12th Annual New Zealand Ocean Acidification Community Workshop

20 – 21st February 2019
Hutton Theatre, Otago Museum

Carbonate System Measurements on a New Zealand Mussel Aquaculture Farm

General Information

Venue: Hutton Theatre, Otago Museum

The workshop will be held at Otago Museum's Hutton Theatre. Otago Museum is located off Cumberland Street, directly across from The University of Otago

There are two entrances to the Hutton Theatre: you can enter from the outside by using the doors just to the right of the wall of glass café windows. Alternatively, if you want into the museum's main entrance, you will find the entrance to the Hutton Theatre behind the café to the right.

Registration for the workshop will be available from 8:30 am Wednesday February 20th in Hutton Theatre.

Otago Museum, 416 Great King St, North Dunedin, Dunedin 9016

Lunch: Lunch is on your own and we suggest that you use the lunch breaks to explore the great restaurants near campus. If you would like company, each day our team of student organisers will be fanning out across the area leading interested attendees to their favourite restaurants. Please see the *Lunch ideas* board near the registration desk to see where groups are heading today.

Social event: a light dinner will be provided at Ombrellos Kitchen and Bar from 5 pm on February 20th.

Address: 10 Clarendon St, North Dunedin, Dunedin 9016

Campus Life

The workshop coincides with University of Otago's Orientation week (*O-week*), which is a week-long event where University students reacquaint themselves with campus life and the city before classes begin. This year, Orientation Week is from February 16th – 24th. This is one of the things that makes Dunedin special and you'll find that it is an exciting time to be near campus!

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Programme Overview

Wednesday 20 February	8:30 – 8:50 am	Registration
	8:50 – 9:00 am	Welcome
	9:00 – 10:30 am	Session 1a: Ecosystems
	10:25 – 11 am	Morning tea & posters #1-5
	11:00 – 12:45 pm	Session 1b: Ecosystems con’t and CARIM 1
	12:45 – 2:10 pm	Lunch
	2:10 – 3:10 pm	Session 2: Sediments
	3:10 – 3:35 pm	Afternoon tea & posters #1-5
	3:35 – 4:50 pm	Session 3: Session in honour of Keith Hunter
	5:00 pm	Social event: Ombrellos Kitchen and Bar
Thursday 21 February	9:00 – 9:05	Welcome
	9:05 – 9:50 am	Plenary: Christopher Harley
	9:55 – 10:25 am	Morning tea & posters #6-10
	10:25 – 12:00	Session 4: National and international coordination
	12:00 – 1:00 pm	Lunch
	1:00 – 3:10 pm	Session 5: CARIM 2
	3:10 – 3:40 pm	Afternoon tea & posters #6-10
	3:40 – 4:40 pm	Session 6: NZOAC
	4:40 – 4:45pm	Close the workshop

Scientific Programme

Wednesday, February 20th 2019		
8:30 - 8:50	Registration opens	
8:50 - 9:00	Welcome and introductions	
9:00-10:30	**Session 1a: Ecosystems**	
9:00 - 9:20	Steve Widdicombe	How do we pull ocean acidification data and understanding together to appreciate the bigger picture?
9:20 - 9:35	Januar Harianto	Ocean acidification and parental environment alters the thermal metabolic performance of the offspring in the sea urchin Heliocidaris erythrogramma
9:35 - 9:50	Ro Allen	Biofilm succession in an acidified ocean: mechanistic insights from a volcanic CO_2 seep study
9:50 - 10:05	Nadjejda Espinel	Effects of altered marine biofilms on the larval settlement of a serpulid polychaete
10:05 - 10:20	Anna Kluibenschedl	New Zealand Coralline algae impacts of ocean acidification under low light
10:20 - 10:25	Poster summaries (#1-5)	Anna Lunde Hermansson, Dione Deaker, Erin Houlihan, Januar Harianto, Samuel Karelitz
10:25 - 11:00	Morning tea & posters #1-5	
	Anne Lunde Hermansson	Solubility of natural carbonate samples
	Dione Deaker	The impact of reduced seawater pH on the starfish and sea urchin egg jelly coat
	Erin Houlihan	The effects of coralline-algal diffusion boundary layers on juvenile sea urchin, Pseudechinus huttoni, under ocean acidification
	Januar Harianto	respR: An R package for the analysis of respirometry data
	Samuel Karelitz	Impact of growing up in a warmer, lower pH future on offspring performance: transgenerational plasticity in a pan-tropical sea urchin
11:00-12:45	**Session 1b: Ecosystems (con't) and CARIM 1**	
11:00 - 11:15	Philip Munday	Ocean warming has a greater effect than acidification on the early life history development and swimming performance of yellowtail kingfish
11:15 - 11:30	Evelyn Armstrong	Adaptation by a NZ coccolithophore to projected conditions in 2100
11:30 - 11:45	Mary Sewell	Assessing resilience of Perna canaliculus larvae to ocean acidification: an integrated-omics approach
11:45 - 12:00	Norman Ragg	Both the intensity and duration of parental exposure to OA influences early offspring resilience to elevated pCO_2 in Greenshell mussels, Perna canaliculus
12:00 - 12:15	Vonda Cummings	What about the parents: how does long term exposure to reduced pH affect adult pāua?
12:15 - 12:30	Bridie Allan	The effects of multiple stressors on the escape and routine swimming performance of the New Zealand snapper Chrysophyrs auratus
12:30 - 12:45	Shannon McMahon	The effects of heatwaves and ocean acidification on juvenile snapper, Chrysophyrs auratus

Wednesday, February 20th 2019, *con't*		
12:45 - 2:10	Lunch	
2:10 - 3:10	**Session 2: Sediments**	
2:10 - 2:25	Kay Vopel	Effect of experimental seawater CO_2 enrichment on pH in subtidal, net-heterotrophic silt deposits
2:25 - 2:40	Kay Vopel	Short-term response of a subtidal, net-heterotrophic silt deposit to experimental warming and CO_2 enrichment
2:40 - 2:55	Alexis Marshall	The effects of ocean acidification on microbial nutrient cycling and productivity in coastal marine sediments
2:55 - 3:10	Tarn Drylie	Calcium carbonate alters the functional resilience of coastal sediments to eutrophication-induced acidification
3:10 - 3:35	Afternoon tea & posters #1-5	
3:35 - 4:50	**Session 3: Session in honour of Keith Hunter**	
3:35 - 3:45	Kim Currie	Keith Hunter's contribution to the field
3:45 - 4:00	Cliff Law	Mitigating low pH for the Mussel aquaculture industry
4:00 - 4:15	Jesse Vance	Leveraging observatory networks to better understand terrestrial coastal Interactions
4:15 - 4:35	Libby Jewett	Global ocean acidification observing network
4:35 - 4:50	Wayne Dillon	A deployable probe for the direct measurement of saturation state
4:50	Ombrellos (drinks and light snacks)	

Thursday, February 21st 2019		
8:30-9:00	Registration opens	
9:00 - 9:05	Welcome	
9:05 - 9:50	Plenary: Christopher Harley	Multiple stressors and other complications: understanding the effects of acidification in an interesting ocean
9:50 - 9:55	Poster summaries (#6-9)	Alyce Hancock, Denise Chen, Morgan Meyers, Naomii Seah, Seyedehhabibeh Hashemi
9:55 - 10:25	Morning tea & posters #6-10	
	Denise Chen	Fibre optic pH microsensor for studying the impact of ocean acidification on the marine environment
	Seyedehhabibeh Hashemi	Refining low-cost carbonate ion selective electrodes for 2D profiling
	Morgan Meyers	Design and employment of a new portable CO_2 system for ocean acidification experiments
	Naomii Seah	Combatting the Effects of ocean acidification on farmed molluscs
	Alyce Hancock	Effects of ocean acidification on Antarctic marine microbial communities
10:25 - 12:00	**Session 4: National and international coordination**	
10:25 - 10:45	Will Howard	Research and policy challenges for ocean acidification in Australia
10:45 - 11:00	Emily Frost	An update on the Auckland Regional Council water quality and ocean acidification monitoring program: from Auckland to beyond
11:00 - 11:20	Bronte Tilbrook	UN sustainable development goals and communities of ocean action
11:20 - 11:40	Duncan McIntosh	New Zealand Pacific partnership on ocean acidification
11:40 - 12:00	Jan Newton	Scientists and shellfish growers working in partnership to measure ocean acidification variables and deliver data to support shellfish aquaculture

Thursday, February 21st 2019 *con't*		
12:00 - 1:00	Lunch	
1:00 - 3:10	**Session 5: CARIM 2**	
1:00 - 1:10	Cliff Law	Intro to CARIM
1:10 - 1:25	Neill Barr	The trials, tribulations and successes in controlling pH and temperature in 9 giant test-tubes
1:25 - 1:40	Cliff Law	Coastal phytoplankton response to acidification and warming
1:40 - 1:55	Alexia Saint-Macary	Will ocean Aaidification and warming alter DMS emissions from coastal waters?
1:55 - 2:10	Amadine Sabadel	Climate change impact on coastal particulate organic matter cycling and nutritional value, using amino acid concentrations and C and N stable isotopes
2:10 - 2:25	Morgan Meyers	Grazing of calanoid copepod Temora turbinata on natural prey communities during the CARIM Mesocosm 4 experiment
2:25 - 2:40	Fenella Deans	Bacterial communities show resilience to climate change in New Zealand's coastal waters
2:40 - 2:55	Helen Macdonald	Biogeochemical ROMS modelling of NZ Shelves for Present Day and Future States
2:55 - 3:10	Helen Bostock	The spatial and temporal variability of ocean acidification in the Firth of Thames/Hauraki Gulf - CARIM
3:10 - 3:40	Afternoon tea & posters #6-10	
3:40 - 4:40	**Session 6: NZOAC**	
4:40 - 4:45	Close the workshop	

Abstracts

Session 1a: Ecosystems

How do we pull ocean acidification data and understanding together to appreciate the bigger picture?

Steve Widdicombe[1*]

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The overall response of marine ecosystems to a rapidly changing ocean is governed by a complex matrix of physiological responses and ecological interactions, both within and between individual organisms. Stress induced changes in individuals' performance will affect population success, largely through altering competitive, facilitative and trophic relationships, ultimately driving shifts in ecosystem structure and functioning. Predicting long-term ecosystem level effects of ocean acidification is therefore challenging and largely reliant on generating understanding across all levels of biological organization. In many previous studies it has been impossible to fully mimic the spatial or temporal scales, or indeed the levels of complexity and variability, over which ocean acidification will operate. Whilst methods for studying each of the separate organizational levels over specific temporal and spatial scales are well developed, e.g. manipulative experiments and observations in the field and in the laboratory, the tools needed to integrate understanding from these separate studies are less well advanced. Further developing these integrative tools will support a more comprehensive appreciation of the future fate of marine organisms, populations and, ultimately, whole marine ecosystems. This talk will explore some examples in which collections of different data and knowledge have been successfully synthesized and scaled up to make predictions at higher, more complex, levels of ecological organization.

Ocean acidification and parental environment alters the thermal metabolic performance of the offspring in the sea urchin *Heliocidaris erythrogramma*

Januar Harianto*[1], Joshua Aldridge[2], Sergio Torres-Gabarda[3], Richard Grainger[1], Maria Byrne[1,3]

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Transgenerational carry-over effects are mechanisms which allow for rapid responses of offspring to environmental stress based on the experiences of their parents to the same stressors. This study investigated the potential transgenerational carry-over effects of adult exposure to warming or low pH on the metabolic responses and growth of their offspring using the model sea urchin species *Heliocidaris erythrogramma*. Adults were exposed to two temperature treatments (ambient, elevated +2 °C) and two pH_T levels (8.0, 7.6) in a fully factorial design. Treatment temperatures were adjusted to an offset with respect to the seasonal cycle to promote gonad development. The sea urchins were spawned to generate offspring which were placed in four temperature treatments (18 °C, 20 °C, 22 °C, 24 °C) and at two pH_T (ambient 8.0, low 7.6) levels over 14 days to the juvenile stage. Metabolic rate and growth performances were tested. Offspring from the warm treatment parents altered their metabolism by increasing their respiration by up to 30% at 24 °C. In contrast, parental pH treatment had no effect on offspring metabolic rates. Growth was not influenced by parental acclimation to temperature and pH. These findings imply that parental exposure to environmental change, particularly warming, may shape the performance of offspring to the same range of conditions. This plasticity may act as an important mechanism for rapid acclimatisation of populations to maximise fitness in a changing ocean.

Biofilm succession in an acidified ocean: mechanistic insights from a volcanic CO_2 seep study

Ro Allen[1*], Tina C. Summerfield[1], Ben Harvey[2], Sylvain Agostini[2], Linn J. Hoffmann[1]

[1] Department of Botany, University of Otago, Dunedin, New Zealand
[2] Shimoda Marine Research Center, University of Tsukuba, Japan

Biolfilms are a key microhabitat In coastal marine environments, and provide an important settlement substrate for invertebrates and habitat-forming organisms. In this study we investigated the effects of ocean acidification on early biofilm succession during an expedition to the recently described volcanic CO_2 seeps at Shikine-Jima, Japan. Volcanic CO_2 seeps are areas where CO_2 gas vents through the seafloor resulting in localized high CO_2 conditions, comparable to those projected by 2100 under the IPCC RCP 8.5 emissions scenario. We deployed acrylic slides at control (pCO_2 ~400 µatm) and high CO_2 (pCO_2 ~1000 µatm) sites, and compared the taxonomic composition of biofilms colonizing these slides after 5, 10, 15, and 21 days post-deployment. Eukaryotic and prokaryotic components of the biofilms were characterized using high-throughput sequencing of the 16S rRNA gene and 18S rRNA gene, respectively. We found that distinct eukaryotic and prokaryotic biofilm communities develop at control and high CO_2 sites over the early-successional time frame of our investigation. Eukaryotic biofilm communities were more diverse at the control site after 5 days post-deployment, but eukaryotic and prokaryotic components of the biofilm did not differ in their diversity between control and high CO_2 sites at any other time point. Moreover, compositional turnover of biofilms between time points did not significantly differ between control and high CO_2 sites. These findings reveal that high CO_2 conditions alter the structure of marine biofilms by selecting for different cohorts of eukaryotes and prokaryotes, but do not impact the successional trajectory or diversity of these communities.

Effects of altered marine biofilms on the larval settlement of a serpulid polychaete

Nadjejda Espinel[1*] & Miles Lamare[1]

[1] Department of Marine Science, University of Otago, Dunedin, New Zealand

Larval settlement and metamorphosis are key processes in the life cycle of benthic marine invertebrates. Ocean acidification (OA) could alter these processes directly (i.e. by altering the physiology or settlement capacity of the larvae), as well as indirectly (i.e. altering settlement substrates or settlement cues).

Settlement substrates and settlement cues play a very important role in the larval recognition and attachment process, and marine biofilms are key settlement inducers for a variety of taxa. Changes in bacterial assemblages or community composition could alter the settlement cues in such a way that larval settlement and metamorphosis success could be compromised.

Here, we performed a settlement experiment with polychaete larvae *(Galeolaria hystrix)* on cultured marine biofilms. For this experiment, marine biofilms were grown in a flow-through system at six pH levels (7.0, 7.2, 7.4, 7.7, 7.9 and 8.1) for 12, 9 and 6 months. Competent polychaete larvae were presented with the different biofilms and left to settle in order to quantify settlement success on the different biofilms.

The results of this research will be presented and will enable us to study the potential mechanisms through which OA might affect settlement substrates, and therefore influence the success of the settlement processes in marine invertebrates.

New Zealand coralline algae impacts of ocean acidification under low light

Christopher Cornwall [2], Chris Hepburn [1], Anna Kluibenschedl* [1] (kluan430@student.otago.ac.nz), Miles Lamare [1] and Wendy Nelson[3,4]

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[3]NIWA, Greta Point, Wellington
[4] School of Biological Sciences, Auckland University, New Zealand

CCA are ubiquitous in coastal benthic marine communities and provide a range of key ecosystem services. CCA act as framework builder, provide habitat and protection for associated organisms and induce larval settlement and survival. New Zealand (NZ) has a particularly rich diversity of CCA and detrimental impacts of climate change on CCA will be especially important to the future functioning of NZ coastal ecosystems. While CCA are generally considered to be low light adapted there is considerable debate on the interactive effects of light and increased $p\text{CO}_2$ on CCA calcification and growth. In this talk we will present results from recruitment and light data collected from a field site in southern New Zealand (Butterfly Bay, Karitane/Huriawa Peninsula, Otago). Using this data to determine ecologically relevant light levels we designed a laboratory experiment exploring the combined effects of low light and increase $p\text{CO}_2$. Natural CCA assemblages were cultivated for a total of 212 days in a 2-way full factorial design. We will share results on the recruitment and preliminary results on CCA community growth and photosynthesis.

Session1b: CARIM 1

Ocean warming has a greater effect than acidification on the early life history development and swimming performance of yellowtail kingfish

Philip L. Munday[1*], Sue-Ann Watson[1], Bridie J.M. Allan[1], Stephen M.J. Pether[2], Stephen Pope[2], Alvin N. Setiawan[2], Darren M. Parsons[3, 4]Simon Nicol[5,] Neville Smith[6]

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The individual and combined effects of warming and ocean acidification on large pelagic fishes are poorly understood. We tested the effects of projected future temperature and CO_2 levels on survival, growth, morphological development and swimming performance in the early life stages of yellowtail kingfish *Seriola lalandi*. Eggs and larvae were reared in cross-factored treatments of temperature (21 and 25 °C) and pCO_2 (500 and 985 µatm) from fertilization to 25 days post-hatching (dph). Temperature had the greatest effect on survival, growth and development. Survivorship was lower, but growth and morphological development were faster at 25 °C, with surviving fish larger and more developed at 1, 11 and 21 dph in 25 °C. Elevated CO_2 affected size at 1 dph, but not at 11 or 21 dph, and did not affect survival or development. Elevated temperature and CO_2 had opposing effects on swimming performance at 21 dph. U_{crit} was increased by elevated temperature, but reduced by elevated CO_2. Additionally, elevated temperature increased the proportion of individuals that responded to a startle stimulus, reduced latency to respond, and increased the maximum escape speed, potentially due to the more advanced developmental stage of juveniles at 25 °C. By contrast, elevated CO_2 reduced the distance moved and average speed of juveniles in response to a startle stimulus. Our results show that higher temperature is likely to be the primary driver of climate change impacts on the early life-history of kingfish; however, elevated CO_2 could affect critical aspects of swimming performance in this pelagic species.

Adaptation by a NZ coccolithophore to projected conditions in 2100

Evelyn Armstrong[1*] and Cliff Law[1,2]

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[2] National Institute of Water and Atmospheric Research, Greta Point, Kilbirnie, Wellington 6002, New Zealand.

Coccolithophores are an important global phytoplankton group that play a significant role in biogeochemistry and foodwebs of subtropical and temperate regions. We incubated a strain of the ubiquitous coccolithophore species, *Emiliania huxleyi*, isolated from NZ subantarctic waters, for two years to determine its capacity to adapt to future temperature and pH. Cells were incubated in current conditions for subantarctic water and also those projected for 2100. Growth rate under 2100 conditions was greater than that for 2015 after approximately 30 generations, and remained higher until the end of the experiment. However, the cells maintained under 2100 conditions had slower growth rates when returned to current conditions than those held consistently at current conditions, indicating adaptation of 2100 cells to future conditions between 30 and 100 generations. Cells incubated in future conditions were smaller than those in current conditions; however, when transferred to the opposing experimental condition, cells rapidly altered cell size to match those consistently cultured under both conditions. These and other physiological parameters will be presented, and the implications for the survival of *E. huxleyi* in the future discussed.

Assessing resilience of *Perna canaliculus* larvae to ocean acidification: an integrated-omics approach.

Mary A. Sewell*[1] and Norman L.C. Ragg

[1] School of Biological Sciences, University of Auckland, Auckland
[2] Cawthron Institute, Nelson

This experiment, assisted by a team of thousands, created 10 genetic families derived from a broad screening of 96 genetic lines of *Perna canaliculus* produced from the Cawthron Institute's Greenshell mussel selective breeding programme. The 96 families were assessed for larval resilience to OA and the subset of 10 families chosen on the basis of highly differentiated performance. Embryos and larvae were cultured in Control and 1100 µatm CO_2 conditions, and whole organism measures of larval performance were assessed (survival, growth, abnormality, metamorphosis success). At Day 2, samples of D-shell larvae from the 10 families were taken for –omics analyses (transcriptomics, proteomics, and metabolomics). Statistical analyses are currently underway and this talk will provide an update on the differences/similarities that we see between families in their OA response.

Both the intensity and duration of parental exposure to OA influences early offspring resilience to elevated *p*CO_2 in Greenshell mussels, *Perna canaliculus*

Norman Ragg[1]*, Emily Frost[2], Jenn Jury[2], Bridget Finnie[1], Joanna Copedo[1], Carol Peychers[1], Caitlin Fielder[1], Nikki Hawes[1], Natalí Delorme[1]

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[2]University of Auckland, Auckland, New Zealand

New Zealand's Coastal Acidification-Rates, Impact and Management programme (CARIM) has identified the endemic Greenshell mussel, *Perna canaliculus*, as a key focus for ocean acidification vulnerability research, due to its ecological and economic importance. Transgenerational plasticity can be critical to a species' ongoing success, reflecting the extent to which parental experience reflects upon offspring performance. Previous experiments conducted within CARIM have identified a key survival bottleneck for *P. canaliculus* during the first 48h of life, when fertilized eggs undergo embryogenesis and form the first shell. Transgenerational trials therefore focused on the potential to influence performance during these critical first two days of offspring development. A longitudinal experiment was undertaken whereby 1.5y-old adult *P. canaliculus* from three genetically distinct commercially-bred families were exposed to constant 400, 850 or 1100µatm *p*CO_2 seawater at 17°C and fed *ad libitum* on cultured microalgae. After three months of exposure, mussels were induced to spawn using thermal shock and gamete fertilization and subsequent embryogenesis carried out *in vitro* at 400 or 1100µatm *p*CO_2. All offspring raised under 400µatm performed well, with ~87% of eggs reaching shelled veliger stage, irrespective of parental history. Incubating embryos at 1100µatm *p*CO_2 reduced net survival to veliger by ~25%; however adult exposure to 850 or 1100µatm incrementally improved offspring performance. Adults were returned to their target *p*CO_2 treatments for a further nine months and the breeding trial repeated. Offspring performance revealed complex interactions as a result of extended adult exposure, with similar embryo survival (70 – 80%) when incubated at 400 or 1100µatm *p*CO_2. However adults exposed to 1100µatm now produced offspring that were *more* sensitive to the same environment. The implications of these findings for the species and for subsequent experimental design will be discussed.

What about the parents: how does long term exposure to reduced pH affect adult pāua?

Vonda J. Cummings[1*], Graeme Moss[1], N. Jane Halliday[1]

[1]National Institute of Water and Atmospheric Research, Wellington

Ocean acidification negatively affects multiple life history stages of marine invertebrates. Molluscs, both as highly susceptible calcium carbonate utilising organisms and an important component of the global food economy, have been well-studied in this context. While mollusc research has focused on the early, most vulnerable shell building stages, understanding the implications of reduced pH to the functioning of adults is important to predicting flow on effects to those early life stages. Additionally, physiological changes will potentially affect the nutritional quality (and taste) of shellfish seafood. Pāua, *Haliotis iris* (Gmelin, 1791) is widespread in New Zealand coastal ecosystems, and of considerable ecological, economic and cultural value. We describe a study designed to investigate the influence of prolonged exposure to reduced pH levels projected for the next decades to end-of-this-century on pāua. Adult broodstock were held at three pH_T levels (8.01, 7.80, 7.65) and ambient temperatures for 16 months. We regularly evaluated growth and examined spawning success after 5 and 16 months. At the end of the experiment, analyses of gonad characteristics (via histology), metabolic rates, scope for growth, physiological condition, and nutritional quality (e.g. fat, carbohydrate, protein), enabled a multi-factor assessment of the overall response of pāua to reduced pH. All adults survived to the end of the experiment, spawning success was clearly negatively influenced by pH, and preliminary analyses also suggest some effects on nutritional quality. We will present a comprehensive summary of the results, and the implications of our findings to future pāua population success.

The effects of multiple stressors on the escape and routine swimming performance of the New Zealand snapper *Chrysophyrs auratus*.

Bridie J.M. Allan[1*], Shannon McMahon[2], Darren M. Parsons[3, 4], Stephen M.J. Pether[5], Stephen Pope[5], & Philip L. Munday[2]

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Ocean acidification and warming are considered to be among the greatest threats facing marine organisms today. While each stressor in isolation has been studied extensively, the independent and combined effects on commercially important fishes are poorly understood. We tested the effects of elevated CO_2 (1000 µatm) and increased temperature (+4°C) on the swimming and escape kinematics of juvenile snapper *Chrysophyrs auratus*. Overall, the combined exposure to elevated CO_2 and elevated temperature had an overwhelming effect on the swimming and escape kinematics of juvenile snapper compared with the independent exposure of elevated CO_2 and elevated temperature. However, the effects were mixed with positive changes on locomotory performance and negative changes in sensory performance. We found that the combined exposure to elevated CO_2 and elevated temperature increased routine swimming behaviour, escape distances and escape speeds, potentially due to the larger size of the juveniles at 22°C yet decreased the responsiveness of individuals to the startle stimulus suggesting that their sensory performance was negatively affected. Escape performance is a consequence of both efficient locomotory capacity and finely tuned sensory responsiveness. Any process that disrupts either one of these can lead to increased predator induced mortality with negative consequences on the number of individuals recruiting to the adult population. This is the first study to address how the kinematics and swimming performance of the juvenile snapper *Chrysophyrs auratus* may change in response to concurrent exposure to elevated CO_2 and elevated temperatures and represents an important step to forecasting the responses of commercially important species to climate change.

“The effects of heatwaves and ocean acidification on juvenile snapper, *Chrysophyrs auratus*.”

Shannon McMahon*[1], Darren Parsons[2], Jennifer Donelson[1], Steve Pether[3], & Philip Munday[1]

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As anthropogenicaly driven climate change advances, coastal marine ecosystems are predicted to experience increasingly frequent and intense heatwaves, which will occur in association with ocean acidification. Elevated temperatures and CO_2 levels can present significant stress to marine organisms, especially if they occur during critical early life history stages; however their effects on ecologically and economically important fish species are relatively understudied. We used a fully cross-factored experiment to test the effects of elevated temperature (+4°C) and CO_2 (1000 µatm) on the metabolic rates, aerobic scope and swimming performance of juvenile snapper, *Chrysophyrs auratus*, in the northland region of New Zealand. Both elevated temperature and elevated CO_2 increased resting metabolic rate. By contrast, maximum metabolic rate was increased by elevated temperature and decreased by elevated CO_2. The different effects of elevated temperature and elevated CO_2 on maximum metabolic rate resulted in the aerobic scope being reduced in the elevated CO_2 treatments. Additionally, critical swimming speed was increased by elevated temperature and decrease by elevated CO_2. Elevated CO_2/low pH events already occur in the coastal habitats that larval and juvenile snapper occupy, and these events will be exacerbated by ongoing ocean acidification. Our results show that elevated CO_2 in coastal habitats will interact with heatwave conditions to affect the metabolic demands, aerobic scope and swimming performance of juvenile snapper, which could reduce their overall fitness and potentially have negative consequences for population recruitment.

Session 2: Sediments

Effect of experimental seawater CO_2 enrichment on pH in subtidal, net-heterotrophic silt deposits

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In the coastal ocean, photosynthesis by benthic microalgae oscillates the porewater pH in the surface layer of cohesive, light exposed sediment. These diel oscillations are limited to the surface layer of the sediment; the pH of the deeper porewater is less variable. A CO_2-induced decrease in the pH of the bottom seawater may offset pH oscillations at the sediment surface but leave the pH in the lower oxic zone, at the oxic–anoxic boundary, and in the deeper anoxic sediment unchanged. That is, CO_2 enrichment of the bottom seawater may not affect microbial processes at depth, e.g., nitrification and denitrification. Here, we measured pH microprofiles in intact cores of a subtidal silt deposit to describe the temporal and spatial variability in porewater pH as function of bottom seawater pH. Our measurements confirmed that diel, light-induced oscillations in porewater pH were restricted to the upper two millimeter of the silt. A decrease in the pH of the bottom seawater from 8.0 to 7.8, however, decreased the pH in the porewater of the upper 12 mm of the silt including the reactive oxic–anoxic boundary. The pH shift was strongest at the silt surface and gradually decreased with increasing depth. Starting at a depth of 12 mm, the porewater pH became independent of the seawater pH. We will discuss why this “large scale” shift in porewater pH may matter.

Short-term response of a subtidal, net-heterotrophic silt deposit to experimental warming and CO_2 enrichment

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Previous experiments with a net-heterotrophic subtidal silt deposit showed that enrichment of its overlying seawater with CO_2 can, failing other limitations, increase photosynthesis of benthic diatoms altering the silt's metabolic state (Vopel et al. 2018 Sci Rep 8:1035). Here, we investigated how such enrichment affects the silt's O_2 consumption and oxygenation as a function of temperature and in the absence of a strong positive CO_2 response of benthic diatoms. First, we submerged intact silt cores in nitrogen depleted seawater kept at in situ (12 °C) and elevated (18 °C) temperature to demonstrate that our measurements detect the expected response to seasonal warming. We then enriched the seawater overlying a subset of cold and warm-incubated cores with CO_2 (+ΔpCO_2: 254–397 µatm, –ΔpH: 0.17–0.24) and repeated these measurements. Analyses of porewater O_2 microprofiles confirmed that warming increased the silt's volume-specific O_2 consumption and deep O_2 consumption maximum (Q_{10} ~ 2.6). This and the lower O_2 saturation of the bottom seawater decreased the O_2 penetration depth. Excess CO_2 did not alter the silt's O_2 consumptions regardless of temperature. Overall, our measurements failed to demonstrate that, in the absence of a CO_2 response of benthic microalgae, excess CO_2 alters the consumption of O_2 in net-heterotrophic silt deposits.

The effects of ocean acidification on microbial nutrient cycling and productivity in coastal marine sediments

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The continued dissolution of atmospheric CO_2 into the surface of the ocean is decreasing global ocean pH which is anticipated to have a significant impact on coastal and estuarine ecosystems worldwide. The benthic microbial community plays a critical role in driving over 80% of coastal ocean primary productivity through a network of complex nutrient cycling processes. However, there is limited knowledge regarding how microbial communities and their associated critical functions will respond and adapt to shifts in water column pH. The aim of this study was to assess the effects of variable pH on benthic microbial community composition and structure. Guided by global IPCC projections this experiment employed an *in situ* mesocosm approach which enabled the simulation of a range of predicted oceanic pH regimes (pH 8.1-7.6). Surface sediment (0-1 cm) was collected for co-extraction of RNA and DNA across five timepoints and the compositional and structural responses of the microbial community to shifting pH were analysed from both 16S rDNA and 16S rRNA. ANCOM (Analysis of composition of Microbiomes) identified significant differences at the OTU level within both 16S rDNA and 16S rRNA for all pH treatments across all sample timepoints. This study demonstrates the effects of a reduction in pH on community composition within the surface sediment. The represented compositional changes are likely to be a response of direct or indirect cascading effects, as these communities are known to possess a high degree of functional resilience.

Calcium carbonate alters the functional resilience of coastal sediments to eutrophication-induced acidification

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In eutrophic systems when algal blooms collapse the input of organic matter (OM) to the benthos increases microbial respiration lowering oxygen levels and acidifying porewaters. Biodiversity losses and/or community composition shifts may follow, affecting ecosystem function. Calcite and aragonite shell material ($CaCO_3$) in coastal sediments may provide a mechanism to maintain ecosystem functions by buffering against acidification. We investigated experimentally the effect of OM loading on ecosystem function, and the potential for excess $CaCO_3$ to provide resilience against negative effects. Intertidal sand plots (1.5 m^2) were enriched with OM quantities ranging from 0-2250 g dw m^2 in a gradient design, each replicated with and without the addition of 2 kg m^{-2} ground oyster shell ($CaCO_3$). After nine weeks, light and dark solute fluxes were measured to derive measures of ecosystem function (community metabolism, nutrient regeneration, primary production), and macrofaunal communities and sediment properties were assessed. The level at which OM loading impacted ecosystem functions was higher in the presence of excess $CaCO_3$ (e.g. +$CaCO_3$ plots exhibited autotrophy up to higher levels of OM treatment than –$CaCO_3$ plots (~1400 g dw m^{-2} versus ~950)). This was despite no significant effect of $CaCO_3$ on biodiversity. Calcium carbonate may provide resilience against negative effects of eutrophication-induced acidification, maintaining some ecosystem functions.

Session 3: Session in honour of Keith Hunter

Mitigating low pH for the Mussel Aquaculture industry

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Ocean acidification is a potential threat to many calcifying organisms, which may have both ecological and economic implications. The exposure of the shellfish aquaculture industry has already resulted in the introduction of measures by industry and regional authorities to reduce potential impacts in regions that already experience low pH. With an eye to the future in NZ we have been working with the shellfish aquaculture industry in a Sustainable Seas Innovation Fund project to carry out a pilot study of methods for mitigating low pH at the scale of a mussel farm. The two methods considered are the dissolution of waste shell to elevate pH and carbonate saturation, and the use of aeration to expel excess CO_2. Preliminary results will be shown from laboratory trials, and field measurements on a Sanford mussel farm in the Marlborough Sounds.

Leveraging Observatory Networks to Better Understand Terrestrial Coastal Interactions

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The amount of atmospheric carbon taken up on land and transported from terrestrial ecosystems to the ocean along the aquatic continuum remains ill-defined and under-represented in many Earth system models. Estimates of the atmospheric carbon transported along this gradient are significant (2.5 PgCyr-1) while the exported terrestrial carbon buried in the ocean has wide range from 0.1 – 0.9 PgCyr-1 indicating a need for greater data coverage and characterization of ecosystem processes on a global scale. Coastal terrestrial-aquatic interfaces are highly dynamic hotspots of energy exchange, yet it remains unclear how much of CO2 sequestration on coastal margins is driven by increasing terrestrial nutrient fluxes. Coastal ecosystems are particularly vulnerable to ocean acidification (OA) due to the generally lower buffering capacity of coastal waters, where the carbonate chemistry is influenced by input of terrestrial carbon and riverine chemistry. Predicting the impacts of anthropogenic OA in coastal zones will require understanding the upland ecosystem processes that will drive future terrestrial-coastal fluxes. The Land-Ocean Aquatic Continuum (LOAC) represents a significant and important pathway for anthropogenic carbon and is typically assumed to be in steady-state with the terrestrial system. However, aquatic fluxes of carbon may not respond to changes in land-use and climate at the same rate and in the same magnitude as terrestrial systems. Scalable process models required for forecasting aquatic ecosystem responses to change remain limited by available data. Observatory networks provide a platform that may serve as a model for capturing such data at regional to continental spatial scales over the temporal scales necessary for both mechanistic understanding and climatological forecasting. The National Ecological Observatory Network (NEON - USA) and the Terrestrial Ecological Research Network (TERN - AUS) are two examples of large-scale networks poised to fill data gaps in the LOAC across multiple ecosystem types. Leveraging open-source, existing infrastructure and data platforms will reduce time and cost requirements for gathering this scope of data. Here I discuss methods for network science to address data and knowledge gaps in the LOAC, impacts on coastal ecosystems and how this information can guide OA mitigation strategies.

Global ocean acidification observing network: looking back, moving forward

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The Global Ocean Acidification Observing Network has grown considerably in the past six years – in membership, countries represented and capacity for information sharing and training. In 2013, at the Second GOA-ON International workshop in St Andrews, Scotland, we drew 150 scientists from 31 countries. In 2019, we now have 542 network members from 84 countries. This growth has been facilitated by energetic transnational coordination and strong public private partnerships. The establishment of the GOA-ON Distributed Secretariat in 2018 is enabling faster communication and better ability to respond to ocean acidification research and monitoring information needs, including how best to address equipping countries to respond to the emerging data needs established in Sustainable Development Goal 14.3. Public private partnerships have enabled the training of scientists new to the field of ocean acidification in developing countries around the world.

A deployable saturation state sensor towards global ocean monitoring

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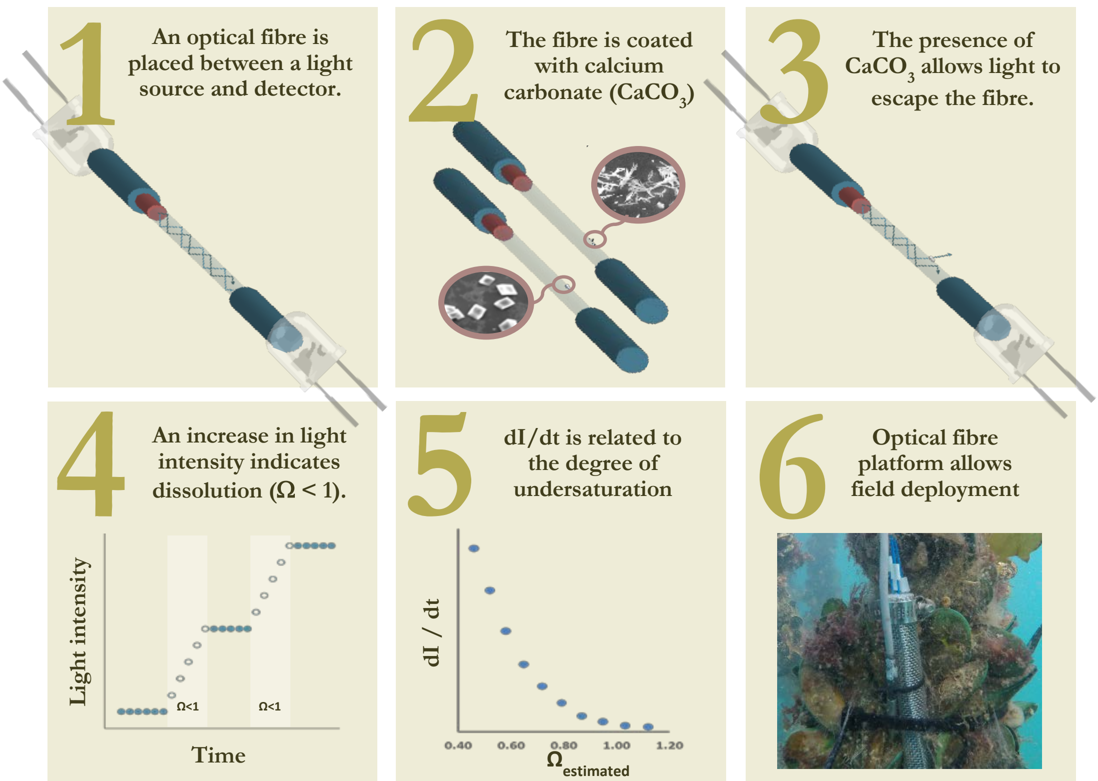
Rising atmospheric CO_2 levels and the associated decrease in ocean pH has resulted in many changes to the marine environment, with current models predicting $CaCO_3$ undersaturation in surface waters of the temperate zones by 2100. Of major concern is the effect on coastal marine ecosystems, where the low pH conditions resulting from natural variability are likely to be exasperated, affecting the growth, construction, and maintenance of $CaCO_3$ shells and skeletons of many ecologically-important calcifying organisms (e.g. corals, calcifying algae, and molluscs). Currently, efforts to monitor coastal undersaturation events and saturation horizon shoaling are constrained by the need to collect discrete samples for costly and time-consuming laboratory analysis, requiring specialized laboratory technicians and instrumentation. Previously, we have reported the development of a fibre optic-based sensor for the detection of $CaCO_3$ undersaturation events in seawater. The approach has been adapted into a field deployable sensing system, with field validation studies of prototypes conducted at the Sanford Ecofarm site in Marlborough Sounds, NZ (May 2018) and Erakor Lagoon, Vanuatu (November (2018).



Session 4: National and international coordination

Research and policy challenges for ocean acidification in Australia

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The Australian research community has played a leading role in understanding to risks of ocean acidification (OA) to marine environment, from tropical reefs to the Antarctic. A recent meeting was held in Canberra to bring researchers, industry and policy makers together to reaffirm and update the scientific community view of the risks associated with ocean acidification.

The meeting emphasised that:

- OA is a risk multiplier that may make marine life more vulnerable to other environment pressures such as extreme warming events;
- the environmental and socio-economic ramifications of OA may manifest themselves in complex ways, necessitating re-examination of current environmental risk management strategies; and
- the knowledge being built by the OA research community across Australia is detailed, world-leading, and needs integration to provide actionable information to reduce risks.

The workshop noted that ocean acidification and other marine climate-related risks need to be integrated into climate risk frameworks now being developed to fulfil the fiduciary responsibilities of companies and government agencies. OA risk needs to be considered along with climate risk in Marine Protected Area (MPA) planning and management, reef management, fisheries and aquaculture to improve informed and effective natural resource and asset management in Australian marine environments.

Research challenges include extending the insights into the ecological and geomorphological impacts from laboratory experiments and models. These need to be coupled to research strategies at ecosystem scale such as 'FOCE' experiments on the Great Barrier Reef and in Antarctica, and observation strategies that integrate long-term archives such as coral cores.

An update on the Auckland Regional Council water quality and ocean acidification monitoring program: from Auckland to beyond.

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The need to forecast anthropogenic ocean acidification (OA) in marine ecosystems has resulted in an increase in the number of publications, however the amount of environmental data which describes high-resolution pH variability in the natural environment is low. It is essential for information to detail the spatial and temporal change in seawater pH to allow researchers and policy makers to adequately understand the impacts of future pH change in marine ecosystems, and the appropriate mediation measures. In New Zealand, the adverse effects of intensive agriculture and urban development, particularly the increase in nutrient and sediment run-off, is of considerable concern. This is especially so coupled with the rise of atmospheric $p\mathrm{CO_2}$. As the Auckland region is experiencing an increase in urban development, issues around commercial and storm water discharge and some intensive agriculture, it has been highlighted that there is a major need to produce high quality, high-resolution time-series of water quality, including pH, in areas of concern. Such areas include the Mahurangi, Manukau, Waitemata and Kaipara Harbors. This presentation will highlight the ongoing water-quality program undertaken at the RIMU unit of the Auckland regional Council and the upcoming increase in high-resolution monitoring sites which will be included in the existing program, and subsequently the NZOA-ON, to help increase our knowledge of water-quality and ocean acidification at the Auckland regional scale.

UN sustainable development goals and communities of ocean action

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Abstract:
The United Nations 2030 Agenda, including the Sustainable Development Goals (SDGs) and the UN Decade of Ocean Science for Sustainable Development (2021-2030), are major initiatives aimed at delivering a sustainable future. SDG14 was established to provide a framework to “Conserve and sustainably use the oceans, seas and marine resources” and consists of ten targets, with the objective of target SDG14.3 to “Minimize and address the impacts of ocean acidification, including through cooperation at all levels”. The collection of data used to assess SDG14.3 and its main indicator of average pH at selected sites relies on national submissions, supported by voluntary commitments from a diverse range of private organizations, government agencies and institutions. The Intergovernmental Oceanographic Commission (IOC) of UNESCO has responsibility for reporting on SDG14.3 and has worked with partner organisations to build capacity and to unify reporting and data handling. The UN Community of Ocean Action on Ocean Acidification provides a framework to assess progress on voluntary commitments to the SDG and to identify gaps and opportunities for increased action to build towards the 2030 Agenda. The New Zealand Ocean Acidification program has an important role in the SDG and Community of Ocean Action processes through engagement with the observing network and coordination at national, regional and international levels to improve understanding of the likely impacts of ocean acidification. This presentation will cover progress on SDG14.3 and the Community of Ocean Action, and highlight opportunities to contribute to the Decade of Ocean Science for Sustainable Development and the 2030 Agenda.

Scientists and shellfish growers working in partnership to measure ocean acidification variables and deliver data to support shellfish aquaculture

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Our goal is improving ocean acidification measurements to yield scientific insights into nearshore OA dynamics that are applicable to aquaculture and management practices. The U.S. Integrated Ocean Observing System (IOOS) and NOAA Ocean Acidification Program have co-sponsored teams of oceanographic experts and shellfish growers at different hatcheries along the west coast of the U.S. to develop technology for near-real-time data streams of pH and aragonite saturation state. These data are viewable on the *IOOS Partners Across Coasts OA* data portal (www.ipacoa.org), with a recent expansion nationally and linkage to GOA-ON. Not only can local scales of variability in these OA parameters be viewed and interpreted, but also these can be compared across the regions, to better understand underlying factors driving variation. Using existing technologies and testing new lower cost pCO_2 sensor technology, we utilize the regional partnerships to test sensor QA/QC and establish data dissemination practices for user-friendly and standards-based web services. We also aim to provide education and outreach services to stakeholders concerned about OA. One of the payoffs to date has been a change in culture, whereby scientists view hatcheries as working laboratories for new scientific insights, and growers view the datastreams as valuable adaptation tools. As one grower put it, checking the web data stream before seeding a beach or filling a settling tank has now become standard practice. This two-way collaboration between scientists and growers is an example of how sharing perspectives serves each group's needs and bridges the science – management gap.

Multiple stressors and other complications: understanding the effects of acidification in an interesting ocean

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Ocean acidification (OA) is a substantial threat to marine species and ecosystems, but its effects will range from subtle to substantial depending on the environmental context, the physiology and genetic diversity of the affected species, and the ecological relationships among species within an ecological community. I will discuss approaches for panning back from single-species, single-stressor studies in order to appropriately capture this complexity. Specifically, I will consider the roles of 1) multiple stressors, 2) intra- and inter-generational population effects, and 3) species interactions. Although multiple stressor effects, most notably between temperature, oxygen, OA, and energy availability, have a certain degree of physiological theory underpinning our understanding of their combined action, current results do not always agree well with existing theory. Population dynamic effects can underlie important thresholds and tipping points, and emphasize the need for considering genetic diversity and multiple life history stages. Interspecific interactions ranging from prey abundance to predator effects to facilitation via biogenic habitat provisioning may all be relevant, and understanding these effects are especially important for certain species and in certain contexts. I will illustrate these ideas primarily with examples from marine invertebrate species, which are often economically valuable, ecologically important, and experimentally tractable. Although ocean acidification effects are challenging to accurately predict in advance, confronting these abiotic and ecological complexities will help us prioritize research efforts and identify systems of high vulnerability.

Session 5: CARIM 2

The trials, tribulations and successes in controlling pH and temperature in 9 giant test-tubes

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The first NIWA Ocean Acidification System (OAS) was developed in 2008 using 8 off-the-shelf industrial pH controllers coupled to a very cold (-1.8°C) custom-built seawater chiller. This early OAS allowed us to keep Antarctic bivalves alive under different constant levels of seawater pH for one year. Since then the system and its operating principles have been modified, improved and expanded to a current system that can deliver 24 different combinations of seawater pH and temperature control. Other work using the OAS has enabled research on New Zealand bivalves, abalone, spiny red lobsters, deep-sea corals, sponges, and both coralline and fleshy macroalgae. A small portable version of the system was also built to conduct experiments in under-sea-ice chambers in Antarctica and also for experiments on juvenile kingfish in the NIWA Bream Bay facility. Taking lessons from all these OASs, we expanded our horizons by designing and building an OAS comprised of 9 giant (4.5m^3) 'test-tubes' to examine the responses of phytoplankton and associated plankton communities in seawater from Evans Bay (Wellington), to predicted future changes in seawater pH and temperature. We have now completed four CARIM experiments during spring in each of the last four years. The aim of this talk is to describe some of the practical challenges and lessons learned along the way.

Coastal phytoplankton response to acidification & warming

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As key determinants of productivity and biogeochemistry, the response of phytoplankton to climate change is of considerable relevance to the future status of coastal ecosystems. This has been studied during the CARIM project in mesocosm experiments on Wellington Harbour water, in which pH and temperature were manipulated to projected future values. Four experiments were carried out over three years, under different nutrient and bloom states, with phytoplankton biomass and community composition compared to controls in low pH, and low pH/high temperature treatments. Changes in phytoplankton size class and groups varied between the experiments, reflecting nutrient and bloom status, and responses did not differ significantly between the low pH, and low pH/high temperature, treatments. Overall, the results suggest that future New Zealand coastal waters will have higher chlorophyll biomass but a less diverse phytoplankton community, with implications for biogeochemistry and foodwebs.

Will ocean acidification and warming alter DMS emissions from coastal waters?

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Certain phytoplankton groups produce dimethylsulphonopropionate (DMSP), a precursor of the trace gas dimethylsulphide (DMS), which is linked to aerosol formation and cloud properties via the CLAW hypothesis. However, future ocean acidification and warming may alter this potential feedback, via changes in plankton community composition and altered process rates. In the New Zealand CARIM project we monitored DMSP and DMS concentration over 20-days in four mesocosm experiments in which the temperature and pH of coastal water were manipulated to future projected values. Treatment-related changes in DMSP and DMS concentrations were associated with changes in phytoplankton community, and the importance of initial phytoplankton speciation was apparent from the differing responses in the four experiments. In addition, temperature had a more significant effect on DMS & DMSP than ocean acidification. The results will be compared with international studies and assessed in the context of future climate feedback.

Climate change impact on coastal particulate organic matter cycling and nutritional value, using amino acid concentrations and C and N stable isotopes

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Anthropogenic emissions are impacting oceans on a global scale and will alter the structure and functioning of marine ecosystems. The health of a marine food web strongly depends on the availability of food at the primary producers' level. We investigated the influence of ocean acidification and global warming on the quantity and quality of C and N, in the form of amino acid (AA), in particulate organic matter (POM) during a 22-day large-scale mesocosm experiment as part of CARIM. We used two treatments and a control (in duplicate), with the control mimicking the 2017 pH and temperature conditions, and the two treatments simulating projected conditions for NZ coastal waters in 2100 (+2.6 ^{o}C, – 0.33 pH) and 2150 conditions (+4.5 ^{o}C, – 0.5 pH).

We found no significant effect of the various treatments on the AA POM concentrations. We then further investigated the origin and subsequent cycling of POM using AA-specific stable isotope analysis, and C and N elemental compositions. The C:N ratio, the δ^{13}C of all AA, as well as the δ^{15}N of threonine (a metabolic AA) indicated a clear species switch in the phytoplankton community in the various treatments. Additionally, heterotrophic bacteria recycling was not exacerbated by the treatments as shown by a $\delta^{15}N_{AA}$-based proxy (ΣV).

Overall, these results suggest that the combined effect of ocean warming and ocean acidification will likely cause a species switch in the phytoplankton community, but should however not affect the food quality and quantity available to the base of future marine ecosystems.

Grazing of calanoid copepod *Temora turbinata* on natural prey communities during the CARIM Mesocosm 4 experiment

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Copepod grazing can place a significant top-down control on phytoplankton biomass and assemblage composition, which can ultimately shape higher trophic level dynamics. Though copepods have been thought to be tolerant of ocean acidification, previous findings suggest future ocean conditions may affect copepod feeding behavior directly through changes in metabolic demands, and indirectly through changes in the nutritional quality of prey. To assess the possible effects of ocean acidification and warming on copepod grazing and feeding selectivity, we employed 24-hour feeding incubations using calanoid copepod *Temora turbinata* and natural prey communities under ambient, low pH, and low pH + high temperature conditions during the CARIM Mesocosm 4 experiment (ME4). Here we present and discuss preliminary data from these ME4 copepod grazing incubations.

Bacterial communities show resilience to climate change in New Zealand's coastal waters

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Bacterial communities are essential in coastal marine ecosystems, cycling nutrients and performing the microbial loop, which transfers dissolved organic matter up the food chain.

As atmospheric concentrations of CO_2 increase, ocean temperatures are increasing and pH is decreasing. In the open oceans, these changes have been shown to have insignificant effects on bacterial diversity and overall community function. However, the effects on coastal waters have had little research, despite the economic and cultural significance of the coastal marine ecosystems.

Bacterial diversity and changes to the community was measured during an 18-day mesocosm experiment conducted at NIWA in Wellington. The experimental treatments compared current conditions with the estimated pCO_2 levels projected to 2100, as well as a treatment with both the pCO_2 and temperature projected for 2100. During the course of the experiments, DNA samples were taken consistently throughout the experiment. From these, the 16s rRNA gene was sequenced to determine the bacterial communities present. There were no significant treatment effects to the overall bacterial communities, backing up the hypothesis that bacterial communities show resilience to climate change.

Biogeochemical ROMS modelling of NZ shelves for present day and future states

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Global climate change is predicted to alter the physical and biogeochemical structure of the world's oceans, affecting stressors such as the oceanic pH. Understanding ocean acidification and knowing what to expect in the future requires an understanding of the non-linear interactions between biological (e.g. food availability, predator-prey dynamics), biogeochemical (nutrient and carbon cycling) and physical (e.g. temperature, currents) processes. Studying these processes can be problematic as data are often sparse and are often not available for all the required variables. Biogeochemical models are a good way to interpolate between sparse data, especially as this approach encompasses the whole system. Here we have set up a coupled physical biogeochemical modelling system for the Hauraki Gulf. The Hauraki Gulf shelf, Gulf and Firth of Thames system is affected by riverine inputs as well as offshore oceanographic conditions and these have been accounted for in the model. We will discuss situations in which the model is useful along with its limitations. We will then present outputs from the model that are important for investigating ocean acidification. We will discuss the impact of the offshore oceanic conditions versus riverine inputs in the Hauraki Gulf system. These models are expected to be useful in understanding ocean acidification and how it will change with changes in land uses and offshore oceanic conditions.

The spatial and temporal variability of ocean acidification in the Firth of Thames/Hauraki Gulf - CARIM

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Carbonate parameters (alkalinity and dissolved inorganic carbon (DIC)) have been analysed on over 300 water samples from the Hauraki Gulf/Firth of Thames over the last 10 years. These carbonate data were used in conjunction with hydrographic data (temperature, salinity, oxygen and depth) to develop multiple linear regression algorithms and neural networks to estimate the carbonate parameters for the Hauraki Gulf region. There is good agreement between the measured and estimated alkalinity (R^2>0.8) and DIC (R^2>0.75) using the MLR and the alkalinity using the neural networks (R^2>0.85). These MLR algorithms were then used to map out the estimated spatial and seasonal changes in the region for the years 2003 and 2013 and temporal changes in carbonate parameters over the last 20 years (1998-2018) at the site SA03. DIC is strongly influenced by oxygen concentrations and as a result displays a strong seasonal cycle with surface waters showing low DIC in the winter, while deep waters (>15m) display high DIC in the summer and autumn. pCO_2 shows a similar trend to DIC, while pH shows the opposite trend (Fig. 1). Alkalinity is strongly associated with the salinity (freshwater influx), which can occur at any time of the year. As a result of the high freshwater flux into the inner Firth, the lowest alkalinity, DIC, pH, pCO_2 and aragonite concentrations are present in this region, and trend to more open ocean values in the outer Hauraki Gulf.

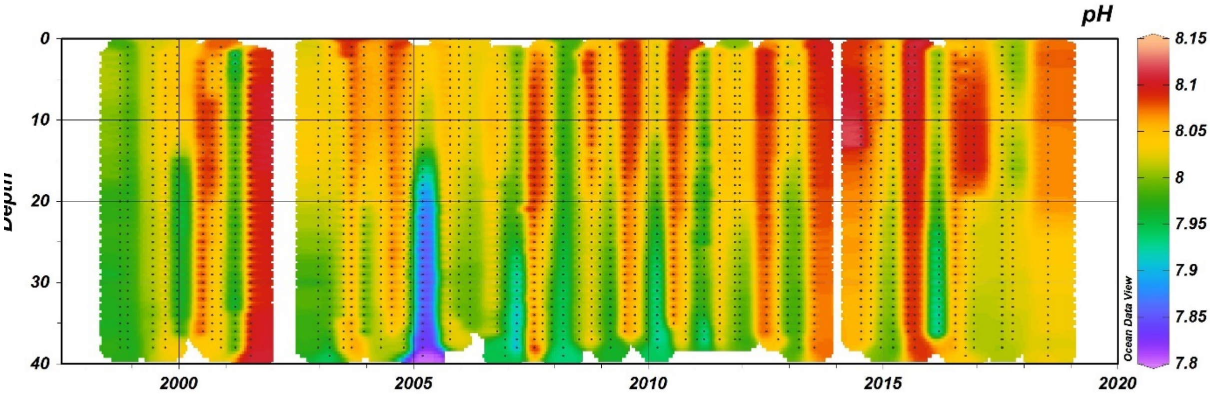

Figure 1: Time series of estimated pH from CTD data at site SA03 from 1998 to 2018, showing seasonal variations. High pH is seen throughout the water column in winter, while low pH is present in the summer and autumn, especially below 15 m.

Posters

1. Solubility of natural carbonate samples.

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Ocean acidification is shifting the equilibria of the carbonate system resulting in a decrease of CO_3^{2-}. Less CO_3^{2-} will lower the carbonate mineral saturation state (Ω) according to equation 1, making the seawater more corrosive if $\Omega_{\mathrm{mineral}} < 1$.

$$\Omega_{\mathrm{mineral}} = \frac{[\mathrm{Me}^{2+}][\mathrm{CO}_3^{2-}]}{\mathrm{K}_{\mathrm{sp}}^{*}} \qquad (1)$$

Many marine organisms incorporate carbonate minerals as biogenic hard parts. A decrease in the saturation state of these minerals will thus have a direct effect on marine biota. Knowing the conditions of undersaturation are key in understanding the implications of ocean acidification but, as of today, little is known regarding the dissolution of natural samples. The goal of this project is to develop a robust and effective method that enables comparison of the dissolution of natural samples, of varying calcium carbonate composition, in a reproducible way. Using a fiber sensor system, designed at the University of Otago, we have developed new methodology to obtain high resolution data of the dissolution behavior of natural carbonate minerals in a controlled environment. This approach can be used to identify the seawater conditions where Ω transitions from >1 to <1, allowing more accurate evaluation of the effects of ocean acidification. Studying natural samples, which better reflect the diversity and complexity of the real world, will improve our understanding and knowledge regarding ocean acidification and its consequences on a local and global scale.

2. The impact of reduced seawater pH on the starfish and sea urchin egg jelly coat

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The echinoderm egg is surrounded by an extracellular jelly coat which is sensitive to seawater pH with ocean acidification reducing its thickness. This reduction may have a negative effect on fertilisation. We investigated the impact of reduced pH (pH 7.8 and pH 7.6) on the jelly coat of the sea urchins *Centrostephanus rodgersii* and *Heliocidaris tuberculata* and the starfish *Odontaster validus*, *Acanthaster planci* and *Patiriella regularis.* For the sea urchins, the jelly coat decreased by up to 60% after 5 minutes in pH 7.6. There was no difference in the jelly coat area of starfish with reduced pH and does not appear to be pH-sensitive. Differences in jelly coat composition and vulnerability to decreased pH may drive the species-specific response to ocean acidification. Reductions to jelly coat size as a result of OA would be expected to be detrimental for fertilisation by decreasing the physical size of the egg for sperm.

3. The effects of coralline-algal diffusion boundary layers on juvenile sea urchin, *Pseudechinus huttoni*, under ocean acidification

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The diffusive boundary layer (DBL) is a micro-layer of seawater around marine organisms where the chemical and physical environment differs from mainstream seawater. Under ocean acidification (OA), DBLs can be an environmental buffer from corrosive mainstream pH. Metabolic processes (photosynthesis and respiration) controlled by light drive pH variability, while physical processes (flow) determine DBL thickness (Hurd et al., 2011, Cornwall et al., 2014). Oxygen and pH in the DBL have been studied, but the effects on invertebrates within the DBL are not well understood. This study aimed to understand the effects of crustose coralline-algal (CCA) DBLs on the growth of newly settled sea urchins, *Pseudechinus huttoni*. Oxygen concentrations were measured above the CCA surfaces in different flow, irradiance and bulk pH conditions to determine DBL thickness and pH deviation from bulk seawater. Oxygen was used as a proxy for pH based on previous research (Cornwall et al. 2014). Sea urchin larvae were settled on CCA and subsequently grown in different DBL conditions: light and dark in three bulk seawater pH levels (7.4, 7.7 and 8.1). After four days, juveniles were removed, preserved and photographed; test diameter and spine length were measured. This study shows that organisms living within the DBL, particularly in slow flow, already experience large variations in pH due to metabolic processes. This has important implications for organisms' ability to adapt and cope under OA. The effect of pH variability on growth of newly settled urchins was less clear, with large variability in morphometrics in different DBL conditions.

4. respR: An R package for the analysis of respirometry data

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In climate change research, estimating metabolic rates with respirometry is increasingly used to study resilience, where both ocean warming and acidification are expected to alter metabolism in ectotherms. As respirometry datasets become increasingly large and analytical approaches more complex, manipulating the data remains a challenge and often intractable with existing tools. Here, we describe the **respR** R package, a collection of functions that implement a workflow-based approach to automate the analysis and visualisation of respirometry data. The package can be used for closed, intermittent flow, flow-through and open-tank respirometry and uses well-defined sets of rules to reliably and rapidly generate reproducible results. We demonstrate how **respR** uses novel computing methods such as rolling regressions and machine learning techniques to reliably detect maximum, minimum, most linear section(s) of the data, and critical oxygen tension P_{crit}. Although designed specifically with aquatic respirometry in mind, the object-oriented approach of the package and the unit-less nature of its analytical functions mean that parts of the package can easily be used to estimate linear relationships from a range of applications in many research disciplines.

5. Impact of growing up in a warmer, lower pH future on offspring performance: transgenerational plasticity in a pan-tropical sea urchin

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Transgenerational plasticity (TGP) may be an important mechanism for marine organisms to acclimate to climate change stressors such as ocean warming and acidification. Conversely, environmental stress experienced by one generation may have detrimental effects on subsequent generations. We examined transgenerational plasticity in embryo and larval stages of the pan tropical sea urchin, Tripneustes gratilla (Linnaeus, 1758) (Toxopneustidae), in response to OA (pH 7.77), OW (+2°C), or both OA and OW, (OAW +2°C, pH 7.77) using an F_0 generation reared in treatments from the early juvenile stage (2-3 cm TD - test diameter) to the mature adult stage (7-8 cm TD), incorporating the entire period of gonadogenesis and germ line differentiation. Larvae of parents cultured in OA and OAW treatments from the outset of gonadogenesis and germ cell differentiation were resilient to the effects of acidification, while larvae of parents acclimated to OW and OAW treatments developed a greater tolerance to warmer temperature (29°C). Environmental stress experienced by parents, however, had predominantly negative effects on the offspring size of OA, OW, and OAW treatment parents, with reductions in larval arm lengths by as much as 21.4%. Eggs produced by females raised at 29°C through ovary development (both OW and OAW) were up to 21.8% smaller than those of females raised at 27°C (both control and OA). In this first study for a marine macroinvertebrate to acclimate the parental generation over their reproductive life, we highlight the complexity of TGP and the importance of trade-offs in terms of parental fitness and reproductive investment when considering the effects of climate change on marine organisms.

6. Fibre optic pH microsensor for studying the impact of ocean acidification on the marine environment

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To understand the effects of ocean acidification on marine organisms, pH microsensors have been widely used to study the biological processes which are typically determined by the localised microenvironment chemistry. Most of the present OA research is based on the miniature pH electrodes. Microelectrode pH sensors are usually expensive and fragile. They suffer interference from electromagnetic fields, high sodium content in seawater and have insufficient spatial resolution. In this research we propose an alternate pH measurement method based on optical fibres. The fibre optical pH microsensor consists of a pH sensitive dye or fluorescence indicator which is immobilised in a polymerised matrix at the end of the unclad portion of the optical fibre. When an incident beam of light passes through the optical fibre the light interacts with the indicator. The outgoing light carries the pH information back to the detector. (Figure 1.) A deployable field application configuration will be developed in this research. Fibre optic pH microsensor is inexpensive compare to microelectrode type thus marine researches should find the fibre optic pH microsensor a useful and affordable tool. The fibre optic pH microsensor developed in this work will allow marine scientists to conduct laboratory based, as well as in-situ studies into the impact of ocean acidification on the microenvironment of marine organisms and coastal ecosystems. The matrix knowledge gained from this research can be further employed to other optical sensing, such as oxygen, CO_2, and salinity.

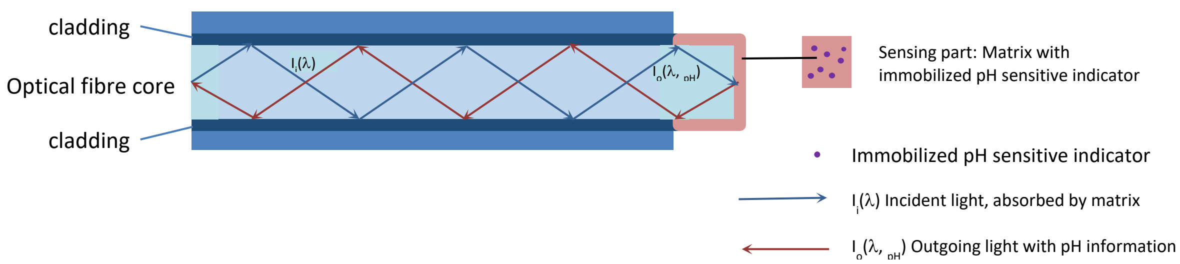

Figure 1. Drawing of the optical sensing configuration

7. Refining low-cost carbonate ion selective electrodes for 2D profiling

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Quantitative knowledge of carbonate ion concentration is desirable due to the critical role the carbonate equilibrium plays in oceanic ecosystems. Carbonate has traditionally been determined indirectly with time consuming and labour intensive techniques. As such, the development of instrumentation capable of direct evaluation of carbonate concentration in aquatic samples is of growing interest to the research and environmental monitoring community. To date, limited success has been achieved with the development of carbonate Ion Selective Electrodes (ISEs), however membrane instability and insufficiently low detection limits (LDL) inhibit their applicability for extended use in marine environments. Here we present a simple and low-cost approach for the preparation of carbonate ISEs with the required stability and sensitivity for environmental deployment. A single strip solid contact electrode, created using pencil graphite applied to the surface of an acetate sheet, can act as the foundation for both carbonate and reference electrodes. Initial results indicate the electrodes exhibit excellent sensing properties, including selectivity towards carbonate ions, a wide dynamic response range, fast response time, and satisfactory long-term stability. Finally, a 2-Dimensional ISE array will be implemented to give a real-time spatial profile of a tidal rockpool, demonstrating the potential of a low-cost sensing system for monitoring carbon cycle parameters.

8. Design and employment of a new portable CO_2 system for ocean acidification experiments

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A new, portable, and customizable Ocean Acidification CO_2 system was completed in mid-September 2018 at Otago University's Botany and Chemistry Departments. The primary system components include a series of mass flow controllers, an aquarium pump, CO_2 scrubbers, and a CO_2 source connected with Tygon tubing. For its inaugural employment, the system was transported to NIWA Wellington for use on an RV Tangaroa voyage (TAN1810, 21 Oct. – 21 Nov. 2018) to research the biogeochemical role of salps and other zooplankton in the Chatham Rise region. On the voyage, the system was used carry out two, five-day experiments designed to assess the effect of ocean acidification on physical and chemical characteristics of salp fecal pellets. Here we discuss the design, construction, and uses for this new Ocean Acidification CO_2 system.

9. Combatting the effects of ocean acidification on farmed molluscs

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As the world's oceans continue to decrease in pH, New Zealand's shellfish industry becomes increasingly vulnerable. Ocean acidification (OA) has already had serious ramifications for marine ecosystems around the globe, most notably in Oregon and Washington (USA). In this region, the seafood industry is projected to experience a loss of $1.4 – 6.5 billion by 2060 due to the widespread effects of OA including − but not limited to − the decline in growth of molluscs, which began in 2006. These dramatic changes can be attributed in part to local conditions that aggravate the effects of OA. Each year, strong northern winds cause a phenomena known as 'coastal upwelling,' where nutrient dense, low pH water is brought up from the ocean floor. When it reaches the surface, plankton break down the rich organic matter and release more CO_2 which further decreases the pH of the surrounding water. Oyster and mollusc larvae have been shown to experience higher mortality, stunted growth and malformation under these conditions, which has decreased the viability of the seafood industry in Oregon. Without intervention − and long term emissions reductions schemes − New Zealand's seafood industry could experience the same decline. This project explores the use of recycled shells to re-release $CaCO_3$ into the local aqueous environment. This process shifts the carbonate chemistry equilibria to super-saturation of $CaCO_3$, which favours the growth and viability of shellfish. Currently, work focuses on finding a suitable substrate for slow release of $CaCO_3$ into seawater.

10. Effects of ocean acidification on Antarctic marine microbial communities

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Antarctic marine microbes are the drivers of productivity, elemental cycling and effect ocean biogeochemistry. Despite Antarctic waters being amongst the most vulnerable in the world to increased CO_2, little is known about how these microbial communities will respond to ocean acidification. A six-level dose-response experiment was conducted using 650 L incubation tanks (minicosms) adjusted to CO_2 levels ranging from 343-1641µatm. Microscopy, flow cytometry and phylogenetic marker gene sequencing (16S rDNA) was used to investigate the effect of ocean acidification on the bacterial, archaeal and protistan community structure. Our results show that the response of both autotrophic and heterotrophic protists to CO_2 was species-specific. The response of diatoms was mainly related to cell size; microplanktonic diatoms (> 20µm) increased in abundance with low to moderate CO_2 (343-634 µatm). Similarly, the abundance of *Phaeocystis antarctica* increased with increasing CO2 peaking at 634µatm. Above this threshold the abundance of micro-sized diatoms and *P. antarctica* fell dramatically, and nanoplanktonic diatoms (≤ 20µm) dominated, therefore culminating in a significant change in the protistan community composition. No significant effect of CO_2 was seen on the bacterial community composition despite higher abundances at CO_2 ≥ 953µatm. Our findings suggest that by 2100 under a "business as usual scenario", ocean acidification could change the microbial community structure and interactions, thereby altering the ecosystem services these communities provide. The flow-on effects of such changes could have significant consequences for the Antarctic food web and elemental cycling if anthropogenic CO_2 release continues unabated.

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