacific. Mana moana (Our Work). To deliver on research excellence for coastal peoples through sustainable processes that are carbon neutral and promote well-being (mauri ora). Mana tangata (Our People): To promote mana enhancing leadership and world class training opportunities that reflect and celebrate diversity.

## DOC and NZOA-ON join forces to expand ocean acidification monitoring in Aotearoa New Zealand

Kim Currie,[1*] Monique Ladds [2]

[1] NIWA, Dunedin
[2] Department of Conservation, Te Papa Atawhai
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THE New Zealand Ocean Acidification Observing Network (NZOA-ON) has worked with sampling partners at 10 coastal sites throughout New Zealand since 2015 to collect samples across diverse ecosystems. These data provide knowledge of present day conditions and variability in carbonate chemistry, and a baseline against which to measure any future change. The Department of Conservation, Te Papa Atawhai, have joined the NZOA-ON and extended the network by implementing ocean acidification monitoring at 9 marine reserves. DOC is committed to monitoring both terrestrial and coastal climate change impacts, and marine reserves offer dedicated areas for scientific monitoring and research. DOC works with Maori and local communities to collect the ocean acidification water samples using NZOA-ON protocols and contributes to national and international environmental reporting. This monitoring has resulted in more regular connection of kaitiaki with their rohe and with marine monitoring more widely.

## **OA in the science curriculum, *value of hands-on learning***

Hanna Ravn,[1] Sally Carson[1*]

[1] New Zealand Marine Studies Centre, University of Otago
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More and more teachers are wanting to incorporate climate change education into classroom studies. A 2019 survey showed that 32% of teachers find it challenging to address climate change issues in the classroom and almost half are reaching out to regional organisations to help teach the subject to their students. At the NZ Marine Studies Centrem(NZMSC), demand for climate change focused onsite education programmes and resources has increase significantly over the last 2-3 years. Teachers are specifically looking for support to link classroom based learning with hands-on activities, that are locally relevant.

At secondary level, the drive for learning about climate change and the ocean is more student lead. Through the Earth and Space Science curriculum senior students have the opportunity to increase understanding of the physical processes in the ocean system. For the past four years, the NZMSC has successfully run teacher workshops and student multiday programmes on ocean acidification. Though provision of scientific equipment, connection with post graduates students and scientists, and access to the marine environment, the NZMSC provides opportunities not available in the classroom. This talk will address outcomes and directions for future development.

# Session 3: Research frontiers

## Ocean acidification impacts on phytoplankton: From microscales to climate change mitigation

Lennart Bach

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Ocean acidification (OA) is the combined change in several carbonate chemistry parameters, each of which could potentially affect organisms in seawater. In this presentation I will first provide an illustrative example how disentangling carbonate chemistry conditions in physiological experiments with coccolithophores can help to generate mechanistic understanding of their response to OA. I will then explain how such mechanistic understanding can be used to explain responses of coccolithophores observed in community OA experiments. In this context, I will raise the question if the approach we took over the last years to study OA-impacts on phytoplankton (and maybe other organisms) was the best possible way and what could be learnt for future research. In the last part, I will try to evaluate how OA-research may evolve and what the next big questions for our research community could become.

## Physiological Traits underpinning Resistance of Coralline Algae to Ocean Acidification

Erik C. Krieger[1*], Juan Diego Gaitán-Espitia[2,3], Wendy A. Nelson[4,5], Simon K. Davy[1], Johan Grand[6,7], Eric Le Ru[6], Aleluia Taise[1], Francesca Hale[1], Peter W. Dillingham[8], Christopher E. Cornwall[1]

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Coralline algae (Rhodophyta) are important calcifying algae that are perceived as being extremely vulnerable to ocean acidification. However, past research and existing theory fail to explain species-specific variability in their responses to climate change, where some species show remarkable resistance. This insufficient knowledge of what drives the susceptibility to local and global change stems from a lack of understanding which traits confer resistance to these drivers. This knowledge gap can only be closed by identifying traits that provide resistance to ocean acidification across several species. To this end, we assessed the physiological, geochemical and transcriptional responses of seven species of coralline algae to the effects of ecologically relevant seawater pH (8.03, 7.93, 7.83 and 7.63) in a manipulative lab experiment. Selected species span a range of morphologies and (micro)habitats and included closely related and unrelated species. Calcification of three species was unaffected by pH. This is in congruence with the apparent lack of influence of pH on their photophysiology. In contrast, physiological impairment by decreasing pH is indicated for species whose calcification rates declined. The results emphasise that resistance to ocean acidification is not promoted by location, (micro)habitat, phylogeny or morphology but by the ability to prevent physiological impairment. Geochemical and transcriptional mechanisms for this will be discussed. This indicates that physiology, rather than simple morphological traits, are required to understand the differential susceptibility of coralline algae to ocean acidification. This will enable more reliable predictions of the future of coralline algal species and reliant ecosystems in an acidifying ocean.

## Near-future oceanic $CO_2$ delays development and growth in early-stage larvae of the endemic New Zealand sea urchin, Evechinus chloroticus

Mary Sewell

School of Biological Sciences, University of Auckland, Auckland, New Zealand

*Presenting author. Email: m.sewell@auckland.ac.nz

Under the ocean acidification (OA) conditions predicted for 2100, the larval stages of temperate sea urchins have been shown to exhibit developmental delay, reduced and abnormal skeletal development, and metabolic rate changes. Here we measure the impact of near-future and long-term predictions of atmospheric $pCO_2$ levels on the early development of the echinometrid sea urchin Evechinus chloroticus using single male: female crosses and a meta-analysis approach. Using the developmental signposts given by cleavage divisions, we show a mean delay of 3.63 and 7.02 mins at the 8-cell stage in Target $pCO_2$ of 1000 and 1800 µatm, with an estimated 4% delay in development to the blastula stage. Echinopluteus larvae raised in OA conditions were ca 10-12% smaller in arm length and 5-10% smaller in body length than controls. Metabolic rate was highly variable between single male: female crosses, with a non-significant effect size in the meta-analysis. Our results suggest that the magnitude of developmental delay seen during early cleavage in OA conditions may be contributing to the larval stunting observed in the early 4-arm echinopluteus (48 h). Single male: female crosses showed variable OA responses in all measurements, emphasizing the value of a meta-analysis approach in assessing the population-level impacts of OA on sea urchin larvae.

## Diffusive Boundary Layers and Ocean Acidification: Implications for Sea Urchin Settlement and Growth

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Chemical changes in the diffusive boundary layer (DBL) generated by photosynthesising macroalgae are expected to play an important role in modulating the effects of ocean acidification (OA), but little is known about the effects on early life stages of marine invertebrates in modified DBLs. Larvae that settle to macroalgal surfaces and remain within the DBL will experience pH conditions markedly different from the bulk seawater. We investigated the interactive effects of seawater pH and DBL thickness on settlement and early post-settlement growth of the sea urchin *Pseudechinus huttoni*, testing whether coralline-algal DBLs act as an environmental buffer to OA. DBL thickness and pH levels (estimated from well-established relationships with oxygen concentration) above the crustose coralline algal surfaces varied with light availability (with photosynthesis increasing pH to as high as pH 9.0 and respiration reducing pH to as low as pH 7.4 under light and dark conditions, respectively), independent of bulk seawater pH (7.5, 7.7, and 8.1). Settlement success of *P. huttoni* increased over time for all treatments, irrespective of estimated pH in the DBL. Juvenile test growth was similar in all DBL manipulations, showing resilience to variable and low seawater pH. Spine development, however, displayed greater variance with spine growth being negatively affected by reduced seawater pH in the DBL only in the dark treatments. Scanning electron microscopy revealed no observable differences in structural integrity or morphology of the sea urchin spines among pH treatments. Our results suggest that early juvenile stages of *P. huttoni* are well adapted to variable pH regimes in the DBL of macroalgae across a range of bulk seawater pH treatments.

# Poster

## The effects of ocean acidification on the establishment and maintenance of cnidarian-dinoflagellate symbioses

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Over 30% of anthropogenic $CO_2$ is taken up by the ocean, altering ocean chemistry and lowering pH in a process known as ocean acidification (OA). While negative effects of OA on coral calcification are well studied, other physiological impacts on cnidarian-dinoflagellate symbioses are less well known. This research examines the cellular impacts of OA on the establishment and maintenance of cnidarian-dinoflagellate symbioses, using proteomic analysis of the cnidarian model system Aiptasia. Our first aim is to assess the impacts of decreased pH on the capacity of Aiptasia to establish persistent symbiosis with its native symbiont *Breviolum minutum*. Our hypothesis is that prior exposure to decreased pH will decrease symbiont uptake and colonisation rates, with more severe effects seen with increasingly extreme exposure. Our second aim is to assess the impact of decreased pH on the ongoing health and maintenance of the cnidarian-dinoflagellate symbiosis. Previous studies have suggested benefits to the host from symbionts under reduced pH. This is likely due to increased translocation of photosynthetic products, mitigating against other acidification impacts. We will compare aposymbiotic and symbiotic Aiptasia to distinguish the effects of symbiosis from those of OA. Our hypotheses are that 1) symbiont density and photosynthetic performance will increase as pH levels decrease; and 2) proteomes will be differentially expressed under decreased pH, with more stress-related proteins expressed in aposymbiotic *vs.* symbiotic anemones, as photosynthetic products are not available to mediate OA effects. This research will improve our understanding of cellular effects of OA on these key ecosystem species.

## Optical fiber pH sensor for marine microenvironments

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An optical fiber pH sensor was developed and successfully demonstrated its suitability in real-time measurements of the ecologically significant green seaweed *Ulva* sp. The optical fiber pH sensor conforms to the Global Ocean Acidification Observing Network "weather" measurement quality guideline with precision of approximately 0.02 pH units, has a dynamic $pH_T$ range of 7.4 to 9.7 ($S$ = 35, T = 20 °C) in seawater, a response time of 2.5 – 6.5 minutes and a usable lifetime of 7 days. The pH sensing layer consists of a pH sensitive indicator, *meta*-cresol purple (*m*CP), entrapped in an porous structure sol-gel matrix to allow $H_3O^+$ to diffuse into and interact with the indicator. The optical fiber pH sensor has additional advantages of being self-referencing, without the need of an external sensor reference, has a simple fabrication method and uses only a basic spectrophotometric system.
The optical fiber pH sensor monitored pH variations due to metabolic activity over 7 days within the seaweed canopy and 4 days within the diffusion boundary layer interface, demonstrating the suitability for measurements in marine microenvironments. Future work will focus on improving the sensor's sensitivity by incorporating fluorescent indicators, reducing indicator leaching, and increasing sensor longevity with covalent binding of indicator to the supporting matrix.

## Redefining $K_{sp}$ for calcite and aragonite with lower uncertainty in artificial seawater

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Future predictions for the response and health of our oceans and the marine ecosystem to ocean acidification depend heavily on our understanding of the marine carbonate system. Of particular importance to many marine organisms is the effect of the calcium carbonate ($CaCO_3$) saturation state (Ω), the value of which indicates whether the dissolution of $CaCO_3$ polymorphs such as calcite and aragonite and their biogenic counterparts is thermodynamically favoured. Ω is calculated from the stoichiometric solubility constant ($K_{sp}$) and eight other parameters (including but not limited to pressure, temperature, salinity, and inorganic carbon). The largest source of uncertainty in this calculation is derived from the $K_{sp}$ of $CaCO_3$ polymorphs, which is an empirically determined constant that could possess a standard uncertainty up to 10%. Recently, C.M. McGraw's research group have developed a fibre-based system to directly determine when seawater conditions transition from supersaturated to undersaturated conditions (i.e. when Ω = 1), a method which allows for precise and accurate experimental determination of the $K_{sp}$ of $CaCO_3$ at various temperatures and salinities. This study extends this work by investigating the pressure dependent dissolution of the $CaCO_3$ polymorphs at pressures up to 1000 bar, corresponding to a depth of 10,000m, using the fibre-based system within a custom build high pressure chamber. The aim of the study is to use this method to determine $K_{sp}$ values for the calcite and aragonite polymorphs of $CaCO_3$ between 0 - 1000 bar at five different temperatures and salinity of 35 with an uncertainty of less than 4%.

## Environmental Science in Civic Society and Policy: Outreach for a better world today

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The climate crisis and associated environmental issues are now well engrained in the consciousness of everyday citizens, thanks to the efforts of outreach and science communication over the past four decades. This societal context is resulting in a paradigm shift in the scientific interaction with the public. Despite the recent declaration of a climate emergency by the state, and the passing of the Climate Change Response (Zero Carbon) Amendment Act, Aotearoa lacks substantive policy to transition into a zero-carbon economy and address the climate crisis at its source. With another decade of inaction looming before Aotearoa, a reconfiguring of the role of environmental science outreach and its relationship to civic society and policymakers is required. Given the consensus amongst environmental scientist for swift political action, there is a need to define what information is required of environmental science expertise by different civic communities and policymakers, to best utilize the resources of academics conducting community outreach. This review explores how marine science expertise can best be utilized to benefit those striving to make change. This work outlines the unavoidable obligations to Te Tiriti o Waitangi presented to scientists whilst engaging in Aotearoa's decision-making process. Through an interdisciplinary discussion of the responsibilities of the environmental science community, a relationship between environmental science and justice is outlined to guide future outreach.

## NZOA monitoring program unaffected by [$Ca^{2+}$]-salinity variability

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It is standard practice in studies of ocean carbonate chemistry to determine the calcium carbonate saturation state, Ω, from the calcium ion concentration, [$Ca^{2+}$], and the carbonate ion concentration [$CO_3^{2-}$]. [$Ca^{2+}$] is calculated from an empirically determined [$Ca^{2+}$]-salinity relationship established for oceanic seawater, while [$CO_3^{2-}$] is determined from carbonate system characterisation. Recently, we have shown that a relatively small deviation (3-4%) from the expected [$Ca^{2+}$]-salinity relationship can lead to uncertainty in Ω exceeding the GOA-ON quality standards guidelines. This is of concern for monitoring programs operating in coastal waters, where the influences of terrestrial inputs and ocean upwelling have been shown to cause significant and variable deviations from the global [$Ca^{2+}$]-salinity relationship. Here, we examine whether sites in the New Zealand Ocean Acidification Observing Network (NZOA-ON) deviate significantly from the [$Ca^{2+}$]-salinity relationship. We measured [$Ca^{2+}$] and salinity of 88 samples from nine NZOA-ON sites and two additional locations. These samples spanned a large salinity range (21.1 to 35.8), representing coastal waters affected by variable degrees of riverine inputs and oceanic mixing. We did not see a significant difference between the expected and measured [$Ca^{2+}$], indicating that NZOA-ON monitoring sites can reliably calculate Ω using the current salinity-based protocol.

## The influence of ocean acidification and warming on DMSP & DMS in New Zealand coastal water

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The cycling of the trace gas dimethyl sulfide (DMS) and its precursor dimethylsulfoniopropionate (DMSP) may be affected by future ocean acidification and warming. DMSP and DMS concentrations were monitored over 20-days in four mesocosm experiments in which the temperature and pH of coastal water were manipulated to projected values for the year 2100 and 2150. This had no effect on DMSP in the nutrient-deplete experiment; however, in the two nutrient-amended experiments, warmer temperature combined with lower pH had a more significant effect on DMSP & DMS concentrations than lower pH alone. This indicates that future warming may have greater influence on DMS production than ocean acidification. The observed reduction in DMSP at warmer temperatures was associated with changes in phytoplankton community and in particular with small flagellate biomass. Temporal variation was also observed with DMS concentration increasing earlier in the higher temperature treatment. Nutrient availability and community composition should be considered in models of future D

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