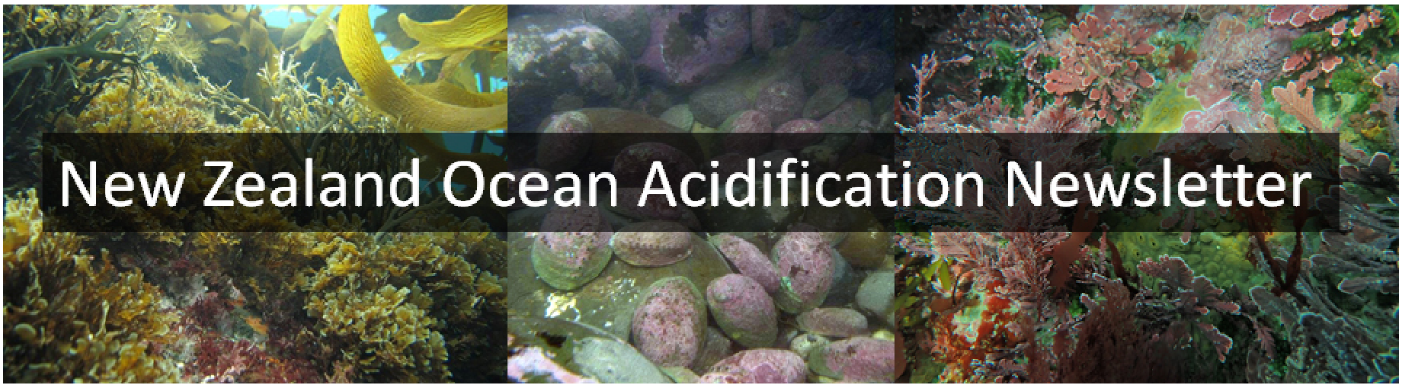
#64 – April to May 2020 (http://nzoac.nz/)



Job opportunities

Graduate assistantship in eutrophication and coastal acidification

Graduate research assistantship is available to support a student pursuing M.S. or Ph. D. degree in the Department of Oceanography and Coastal Sciences, College of Coast and Environment, Louisiana State University, starting Fall 2020. LSU's College of the Coast & Environment (CC&E) has been at the forefront of coastal and environmental issues for nearly a century. Interested candidates should have a B.S. or M.S. degree in environmental sciences, marine sciences, marine biology, geology, physical sciences or related fields.

The major focus of research for the selected student would be to work on a funded project to understand the impact of eutrophication and estuarine acidification on water quality and biology in coastal Louisiana.

Tuition waiver and 12-month research assistantship will be provided for admitted applicant, who are expected to conduct lab and field research and report the results in scientific conferences and peer-reviewed journals, leading towards a successful completion of graduate degree.

If you meet the minimum qualifications and would like to know more about it, please contact Dr. Kanchan Maiti at kmaiti@lsu.edu for further information.

More information.

Selection of recent papers

Global ocean spectrophotometric pH assessment: consistent inconsistencies. Ocean Acidification (OA)—or the decrease in seawater pH resulting from ocean uptake of CO_2 released by human activities—stresses ocean ecosystems and is recognized as a Climate and Sustainable Development Goal Indicator that needs to be evaluated and monitored. Monitoring OA related pH changes requires a high level of precision and accuracy. The two most common ways to quantify seawater pH are to measure it spectrophotometrically or to calculate it from Total Alkalinity (TA) and Dissolved Inorganic Carbon (DIC). However, despite decades of research, small but important inconsistencies remain between measured and calculated pH. To date, this issue has been circumvented by examining changes only in consistently-measured properties. Currently, the oceanographic community is defining new observational strategies for OA and other key aspects of the ocean carbon cycle based on novel sensors and technologies, that rely on validation against data records and/or synthesis products. Comparison of measured spectrophotometric pH to calculated pH from TA and DIC measured during the 2000s and 2010s eras, reveals that: 1) there is an evolution towards a better agreement between measured and calculated pH over time from 0.02 pH units in the 2000s to 0.01 pH units in the 2010s at pH>7.6; 2) a disagreement greater than 0.01 pH units persists in waters with pH<7.6, and 3) inconsistencies likely stem from variations in the spectrophotometric pH standard operating procedure (SOP). A reassessment of pH measurement and calculation SOPs and metrology is urgently needed.

Álvarez M, Fajar N. M., Carter B. R., Guallart E. F., Pérez F. F., Woosley R. J. & Murata A., in press. Global ocean spectrophotometric pH assessment: consistent inconsistencies. *Environmental Science & Technology*. Article.

Response of phytoplankton assemblages from naturally acidic coastal ecosystems to elevated pCO_2. The interplay of coastal oceanographic processes usually results in partial pressures of CO_2 (pCO_2) higher than expected from the equilibrium with the atmosphere and even higher than those expected by the end of the century. Although this is a well-known situation, the natural variability of seawater chemistry at the locations from which tested organisms or communities originate is seldom considered in ocean acidification experiments. In this work, we aimed to evaluate the role of the carbonate chemistry dynamics in shaping the response of coastal phytoplankton communities to increased pCO_2 levels. The study was conducted at two coastal ecosystems off Chile, the Valdivia River estuary and the coastal upwelling ecosystem in the Arauco Gulf. We characterized the seasonal variability (winter/summer) of the hydrographic conditions, the carbonate system parameters, and the phytoplankton community structure at both sites. The results showed that carbonate chemistry dynamics in the estuary were mainly related to seasonal changes in freshwater discharges, with acidic and corrosive conditions dominating in winter. In the Arauco Gulf, these conditions were observed in summer, mainly associated with the upwelling of cold and high pCO_2 (>1,000 µatm) waters. Diatoms dominated the phytoplankton communities at both sites, yet the one in Valdivia was more diverse. Only certain phytoplankton groups in this latter ecosystem showed a significant correlations with the carbonate system parameters. When the impact of elevated pCO_2 levels was investigated by pCO_2 manipulation experiments, we did not observe any significant effect on the biomass of either of the two communities. Changes in the phytoplankton species composition and abundance during the incubations were related to other factors, such as competition and growth phases. Our findings highlight the importance of the natural variability of coastal ecosystems and the potential for local adaptation in determining responses of coastal phytoplankton communities to increased pCO_2 levels.
Osma N., Latorre-Melín L., Jacob B., Contreras P. Y., von Dassow P., Vargas C. A., 2020. Response of phytoplankton assemblages from naturally acidic coastal ecosystems to elevated pCO2. *Frontiers in Marine Science* 7, 323. doi: 10.3389/fmars.2020.00323

Trace metal accumulation in the commercial mussel *M. galloprovincialis* under future climate change scenarios. The current trend of climatic alterations will accelerate the modification of the ocean system by, among other aspects, changing the metal speciation and its bioavailability which may have an impact in their accumulation by marine organisms. Understanding the impact of these potential changes is essential for future risk assessment of metal contamination. In the present study, we selected the species Mediterranean mussel (*Mytilus galloprovincialis*) as the main European aquaculture production bivalve and due to its widespread use for biomonitoring purposes. A long-term test (2 months) was carried out to explore the impact that global change in the marine environment (warming and CO_2 increase) may exert on the accumulation of dissolved trace metals (Cu, Co, Pb, Cd, Cr, As and Ni) in different body parts of mussels (foot and soft tissue).
Studied mussels were collected at two different climatic locations (Atlantic and Mediterranean Sea) and exposed to unspiked, unpolluted seawater from the Vigo Ria (NW Iberian Peninsula). Results showed that under the global change conditions proposed in this study (1100 pCO_2 and 25 °C), the increase in temperature resulted in a lower condition index and byssus strength for mussels from Atlantic Sea, while Mediterranean sea mussels, adapted to higher temperatures, did not show remarkable variations. According to trace metals accumulation in different body parts of the studied mussels, it was observed that the effect of increasing CO_2 alone did not show to have an impact in the bioaccumulation, but the combined stressors (increase in CO_2 and temperature) may lead to an increase in the bioaccumulation for some elements. The increase in temperature resulted in a decrease of the Cu content of foot tissue (byssus gland) in mussels from Atlantic Sea, which is in accordance with the lower byssus strength observed under such conditions. Our results indicate that the expected seawater temperature increase, which will be produced gradually during next decades, should be further study to ensure the species adaptability and aquaculture production.

Romero-Freire A., Lassoued J., Silva E., Calvo S., Pérez F. F., Bejaoui N., Babarro J. M. F. & Cobelo-García A., in press. Trace metal accumulation in the commercial mussel *M. galloprovincialis* under future climate change scenarios. *Marine Chemistry*. Article (subscription required).

Toward a mechanistic understanding of marine invertebrate behavior at elevated CO_2. Elevated carbon dioxide (CO_2) levels can alter ecologically important behaviors in a range of marine invertebrate taxa; however, a clear mechanistic understanding of these behavioral changes is lacking. The majority of mechanistic research on the behavioral effects of elevated CO_2 has been done in fish, focusing on disrupted functioning of the $GABA_A$ receptor (a ligand-gated ion channel, LGIC). Yet, elevated CO_2 could induce behavioral alterations through a range of mechanisms that disturb different components of the neurobiological pathway that produces behavior, including disrupted sensation, altered behavioral choices and disturbed LGIC-mediated neurotransmission. Here, we review the potential mechanisms by which elevated CO_2 may affect marine invertebrate behaviors. Marine invertebrate acid–base physiology and pharmacology is discussed in relation to altered $GABA_A$ receptor functioning. Alternative mechanisms for behavioral change at elevated CO_2 are considered and important topics for future research have been identified. A mechanistic understanding will be important to determine why there is variability in elevated CO_2-induced behavioral alterations across marine invertebrate taxa, why some, but not other, behaviors are affected within a species and to identify which marine invertebrates will be most vulnerable to rising CO_2 levels.

Thomas J. T., Munday P. L. & Watson S-A., 2020. Toward a mechanistic understanding of marine invertebrate behavior at elevated CO2. *Frontiers in Marine Science*. 7:345. doi: 10.3389/fmars.2020.00345. Article.

Decreased motility of flagellated microalgae long-term acclimated to CO_2-induced acidified waters. Motility plays a critical role in algal survival and reproduction, with implications for aquatic ecosystem stability. However, the effect of elevated CO_2 on marine, brackish and freshwater algal motility is unclear. Here we show, using laboratory microscale and field mesoscale experiments, that three typical phytoplankton species had decreased motility with increased CO_2. Polar marine *Microglena* sp., euryhaline *Dunaliella salina* and freshwater *Chlamydomonas reinhardtii* were grown under different CO_2 concentrations for 5 years. Long-term acclimated *Microglena* sp. showed substantially decreased photo-responses in all treatments, with a photophobic reaction affecting intracellular calcium concentration. Genes regulating flagellar movement were significantly downregulated ($P < 0.05$), alongside a significant increase in gene expression for flagellar shedding ($P < 0.05$). *D. salina* and *C. reinhardtii* showed similar results, suggesting that motility changes are common across flagellated species. As the flagella structure and bending mechanism are conserved from unicellular organisms to vertebrates, these results suggest that increasing surface water CO_2 concentrations may affect flagellated cells from algae to fish.
Wang, Y., Fan, X., Gao, G., Beardall J., Inaba K., Hall-Spencer J. M., Xu D., Zhang X., Han W., McMinn A. & Ye N., in press. Decreased motility of flagellated microalgae long-term acclimated to CO_2-induced acidified waters. *Nature Climate Change*. Article.

The pH dependency of the boron isotopic composition of diatom opal. The high-latitude oceans are key areas of carbon and heat exchange between the atmosphere and the ocean. As such, they are a focus of both modern oceanographic and palaeoclimate research. However, most palaeoclimate proxies that could provide a long-term perspective are based on calcareous organisms, such as foraminifera, that are scarce or entirely absent in deep-sea sediments south of 50◦ S in the Southern Ocean and north of 40◦ N in the North Pacific. As a result, proxies need to be developed for the opal-based organisms (e.g. diatoms) found at these high latitudes, which dominate the biogenic sediments recovered from these regions. Here we present a method for the analysis of the boron (B) content and isotopic composition (δ^{11}B) of diatom opal. We apply it for the first time to evaluate the relationship between seawater pH, δ^{11}B and B concentration ([B]) in the frustules of the diatom *Thalassiosira weissflogii*, cultured across a range of carbon dioxide partial pressure (pCO_2) and pH values. In agreement with existing data, we find that the [B] of the cultured diatom frustules increases with increasing pH (Mejía et al., 2013). δ^{11}B shows a relatively well defined negative trend with increasing pH, completely distinct from any other biomineral previously measured. This relationship not only has implications for the magnitude of the isotopic fractionation that occurs during boron incorporation into opal, but also allows us to explore the potential of the boron-based proxies for palaeo-pH and palaeo-CO_2 reconstruction in high-latitude marine sediments that have, up until now, eluded study due to the lack of suitable carbonate material.

Donald, H. K., Foster, G. L., Fröhberg, N., Swann, G. E. A., Poulton, A. J., Moore, C. M. & Humphreys, M. P., 2020. The pH dependency of the boron isotopic composition of diatom opal (*Thalassiosira weissflogii*). *Biogeosciences* 17, 2825–2837. Article.

Characterizing biogeochemical fluctuations in a world of extremes: A synthesis for temperate intertidal habitats in the face of global change Coastal and intertidal habitats are at the forefront of anthropogenic influence and environmental change. The species occupying these habitats are adapted to a world of extremes, which may render them robust to the changing climate or more vulnerable if they are at their physiological limits. We characterized the diurnal, seasonal and interannual patterns of flux in biogeochemistry across an intertidal gradient on a temperate sandstone platform in eastern Australia over 6 years (2009–2015) and present a synthesis of our current understanding of this habitat in context with global change. We used rock pools as natural mesocosms to determine biogeochemistry dynamics and patterns of eco-stress experienced by resident biota. In situ measurements and discrete water samples were collected night and day during neap low tide events to capture diurnal biogeochemistry cycles. Calculation of pH_T using total alkalinity (TA) and dissolved inorganic carbon (DIC) revealed that the mid-intertidal habitat exhibited the greatest flux over the years (pH_T 7.52–8.87), and over a single tidal cycle (1.11 pH_T units), while the low-intertidal (pH_T 7.82–8.30) and subtidal (pH_T 7.87–8.30) were less variable. Temperature flux was also greatest in the mid-intertidal (8.0–34.5°C) and over a single tidal event (14°C range), as typical of temperate rocky shores. Mean TA and DIC increased at night and decreased during the day, with the most extreme conditions measured in the mid-intertidal owing to prolonged emersion periods. Temporal sampling revealed that net ecosystem calcification and production were highest during the day and lowest at night, particularly in the mid-intertidal. Characterization of biogeochemical fluctuations in a world of extremes demonstrates the variable conditions that intertidal biota routinely experience and highlight potential microhabitat-specific vulnerabilities and climate change refugia.

Wolfe K., Nguyen H. D., Davey M. & Byrne M., in press. Characterizing biogeochemical fluctuations in a world of extremes: A synthesis for temperate intertidal habitats in the face of global change. *Global Change Biol*ogy. Article (subscription required).

Temporal variability modulates pH impact on larval sea urchin development: Themed issue article: Biomechanics and climate change Coastal organisms reside in highly dynamic habitats. Global climate change is expected to alter not only the mean of the physical conditions experienced but also the frequencies and/or the magnitude of fluctuations of environmental factors. Understanding responses in an ecologically relevant context is essential for formulating management strategies. In particular, there are increasing suggestions that exposure to fluctuations could alleviate the impact of climate change-related stressors by selecting for plasticity that may help acclimatization to future conditions. However, it remains unclear whether the presence of fluctuations alone is sufficient to confer such effects or whether the pattern of the fluctuations matters. Therefore, we investigated the role of frequency and initial conditions of the fluctuations on performance by exposing larval sea urchin *Heliocidaris crassispina* to either constant or fluctuating pH. Reduced pH alone (pH 7.3 vs 8.0) did not affect larval mortality but reduced the growth of larval arms in the static pH treatments. Changes in morphology could affect the swimming mechanics for these small organisms, and geometric morphometric analysis further suggested an overall shape change such that acidified larvae had more U-shaped bodies and shorter arms, which would help maintain stability in moving water. The relative negative impact of lower pH, computed as log response ratio, on larval arm development was smaller when larvae were exposed to pH fluctuations, especially when the change was less frequent (48- vs 24-h cycle). Furthermore, larvae experiencing an initial pH drop, i.e. those where the cycle started at pH 8.0, were more negatively impacted compared with those kept at an initial pH of 7.3 before the cycling started. Our observations suggest that larval responses to climate change stress could not be easily predicted from mean conditions. Instead, to better predict organismal performance in the future ocean, monitoring and investigation of the role of real-time environmental fluctuations along the dispersive pathway is key.

Chan K. Y. K & Tong C. S. D., 2020. Temporal variability modulates pH impact on larval sea urchin development: Themed issue article: Biomechanics and climate change,. *Conservation Physiology* 8(1): coaa008. doi:10.1093/conphys/coaa008. Article.

Examining the role of DNA methylation in transcriptomic plasticity of early stage sea urchins: developmental and maternal effects in a kelp forest herbivore. Gene expression plasticity can confer physiological plasticity in response to the environment. However, whether epigenetic marks contribute to the dynamics of gene expression is still not well described in most marine invertebrates. Here, we explored the extent and molecular basis of intra- and intergenerational plasticity in the purple sea urchin, *Strongylocentrotus purpuratus*, by examining relationships between changes in DNA methylation, transcription, and embryo spicule length. Adult urchins were conditioned in the lab for 4 months to treatments that represent upwelling (~1200 µatm pCO_2, 13°C) and non-upwelling conditions (~500 µatm pCO_2, 17°C). Embryos spawned from conditioned adults were reared in either the same adult treatment or the reciprocal condition. Maternal conditioning resulted in significantly differentially methylated CpG sites and differential gene expression in embryos, despite no evidence of maternal effects on embryo spicule length. In contrast, conditions experienced during development resulted in significant differences in embryo spicule length. Intragenerational plasticity in spicule length was strongly correlated to transcriptomic plasticity, despite low levels of intragenerational plasticity in CpG methylation. We find plasticity in DNA methylation and gene expression in response to different maternal environments and these changes have similarities across broad functional groups of genes; yet exhibit little overlap on a gene-by-gene basis. Our results suggest that different forms of environmentally induced plasticity are observable across different time scales and that DNA methylation dynamics may be uncoupled from fast transcriptional responses to the environment and whole organism traits. Overall, this study illuminates the extent to which environmental differences can induce both intra- and intergenerational phenotypic plasticity in a common kelp forest herbivore.

Strader M. E., Kozal L. C., Leach T. S., Wong J. M., Chamorro J. D., Housh M.J. & Hofmann G. E., 2020. Examining the role of DNA methylation in transcriptomic plasticity of early stage sea urchins: developmental and maternal effects in a kelp forest herbivore. *Frontiers in Marine Science* 7: 205. doi: 10.3389/fmars.2020.00205. Article.

Ocean acidification and dynamic energy budget models: parameterisation and simulations for the green-lipped mussel Ocean acidification (OA), the change in ocean chemistry caused by carbon dioxide emissions, poses a serious imminent threat to marine organisms, especially those with calcium carbonate shells. The green-lipped mussel (Perna canaliculus), endemic to New Zealand, is common in coastal ecosystems and is an economically important aquaculture species. As a step towards supporting aquaculture management in a changing environment, we used a dynamic energy budget (DEB) model to investigate the potential influence of OA on growth and reproduction of the mussel. Zero-variate and growth data from local mussel farms were used to parameterise the model with the AmP method. The parameter estimation showed an acceptable goodness of fit, with a low mean relative error of 0.143 and the symmetric mean squared error of 0.125. The model was subsequently modified to estimate parameter values under OA conditions, based on data obtained from laboratory experiments where mussels were grown at future projected reduced pH (elevated pCO2) levels. The maintenance ([ṗM]) and volume-specific cost for growth ([EG]) were identified as the key parameters in response to OA. The model was then applied to simulate mussel energetics under pCO2 scenarios projected for 2050 and 2100. The model predicts that decreasing pH would cause reductions in shell length growth, flesh weight and reproductive capacity. As well as providing a quantitative tool for understanding the influence of OA on mussel physiology, this DEB model is also an important component of individual-based population and ecosystem models, enabling simulation of complex population and ecosystem level responses to OA.

Ren J. S., Ragg N. L. C., Cummings V. J. & Zhang J., 2020. Ocean acidification and dynamic energy budget models: parameterisation and simulations for the green-lipped mussel. *Ecological Modelling* 426: 109069. doi: 10.1016/j.ecolmodel.2020.109069. Article.

Adjustments in fatty acid composition is a mechanism that can explain resilience to marine heatwaves and future ocean conditions in the habitat-forming seaweed *Phyllospora comosa* (Labillardière) C.Agardh. Marine heatwaves are extreme events that can have profound and lasting impacts on marine species. Field observations have shown seaweeds to be highly susceptible to marine heatwaves, but the physiological drivers of this susceptibility are poorly understood. Furthermore, the effects of marine heatwaves in conjunction with ocean warming and acidification are yet to be investigated. To address this knowledge gap, we conducted a laboratory culture experiment in which we tested the growth and physiological responses of Phyllospora comosa juveniles from the southern extent of its range (43–31°S) to marine heatwaves, ocean warming and acidification. We used a 'collapsed factorial design' in which marine heatwaves were superimposed on current (today's pH and temperature) and future (pH and temperature projected by 2100) ocean conditions. Responses were tested both during the heatwaves, and after a 7-day recovery period. Heatwaves reduced net photosynthetic rates in both current and future conditions, while respiration rates were elevated under heatwaves in the current conditions only. Following the recovery period, there was little evidence of heatwaves having lasting negative effects on growth, photosynthesis or respiration. Exposure to heatwaves, future ocean conditions or both caused an increase in the degree of saturation of fatty acids. This adjustment may have counteracted negative effects of elevated temperatures by decreasing membrane fluidity, which increases at higher temperatures. Furthermore, P. comosa appeared to down-regulate the energetically expensive carbon dioxide concentrating mechanism in the future conditions with a reduction in δ13C values detected in these treatments. Any saved energy arising from this down-regulation was not invested in growth and was likely invested in the adjustment of fatty acid composition. This adjustment is a mechanism by which P. comosa and other seaweeds may tolerate the negative effects of ocean warming and marine heatwaves through benefits arising from ocean acidification.

Britton D., Schmid M., Noisette F., Havenhand J. N., Paine E. R., McGraw C. M., Revill A. T., Virtue P., Nichols P. D., Mundy C. N. & Hurd C. L., in press. Adjustments in fatty acid composition is a mechanism that can explain resilience to marine heatwaves and future ocean conditions in the habitat-forming seaweed Phyllospora comosa (Labillardière) C.Agardh. *Global Change Biology*. Article (subscription required).