



The Ocean in a High-CO₂ World

Ocean Acidification

6th International Science Symposium

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THE 6TH INTERNATIONAL SYMPOSIUM ON THE OCEAN IN A HIGH-CO₂ WORLD

BOOK OF ABSTRACTS

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Abstracts are presented in programme order and
organised by session date and time, session title,
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Safeguarding Taonga in a Changing World: Leveraging Genomics for Climate-Resilient Kaimoana in Aotearoa New Zealand

Dr Nathan Kenny

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Keynote 1: Nathan Kenny, Rongomātāne, October 13, 2026, 09:50 - 10:30

As climate change reshapes ecosystems through ocean warming, acidification, marine heatwaves, and changing patterns of disease and productivity, it threatens the sustainability of culturally, nutritionally, and economically important kaimoana (seafood). In Aotearoa/New Zealand, many of these species are also taonga (treasured species), underpinning the wellbeing, identity, and customary practices of Māori communities. Developing effective adaptation strategies to safeguard these species therefore requires approaches that simultaneously strengthen ecological resilience and support community aspirations.

Applying genomic analyses, population genetics, and novel molecular-based biodiversity monitoring tools, our work identifies patterns of connectivity, adaptive variation, and population resilience that inform conservation, restoration, and fisheries management. We have applied these approaches in a number of invertebrate species, particularly mollusc species of interest to aquaculture, generating results that inform industry as well as providing actionable information for safeguarding marine biodiversity and maintaining ecosystem services.

Central to this research is partnership with Māori, who exercise kaitiakitanga (guardianship) over relevant coastal environments and resources. Research priorities, sampling strategies, and pathways to application have been developed collaboratively to ensure outcomes are relevant to local communities and support intergenerational stewardship. Equally important is the recognition of Māori data sovereignty, with genomic and environmental data governed through frameworks that respect indigenous rights, authority, and decision-making.

By integrating cutting-edge genomics with mātauranga (indigenous knowledge) and community-led stewardship, our work attempts to move climate adaptation science beyond documenting impacts, to delivering practical, equitable solutions for coastal resilience in a high-CO₂ world.

“Our Own Cultural Rules”: Indigenous Leadership and the Future of Arctic Ocean Stewardship

Dr Cana Uluak Itchuaqiyaq¹

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Keynote 2: Cana Uluak Itchuaqiyaq, Rongomātāne, October 13, 2026, 10:30 - 11:10

In 1994, Inuit leader Caleb Pungowiyi testified before the US Congress about marine mammals. In that testimony he reminded lawmakers that Inuit communities “have managed our resources and our use of marine mammals by our own cultural rules. And these rules have been successful for hundreds of years. And we continue to abide by them today.” In the context of authority over Arctic resources, this statement was also an assertion of sovereignty—an insistence that Inuit systems of knowledge and stewardship have long governed Arctic waters.

That same year, his strong-willed and rebellious daughter began college intending to study environmental science, only to pursue the humanities. Thirty years later, as a humanities scholar, she founded the Center for Sustainable Engagement in the Arctic (CSEA) at Virginia Tech—an Arctic research center designed to address Arctic Indigenous self-determined priorities through scientific collaboration.

In developing CSEA's Central Arctic Ocean (CAO) Working Group, Cana Uluak Itchuaqiyaq brings together Inuit scholars from the Alaskan Arctic, including Inuit youth, alongside Virginia Tech researchers from the humanities to engineering. Members are disciplinary outsiders to CAO research. In its own way, the group continues the earlier assertion of “our own cultural rules,” approaching questions through curiosity rather than established disciplinary pathways.

This approach offers a different vantage point on Arctic Ocean futures—one shaped by Indigenous leadership, community priorities, and collaboration across fields and generations. This keynote argues that the future of Arctic Ocean stewardship may depend on voices that have long been outside the institutions that study it.

The effects of ocean acidification to coral eco-physiology seen from shallow CO₂ vents studies

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1A: Assessing high-CO₂ and multi-stressor effects on aquatic organisms using natural laboratories of climate change, Rongomātāne A, October 13, 2026, 11:45 - 13:00

Shallow volcanic CO₂ vents provide unique opportunities to investigate the effects of chronic exposure to elevated CO₂ on coral ecophysiology. Here, we reviewed the literature on this topic. An extensive Web of Science search yielded 153 papers, of which 43 were relevant; an additional Google Scholar search increased this number to 58. In total, 20 study sites were identified, with the Upa Upasina site in Papua New Guinea being the most extensively studied (20 studies). The pioneering Castello Aragonese site in Ischia, Italy—despite its location in the warm-temperate Mediterranean Sea—was the third most frequently used site for studying the effects of elevated CO₂ on corals. Most studies were conducted in the Indo-Pacific region. All sites exhibited CO₂ levels representative of or exceeding future projections, but also showed large temporal variability that may influence observations, and lacked the combined effects of warming.

Ecological studies dominated the literature (28 studies), followed by physiological studies (22 studies), of which 21 focused on host responses—particularly calcification—while fewer addressed zooxanthellae (7 studies). Only three studies employed genomic approaches to investigate potential adaptive mechanisms in corals under elevated CO₂. This review highlights both the insights gained from shallow CO₂ vents as natural laboratories and the existing gaps, particularly the need for greater replication across systems. Addressing this is a key focus of the ICONA network, which aims to foster collaboration among researchers working in these unique systems.

Temperature structures sea urchin responses to ocean acidification across global CO₂ seeps

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1A: Assessing high-CO₂ and multi-stressor effects on aquatic organisms using natural laboratories of climate change, Rongomātāne A, October 13, 2026, 11:45 - 13:00

Naturally acidified CO₂ seeps provide opportunities to assess the capacity of organisms to persist under low pH conditions in ecologically realistic settings. However, few studies systematically compare responses to low pH at CO₂ seeps across multiple regions and taxa, making it difficult to disentangle variation attributable to biogeography, taxonomy, or other environmental factors from consistent trends driven by ocean acidification. Here, we analysed the skeletal traits of five sea urchin genera distributed across ten natural CO₂ seeps and nearby reference sites spanning temperate, subtropical, and tropical reefs, to examine their responses to varying pH and temperature regimes. Our analyses reveal general patterns that demonstrate both the limits and flexibility of calcifier plasticity; while some skeletal properties, such as test biomineral content and thickness, are typically compromised under low pH, others are preserved. Seawater temperatures strongly structured responses to reduced pH between regions: for almost all skeletal properties, higher median sea surface temperature buffered or even reversed the negative effects of low pH. Deviations from global trends among genera revealed genus-specific sensitivities to OA, highlighting the need for caution when generalising from single-species studies. Together, our results reveal trade-offs in skeletal responses to ocean acidification, and show that their magnitude and direction vary with latitude, temperature regime, and evolutionary history, underscoring the nuanced, context-dependent nature of calcifier vulnerability in warming, high-CO₂ oceans.

Natural analogues of climate change as a tool to study processes from genes to ecosystems

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1A: Assessing high-CO₂ and multi-stressor effects on aquatic organisms using natural laboratories of climate change, Rongomātāne A, October 13, 2026, 11:45 - 13:00

Climate change is rapidly reshaping fish populations, communities, and ecosystem functioning across marine, freshwater, and estuarine systems. While laboratory experiments have revealed important physiological and behavioural responses, they often fail to capture ecological complexity, long-term exposure, and feedbacks across biological levels of organisation. Natural analogues of climate change, such as ocean warming hotspots and volcanic CO₂ seeps, are therefore a useful tool to study climate change impacts in a natural setting. They can not only reveal the potential direct effect of various climate stressors, but also indirect effects such as habitat change and altered species interactions. A review of the literature on fish studies performed at climate change analogues reveals how gene expression, physiological compensation and behavioural plasticity can scale up to influence population demography, species interactions, food-web structure, and ecosystem processes. Across systems, climate change further appears to favour ecological generalists, alter trophic pathways, reduce functional diversity, mediate poleward range shifts, and drive habitat phase shifts. These changes can reorganise energy flow, intensify herbivory, simplify food webs, and modify ecosystem resilience, with important consequences for fisheries and conservation. To better predict future fish communities and ecosystem functioning, integrated frameworks are needed that combine natural analogues, laboratory experiments and quantitative modelling to link mechanisms with emergent ecological outcomes. Such holistic approaches are essential for developing realistic climate adaptation, conservation, and management strategies in a rapidly changing ocean.

Molecular basis and behavioral adjustments reveal potential local adaptation to acidifying oceans, a lesson from natural analogues.

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1A: Assessing high-CO₂ and multi-stressor effects on aquatic organisms using natural laboratories of climate change, Rongomātāne A, October 13, 2026, 11:45 - 13:00

The first response by animals to a changing environment is predominantly through modification of their behavior. In this context, investigating behavioral responses of fish living under low pH/high-CO₂ conditions may contribute to a better understanding of how marine species might adjust or adapt to future environmental conditions. We carried out field-based observations and translocation experiments in Nikko Bay (Palau) to assess whether there is evidence for local behavioral adaptation and/or acclimatization of fish after long and short-term exposure to ocean acidification conditions. We examined whether environmentally driven shifts in habitat structure inside Nikko Bay influence the behavior and brain gene expression of the pajama cardinalfish (*Sphaeramia nematoptera*), a coral-associated specialist. Using in situ observations and a reciprocal transplant experiment, we moved individuals between control reefs and inner-bay sites to assess both short- and long-term acclimation potential. Furthermore, understanding the molecular underpinnings responsible for acclimatization to acidified waters, by means of an integrated study of the brain transcriptional program of wild fish species, can elucidate on the variation in responses. We collected 130 individuals of six different reef fish species from a natural volcanic CO₂ seep and nearby control reefs in Upa Upasina in Papua New Guinea. Differences in brain gene expression in fish from CO₂ seeps compared to fish from control sites as well as differences among species identified the molecular pathways controlling the cellular responses to elevated CO₂. These studies provide a broader understanding as to the behavioral and molecular alterations crucial for coping with naturally elevated CO₂ conditions.

Assessment of community photosynthesis of macroalgal beds using volcanic CO₂ seep

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1A: Assessing high-CO₂ and multi-stressor effects on aquatic organisms using natural laboratories of climate change, Rongomātāne A, October 13, 2026, 11:45 - 13:00

Ocean acidification (OA), driven by rising CO₂, is expected to impact marine ecosystems. While elevated CO₂ might enhance “Blue Carbon” storage in vascular plants, the response of macroalgal-dominated communities remains poorly understood due to their unique photosynthetic physiology. This study investigated whether elevated CO₂ increases macroalgal community photosynthesis. We conducted experiments at volcanic CO₂ vents off Shikine Island, Japan, using these as natural analogues for future ocean conditions. Two independent approaches were used to estimate net community photosynthesis; Chamber experiment and monitoring water mass dynamics. Additionally, δ¹³C isotope analysis was performed to evaluate the performance of CO₂ Concentrating Mechanisms (CCMs). Despite significant shifts in species composition from canopy-forming and coralline algae at reference sites to low-profile and turf algae at high-CO₂ sites, net community photosynthesis remained similar between locations. Isotope data showed that high-CO₂ environments favored species with reduced CCM activity. These findings challenge the assumption that OA will boost Blue Carbon sequestration in macroalgal beds, necessitating a reevaluation of their role in climate change mitigation.

Bringing Together Indigenous Observations and Ocean Modeling to Understand Arctic Extreme Events

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1B: Knowledge systems: Understanding a high-CO₂ Arctic: observations, modeling, impacts, and emerging approaches across scientific and Indigenous knowledge systems, Rongomātāne B, October 13, 2026, 11:45 - 13:00

Arctic Indigenous communities are on the front lines of rapid ocean change. Marine heatwaves, ocean acidification, and low-oxygen events are increasing in frequency and intensity, with direct consequences for food security, harvesting practices, and coastal livelihoods. Indigenous Peoples have observed and documented these changes through sustained relationships with Arctic marine environments for time immemorial, yet this knowledge has not been brought into regional ocean model development and evaluation. As a result, models remain disconnected from the lived realities of the people most affected by Arctic change.

We present an emerging approach to evaluating Arctic Ocean model output with Indigenous observations from the Alaska Arctic Observatory and Knowledge Hub (AAOKH), an Indigenous-led network with nearly two decades of environmental observations across Arctic Alaska. In partnership with Iñupiat observers and Indigenous scholars we are developing ARC10, a prototype Arctic regional configuration of MOM6-COBALT.

AAOKH observations of sea ice, ocean temperature, and ecosystem conditions reveal fine-scale coastal dynamics, seasonal nuance, and ecological linkages that conventional datasets miss. A key focus is aligning model-derived patterns of extreme events, with what Indigenous observers have documented on the water. Community priorities directly shape the questions we ask of the model, and as Indigenous observations reveal where the model falls short, targeted improvements make it progressively more useful for addressing those questions.

This work moves toward Arctic Ocean models that are scientifically rigorous and grounded in Indigenous ways of knowing, tools that serve the people who depend on a rapidly changing Arctic Ocean.

Community and Indigenous-led observations are essential for understanding the effects of marine climate change

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1B: Knowledge systems: Understanding a high-CO₂ Arctic: observations, modeling, impacts, and emerging approaches across scientific and Indigenous knowledge systems, Rongomātāne B, October 13, 2026, 11:45 - 13:00

Effective rebuilding of coastal ecosystems affected by climate change requires accurate and timely information, ideally over long time periods. In remote Arctic regions experiencing accelerated marine ecosystem changes such as Alaska's coastal region, these data are often sparse, logistically challenging, and costly - as well as limited in space and time. Furthermore, community-led observations rooted in the Indigenous Knowledge of the Iñupiat of Arctic Alaska are an underutilized, and perhaps undervalued, resource to fill these gaps. The Alaska Arctic Observatory and Knowledge Hub (AAOKH; <https://arctic-aok.org/>) is a community-based network of Iñupiaq environmental observers focused on local monitoring and knowledge exchange, allowing a platform for Indigenous observers to tell their region's story of environmental conditions and what it means – from their own perspectives. Since 2006, AAOKH has recorded over 12,000 records from across Arctic Alaska coastal communities, documenting sea ice, ocean conditions, weather, wildlife, coastal erosion, flooding, and extreme events. These observations are shared in the context of customary Indigenous harvesting, making the dataset more holistic and directly relevant to establishing community priorities and transformative and actionable science. With a mission to strengthen Indigenous-led stewardship of environmental observations and knowledge, we use AAOKH examples to show that when community-led observations are put into practice alongside other scientific approaches the result is not just more relevant and responsive to the needs and priorities of the people most affected by environmental change; community-led observations serve critical roles to produce better science with more robust results to understand Arctic marine ecology and conservation.

Ocean acidification may increase the biological impact of legacy metal pollution; a study of mine waste deposits in Arctic Norway.

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1B: Knowledge systems: Understanding a high-CO₂ Arctic: observations, modeling, impacts, and emerging approaches across scientific and Indigenous knowledge systems, Rongomātāne B, October 13, 2026, 11:45 - 13:00

Historically Norway has used fjords for the disposal of waste including mine-tailings, fine grained waste material produced by mining activity which is often contaminated with toxic metals. At present advice to regulators regarding the possible legacy effects of proposed, present, and historic mine-tailing deposits in Arctic fjords is based on current environmental conditions. However, little is known about how metals associated with these mine tailings will interact with climate change and ocean acidification and subsequent effects on costal fisheries and aquaculture. Recent studies of commercial bivalve species show that elevated pCO₂ leads to adjustments in coelomic acid-base balance, with increased bicarbonate concentrations buffering pH in response to elevated pCO₂. However, this bicarbonate compensation is not observed in bivalve's exposed to mine tailings resulting in significant acidosis, increased metabolic costs, and mortality. To further investigate the mechanisms and breakpoints behind these physiological responses *A. islandica*, and *V. corrugate* were exposed for 5 weeks to sediments collected from historic mine-tailing deposits (Repparfjorden, Norway) in combination with 5 different pH/pCO₂ treatments (pH 7.4 to 8.2). When exposed to mine-tailings the activity of gill enzymes (Na⁺/K⁺-ATPase) involved in ion-regulation and critical for bicarbonate up-take was reduced. Combined with effects on energetics and electron transport chain activity, and the increased bioavailability of metals under more acidic conditions, metal contamination may further exacerbate the negative effects of ocean acidification. The findings from our investigation highlight the regulatory importance of considering future environmental conditions when assessing the possible legacy effects of proposed, present, and historic mining activities.

Sensitivity of Arctic Ocean CO₂ Uptake to Carbon Release from Seafloor Sediments

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1B: Knowledge systems: Understanding a high-CO₂ Arctic: observations, modeling, impacts, and emerging approaches across scientific and Indigenous knowledge systems, Rongomātāne B, October 13, 2026, 11:45 - 13:00

Arctic shelf seas absorb a substantial amount of atmospheric CO₂ owing to their extensive open-water areas and high primary productivity. However, seafloor sediments and subsea permafrost can supply additional carbon to the water column, modifying the seawater carbonate system and corresponding air–sea CO₂ exchange. To quantify these impacts, we conducted multi-decadal sensitivity experiments for 1979–2025 using a pan-Arctic sea ice–ocean biogeochemical model (COCO & Arctic NEMURO-C), in which additional biogeochemical inputs from seafloor sediments are incorporated in selected regions.

The simulation results indicate that additional biogeochemical inputs from seafloor substantially elevate surface seawater pCO₂ over Arctic shelf seas. Especially in the Eurasian Arctic seas, air–sea CO₂ exchange shifts from net uptake in the baseline simulation to net outgassing, suggesting a reversal from an atmospheric CO₂ sink to a source. The effects of carbon release from seafloor are not limited to source regions, but extend to the central Arctic Ocean, likely driven by lateral carbon transport associated with ocean circulation.

Under ongoing climate warming and enhanced benthic carbon release, Arctic shelf seas may gradually lose their capacity to mitigate rising atmospheric CO₂. This process provides important implications for future Arctic carbon–climate feedbacks.

Biological thresholds and monitoring needs for ocean alkalinity enhancement across marine taxa

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1C: Ocean Solutions: Global Ocean Acidification Observing Network Perspectives on Ocean Solutions, Rongomātāne C, October 13, 2026, 11:45 - 13:00

Ocean alkalinity enhancement (OAE) is increasingly considered as a climate mitigation strategy, yet its biological impacts across taxa and life stages remain insufficiently constrained. Understanding organismal responses to altered carbonate chemistry is essential for evaluating ecological risk and informing safe deployment. Here, we synthesize experimental evidence across multiple marine invertebrates, including crabs, krill, copepods, oyster larvae, and echinoderms, to examine sensitivity to OAE under controlled laboratory conditions. Using phase-structured exposure regimes, we investigate responses to both transient and sustained carbonate chemistry changes across early life stages and developmental transitions. Endpoints include survival, molting, development, and calcification, alongside sublethal indicators of physiological stress. Our approach focuses on identifying biological thresholds and response domains that differentiate lethal from sublethal effects. Across taxa, early developmental stages emerge as particularly sensitive, with disruptions to molting and development occurring under conditions that do not induce acute mortality. These patterns suggest a hierarchical sensitivity structure, where sublethal processes respond at lower thresholds than survival, with potential consequences for recruitment and population dynamics. Persistent governance fragmentation, limited MRV capacity, and uneven readiness highlight the need to operationalize biological thresholds as decision-relevant indicators, enabling standardized monitoring, risk assessment, and credible, scalable deployment pathways. We further evaluate how experimentally derived thresholds can inform monitoring strategies by identifying early-warning biological indicators that precede population-level impacts. This work advances a biology-centered framework for evaluating OAE impacts and highlights the importance of incorporating mechanistic, life-stage-resolved responses into assessment, monitoring, and governance of ocean-based climate interventions.

Monitoring of physico-chemical parameters related to ocean acidification: The case of Mauritius

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1C: Ocean Solutions: Global Ocean Acidification Observing Network Perspectives on Ocean Solutions,
Rongomātāne C, October 13, 2026, 11:45 - 13:00

Five stations around Mauritius namely Flic-en-Flac, Albion, Mont Choisy, Trou-d'Eau-Douce and La Cambuse were selected for sea water sampling over 12 months from July 2021 to June 2022 for the analysis of dissolved oxygen (D.O), pHT and Total alkalinity (AT). This pioneered study provided reliable data related to ocean acidification for Mauritius. The summer mean values of sea surface temperature (SST), D.O, pHT and AT varied from 28.2 ± 1.3 °C to 29.8 ± 2.2 °C, from 6.60 ± 1.15 mgL⁻¹ to 8.11 ± 0.51 mgL⁻¹, from 8.10 ± 0.09 to 8.20 ± 0.12 and from 2324.5 ± 110.6 μmolkg⁻¹ to 2384.8 ± 118.6 μmolkg⁻¹, respectively. The winter mean values of these parameters varied from 24.7 ± 1.1 °C to 26.1 ± 1.4 °C, from 6.55 ± 1.21 mgL⁻¹ to 8.26 ± 0.67 mgL⁻¹, from 8.00 ± 0.08 to 8.13 ± 0.14 and from 2397.2 ± 84.9 μmolkg⁻¹ to 2448.7 ± 108.5 μmolkg⁻¹, respectively. The Two-way measures ANOVA and the post hoc analysis showed that (1) Albion and La Cambuse had a comparable mean pHT variability over the two seasons, even though they have opposite bearings and morphology, but their mean D.O variability was the opposite (2) the mean temporal variability in D.O and pHT at Mont Choisy were not significant due to the presence of sea grasses.

Diel pH and pCO₂ trends in estuarine mariculture sites in Pangasinan, Northwestern Philippines

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1C: Ocean Solutions: Global Ocean Acidification Observing Network Perspectives on Ocean Solutions,
Rongomātāne C, October 13, 2026, 11:45 - 13:00

Estuaries are sites of dynamic coastal processes that are acting in concert with riverine, tidal, atmospheric, and anthropogenic forcings. To understand the influence of riverine inputs to coastal acidification in a tropical mariculture area, we utilized the Global Ocean Acidification-Observing Network (GOA-ON)-in-a-Box kit's autonomous sensors for pH and pCO₂, along with temperature, salinity, and dissolved oxygen, which were deployed at strategic sites (Bani River mouth and mariculture-impacted Caquiputan Strait) in an estuarine embayment in Pangasinan, Philippines. Continuous 24-hour measurements (15-minute intervals) at one-meter depth were conducted during a spring tidal cycle in May 2025 to characterize diel variability in carbonate parameters during the dry season. Results revealed distinct spatial and temporal patterns, potentially driven by tidal mixing, freshwater influence, and mariculture activity. Bani River mouth exhibited relatively lower pH (7.2163–7.7315) and salinity ranges, a wide range of pCO₂ values (710–3,500 ppm), and large dissolved oxygen fluctuations (0.38–12.14 mg/L), possibly indicating strong biological activity and restricted water exchange. In contrast, Caquiputan Strait showed relatively higher pH (7.3983–8.0705) and salinity, and atypically elevated daytime pCO₂ (up to 2,060 ppm), likely linked to decomposition of organic matter from mariculture. Both sites exhibited strong diel coupling among pH, pCO₂, dissolved oxygen, temperature, and salinity, confirming the sensitivity of the system to short-term environmental forcing. In-depth analysis of data will help estimate the contribution of rivers to acidification in the estuarine embayment, which is important for long-term time-series monitoring and as inputs to biogeochemical models that will aim to simulate recovery from coastal acidification.

Addressing the current metrology challenges involved in quantification of baseline conditions for mCDR in coastal and open ocean environments

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1C: Ocean Solutions: Global Ocean Acidification Observing Network Perspectives on Ocean Solutions,
Rongomātāne C, October 13, 2026, 11:45 - 13:00

To adequately assess the utility of mCDR schemes requires a thorough determination of the baseline conditions at each site, with respect to carbon system parameters (DIC, alkalinity, pCO₂ and pH). Best practice for determining this parameters involves the use of Certified Reference Materials (CRMs), which have been characterized by metrologically valid procedures to ensure traceability, and that the measurements are accurate and comparable for quality control purposes. Presently there is a global shortage of CRMs suitable for determining the carbon system in seawater, coupled with logistical and environmental concerns which likely limit the collection of GOA-ON 'climate' quality data. In Europe the JPI-Oceans Knowledge Hub on Ocean Carbon Capacities has recently developed a road map for Ocean Carbon Reference Materials (https://www.jpi-oceans.eu/sites/jpi-oceans.eu/files/2025-08/occ_roadmap_august_2025.pdf). In the context of the JPI-Oceans road map, this presentation will outline current research in our laboratory in Ireland that is focused on developing new approaches to ocean carbon CRMs and encouraging their use in mCDR and OA studies. This includes: (i) the applicability of alternative preservation methods to HgCl₂ for seawater CRMs and how these use can be incorporated into the design of mCDR quantification schemes, (ii) lessons from a shipboard intercomparison for pH, using GOA-ON protocols, on a GO-SHIP expedition in the North Pacific, (iii) application of a Membrane Inlet Mass Spectrometer (MIMS) to carbon and oxygen isotopic measurements in the Atlantic.

Ocean Acidification in Papua New Guinea: Challenges, Opportunities, and Next Steps for Action

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1C: Ocean Solutions: Global Ocean Acidification Observing Network Perspectives on Ocean Solutions, Rongomātāne C, October 13, 2026, 11:45 - 13:00

Papua New Guinea's coastal and island communities depend heavily on healthy marine ecosystems for food security, livelihoods, shoreline protection, and cultural well-being. However, increasing ocean acidification, warming seas, coral reef degradation, and other climate-driven stressors are placing significant pressure on these systems, threatening fisheries, biodiversity, and long-term coastal resilience. Despite the country's high vulnerability, ocean acidification remains an under-monitored and under-prioritized issue within national marine management and climate adaptation planning.

This presentation provides an overview of the current ocean acidification landscape in Papua New Guinea, highlighting existing knowledge, emerging risks, and critical research gaps that require urgent attention. It draws on professional experience, regional research, and ongoing scientific engagement to examine the practical challenges facing ocean acidification action, including limited monitoring infrastructure, technical capacity constraints, fragmented institutional coordination, insufficient long-term funding, and weak integration of ocean acidification science into policy and decision-making.

At the same time, significant opportunities exist to strengthen national response systems through improved monitoring, stronger partnerships between government, researchers, communities, and regional networks, and greater investment in nature-based solutions such as coral reef restoration, mangrove protection, and blue carbon ecosystem management. Tools such as the Global Ocean Acidification Observing Network in a Box Kit demonstrate the potential for accessible local monitoring and capacity building.

This presentation outlines practical next steps for advancing ocean acidification action in Papua New Guinea and emphasizes the importance of moving from awareness to implementation to support long-term ocean sustainability and coastal resilience in a high-CO₂ world.

Pacific Islands Ocean Acidification Centre

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1C: Ocean Solutions: Global Ocean Acidification Observing Network Perspectives on Ocean Solutions, Rongomātāne C, October 13, 2026, 11:45 - 13:00

To address the impacts of ocean acidification, Pacific Islands and Territories must understand local ocean acidification conditions, draw on multiple knowledge systems, and identify effective and sustainable adaptation and mitigation approaches. These efforts are critical to addressing changes to ecosystems, communities, livelihoods, and economies across the region.

Established in 2021, the Pacific Islands Ocean Acidification Centre (PIOAC) was created to support ocean acidification capacity development throughout the Pacific by working across scientific, local, and Indigenous knowledge systems. PIOAC is working with Pacific partners to co-develop Pacific-led solutions that respond to ocean acidification through:

- Training to increase regional expertise in ocean acidification monitoring
- Advice on applying monitoring information to support adaptation, mitigation, and decision-making
- Access to international networks that support monitoring, policy, and action
- Assistance with ocean acidification data management, accessibility, and regional knowledge sharing

Supported by NOAA and The Ocean Foundation, this SPC-led initiative includes partners from the University of the South Pacific, New Zealand's National Institute of Water and Atmospheric Research (NIWA), and the University of Otago. Through an expanding network, PIOAC works alongside Pacific Island researchers, government officials, and community members to foster knowledge co-production and strengthen regional responses to ocean acidification and welcomes new collaborators.

Drivers of Coastal Acidification in the surface and subsurface waters of the Northern California Current Ecosystem

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1D: Technological advances: New approaches for quantifying variability and human impacts on ocean biogeochemistry from sparse observational data, Mātiu, October 13, 2026, 11:45 - 13:00

Coastal acidification is the regional manifestation of ocean acidification in coastal waters and arises from both atmospheric CO₂ uptake and changes in coastal biogeochemical and hydrographic processes. Locally, coastal acidification is intensified by a combination of processes such as atmospheric CO₂ absorption, upwelling, the decomposition of organic matter, river discharge, and the changing buffer capacity of seawater. These factors collectively challenge calcifying organisms' ability to build shells or skeletons and hinder normal development in many fish species. The California Current is a southward-flowing eastern boundary current that encompasses the region off the west coast of Vancouver Island in Canada to the coastal waters off northern Mexico. From spring to early fall the coastal waters experience strong seasonal upwelling of intermediate depth offshore waters onto the continental shelf as a component of the California Undercurrent. Upwelling significantly enhances primary production rates over the continental shelf, and particularly within the Juan de Fuca Eddy, which exhibits extremely high surface water productivity and increased respiration in subsurface waters. As a result, there is considerable spatial variability in parameters including the partial pressure of CO₂ (pCO₂), total dissolved inorganic carbon (DIC), pH, and the saturation state of aragonite (Ω_{arag}) in the upper part of the water column. In this presentation, we utilize data from the 2021 West Coast Ocean Acidification (WCOA2021) cruise to delineate the spatial distribution of the primary drivers of coastal acidification in the northern California Current Ecosystem from the southern tip of Vancouver Island to the waters off northern California.

Spatial variability of seawater pH along the northern Antarctic Peninsula during the austral summer

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1D: Technological advances: New approaches for quantifying variability and human impacts on ocean biogeochemistry from sparse observational data, Mătiu, October 13, 2026, 11:45 - 13:00

Seawater pH is a key parameter for understanding marine biogeochemical processes and ecosystem functioning. While traditionally measured using discrete laboratory analyses, such approaches are limited temporal and spatial resolution. In situ sensors enable high-frequency, offering new opportunities to resolve fine-scale variability. Here, we assess the performance of pH sensors and investigate how water-mass mixing influences pH variability along the northern Antarctic Peninsula. Vertical profiles of pH were obtained in February-March 2017 across the Bellingshausen Sea and the Bransfield and Gerlache Straits, using an SBE 18 sensor, alongside temperature, salinity, and dissolved oxygen (DO). Sensor DO was corrected against Winkler titrations ($r^2 = 0.91$), and pH was calibrated using discrete samples analysed with a glass electrode. Sensor–discrete pH agreement was highest in the Bellingshausen Sea ($r^2 = 0.82$; RMSE = 0.019), followed by Gerlache ($r^2 = 0.80$; RMSE = 0.024) and Bransfield ($r^2 = 0.60$; RMSE = 0.025). Surface waters (>10 m) exhibited relatively homogeneous pH, with highest mean values in Bransfield (8.28 ± 0.09) and lowest in the Bellingshausen Sea (8.16 ± 0.04). At intermediate (200–400 m) and deep (>400 m) layers, pH decreased markedly in the Bellingshausen Sea, consistent with lower DO and warmer waters associated with Circumpolar Deep Water. Conversely, higher pH, elevated DO, and lower temperatures in the Bransfield Strait reflect the influence of Dense Shelf Water from Weddell Sea. These results demonstrate that high-resolution sensor measurements effectively capture spatial pH variability driven by water-mass mixing in the Southern Ocean.

Ocean Carbon Accumulation and Variability Revealed by a High-Resolution Mapped Observational Data Product

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1D: Technological advances: New approaches for quantifying variability and human impacts on ocean biogeochemistry from sparse observational data, Mātiu, October 13, 2026, 11:45 - 13:00

High-quality observations of dissolved inorganic carbon (DIC) have been collected for decades on basin-scale hydrographic cruises. More recently, Argo profiling floats have been outfitted with pH sensors that provide an opportunity to evaluate inorganic carbon dynamics on seasonal scales and with more complete spatial coverage throughout the global ocean. This presentation will describe a high-resolution mapped data product of DIC (i.e., Gridded Ocean Biogeochemistry from Artificial Intelligence - DIC, or GOBAI-DIC), created using machine learning algorithms trained on a harmonized dataset of DIC from direct measurements and DIC calculated from in situ pH. The mapped product leverages high-resolution, observation-based maps of temperature and salinity (i.e., Random Forest Regression Ocean Maps, or RFROM), that are also built using machine learning techniques. We validate the product against independent observations at time series sites and against published DIC climatologies. Finally, we use the mapped DIC data product to evaluate carbon accumulation in the ocean over time, assess regional variability in DIC, and explore potential applications of a low-latency DIC product.

Compound emergence of warming, deoxygenation and acidification across western Mediterranean water masses.

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1E: Global-driven changes in biodiversity: OA in Mediterranean, Mākaro, October 13, 2026, 11:45 - 13:00

Ocean warming, deoxygenation, and acidification in the Mediterranean Sea are well-documented individually. However, whether these stressors co-occur systematically throughout the water column remains unquantified. We present over a decade of continuous hydrographic observations from the CANALES monitoring program in the Balearic Sea to track the combined evolution of temperature, dissolved oxygen, and pH across four western Mediterranean water masses: Modified Atlantic Water (MAW), Western Intermediate Water (WIW), Levantine Intermediate Water (LIW), and Western Mediterranean Deep Water (WMDW). Seawater pH was reconstructed using a gradient-boosting machine-learning model, enabling compound analysis across campaigns lacking direct pH measurements. Significant warming, deoxygenation, and acidification were detected in all water masses, with intermediate waters exhibiting the fastest rates. The annual compound event frequency (CEF), the fraction of observations in which all three stressors were simultaneously abnormal relative to an early-record baseline, increased significantly over the study period. Using a signal-to-noise framework with bootstrap-based uncertainty quantification, stressor signals in intermediate and deep water masses seem to be approaching or crossing the threshold.

Detection threshold, with temperature emerging first, followed by pH and dissolved oxygen, a sequence consistent with coupled model projections but potentially ahead of their timelines. In MAW, the North Atlantic Oscillation influences interannual temperature variability and masks long-term trends, while acidification occurs independently of atmospheric circulation. These findings offer the first observational evidence that compound climate stress in the western Mediterranean subsurface is already happening, with direct implications for ecosystem vulnerability assessments.

Acidification and warming of Atlantic and Mediterranean water masses in the Strait of Gibraltar: insights from a 20-year time series

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1E: Global-driven changes in biodiversity: OA in Mediterranean, Mākaro, October 13, 2026, 11:45 - 13:00

The Strait of Gibraltar is the only open-ocean connection between the Atlantic Ocean and the Mediterranean Sea, where the exchange of water masses controls basin-scale biogeochemical properties. The Gibraltar Fixed Time Series (GIFT), established in 2005, provides a sustained observing system specifically designed to quantify these exchanges. This study presents an integrated analysis of acidification and warming trends in the major water masses crossing the Strait, based on two complementary observational approaches. First, repeated campaigns conducted between 2005 and 2024 in the channel provide vertically resolved measurements of temperature, salinity, oxygen and pH. Second, a fixed mooring deployed at intermediate depths since 2012 delivers high-frequency time series of temperature, salinity and pH, enabling the characterization of variability at daily to interannual scales. Water masses were objectively classified according to their thermohaline properties, allowing the identification of North Atlantic Central Water (NACW), Levantine Intermediate Water (LIW) and Western Mediterranean Deep Water (WMDW). A consistent thermodynamic framework was applied to harmonize pH measurements from discrete and autonomous platforms. Temporal trends were assessed using a harmonic model with a linear component and bootstrap-based uncertainty estimation. The results reveal coherent patterns of warming and acidification across the three water masses over the past 20 years, with distinct signatures linked to their origin and transformation processes. These findings show that climate-driven changes in the Mediterranean are rapidly transmitted through the Strait, emphasizing the need to explicitly account for ocean gateway processes when assessing regional vulnerability and developing adaptation strategies in a high CO₂ ocean.

Seagrass Carbon Sinks in a Changing Ocean: Insights from Multi-Scale Responses to Ocean Acidification

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1E: Global-driven changes in biodiversity: OA in Mediterranean, Mākaro, October 13, 2026, 11:45 -

13:00

Seagrass meadows of *Posidonia oceanica* are key players in coastal carbon cycling, capable of sequestering substantial amounts of carbon. Yet, we lack an understanding of how carbon cycling at the community level of *P. oceanica* will respond to ocean acidification (OA) and interacting climate stressors, and how short-term carbon fluxes translate into long-term CO₂ sequestration.

Here, we present results from three complementary studies exploring seagrass community carbon cycling in response to OA and global change: 1) a multi-driver flume experiment using intact *P. oceanica* communities exposed to future warming and OA; 2) field measurements of benthic carbon fluxes and community composition along natural CO₂ gradients at volcanic vent systems; and 3) sediment burial rates and carbon source contributions over the past century at the same vent sites.

We found elevated net community productivity under ocean acidification in laboratory experiments, consistent with observed higher rates of sediment carbon burial at CO₂ vent sites. Together, these findings suggest that macroalgae and epiphytic algae, likely stimulated by high CO₂ conditions, may play a central role in mediating these increases in productivity and carbon burial rates. By linking controlled experiments and field observations across multiple time scales, we show how community interactions shape carbon cycling responses to OA, with implications for the future carbon sink potential and ecosystem functioning of seagrass meadows in a changing ocean.

Oxygen deprivation implicated in rapid coral mortality under acute heating events

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2A: Ocean Deoxygenation: A Twin Threat to Ocean Health in a High CO₂ World, Rongomātāne A, October 13, 2026, 16:00 - 18:00

While coral bleaching is a well-known ramification of marine heatwaves, rapid coral mortality via tissue disintegration is an understudied threat that precludes any chance of recovery. We show that tissue disintegration can occur within hours to days of acute heat stress, marking a critical survival threshold. Microscale oxygen measurements indicate rapid deoxygenation of coral tissue immediately preceding tissue disintegration. We hypothesise that the simultaneous impairment of photosynthetic oxygen supply and increasing holobiont oxygen demand overwhelms a coral's ability to maintain basal metabolic functions. Theoretical oxygen flux calculations, grounded in the Einstein–Smoluchowski kinetic theory of gases, support this by suggesting that passive diffusion alone is insufficient to meet metabolic demand under these conditions. In the context of global ocean deoxygenation, a reduced ambient oxygen supply further exacerbates this diffusion-limited state. This "squeeze" between rising metabolic demand and a dwindling supply creates a lethal bottleneck, suggesting that corals in deoxygenated or stagnant waters may be significantly more vulnerable to acute heating than previously recognised. These findings highlight intrinsic oxygen deprivation as a potential mechanism for rapid coral mortality and suggest a new, more immediate thermal limit for corals. As ocean deoxygenation and warming act as twin threats in a high-CO₂ world, understanding these biophysical constraints is urgent. This study provides a granular look at the mechanisms triggering rapid mortality, necessitating a re-evaluation of the immediate threats facing reef-building corals under future climate scenarios.

Take my breath away: effects of hypoxic events on coral photometabolism in a high-temperature environment.

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2A: Ocean Deoxygenation: A Twin Threat to Ocean Health in a High CO₂ World, Rongomātāne A, October 13, 2026, 16:00 - 18:00

The Arabian/Persian Gulf is recognized as a unique marine ecosystem, characterized by an extreme natural environment, including elevated temperatures, hypersalinity, high evaporation rates, and limited freshwater input. These inherent challenges have been intensified in recent decades due to climate change and local anthropogenic pressures, resulting in more frequent algal blooms and coastal hypoxia. This work focuses on the physiological effects of low-oxygen levels on corals that survive in this extreme environment.

Coral fragments of *Cyphastrea microphthalma* and *Platygyra daedalea* (n=144 each) were collected from Abu Dhabi reefs and acclimated at 33.5°C. Corals were then exposed to control (33.5°C, no hypoxic events) and experimental conditions (33.5°C, with three distinct overnight hypoxic events; 35.5°C, with no overnight hypoxic events; and 35.5°C, with three distinct overnight hypoxic events) for 14 days. Photosynthetic performance (Fv/Fm) was monitored every two days via PAM fluorometry. Additionally, subsets of coral fragments were sampled after each night hypoxic event to assess stress responses across treatments, including monitoring antioxidant enzyme activities (CAT and SOD), symbiont density, and chlorophyll concentration.

Preliminary results show that prolonged elevated temperatures reduced photosynthetic performance and exacerbated bleaching, even at temperatures considered standard for the Arabian Gulf summer waters. Interestingly, in *Platygyra*, hypoxia appears to have a greater impact on photosynthetic efficiency in the absence of high temperature without exacerbating its effect. These findings suggest that low oxygen levels could affect the Gulf reef year-round, possibly leading to more severe coral bleaching events in summer, when temperatures are highest.

Sponges tolerate projected end-of-century ocean warming, acidification and deoxygenation

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2A: Ocean Deoxygenation: A Twin Threat to Ocean Health in a High CO₂ World, Rongomātāne A,
October 13, 2026, 16:00 - 18:00

Steadily increasing atmospheric carbon dioxide concentrations are driving a ‘deadly trio’ of stressors in marine systems: ocean warming (OW), ocean acidification (OA), and ocean deoxygenation (OD). Most laboratory studies have examined these stressors in isolation, overlooking their potential synergistic or antagonistic effects on different taxa. Marine sponges are key components of benthic communities on rocky reefs throughout Aotearoa New Zealand and host diverse microbial assemblages that contribute to host health and may enhance resilience to environmental change. Here, we conducted a multi-driver experiment using an ecologically relevant design to assess the combined effects of IPCC-projected end-of-century conditions (SSP5–8.5) of OW, OA, and OD on sponges and their microbiomes. We investigated three endemic, abundant and ecologically important species from the Fiordland Marine Area: *Cymbastela lamellata*, *Axinella richardsoni*, and *Pararhaphoxya sinclairi*. Given that OW is widely considered the dominant climate stressor affecting sponge physiology, we hypothesised that warming would increase sensitivity to OA and OD, exacerbating their effects. However, all three species exhibited strong tolerance to combined future conditions. Survival remained at 100% after four weeks at peak treatment conditions, with no measurable changes in respiration rates, biomass, or microbiome composition, suggesting maintenance of holobiont core functionality. Microbial analyses revealed in all sponge species a high relative abundance of ammonia-oxidising archaea (order Nitrososphaerales), which may mitigate toxic ammonia accumulation associated with elevated metabolic demand under stress. Our results indicate that these sponge species can withstand changes in multiple ocean properties projected for the end of this century.

Hot, Acidic, and Out of Breath: Understanding the Impacts of Ocean Deoxygenation in a Changing Ocean

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2A: Ocean Deoxygenation: A Twin Threat to Ocean Health in a High CO₂ World, Rongomātāne A,
October 13, 2026, 16:00 - 18:00

Declining dissolved oxygen concentrations in coastal waters are predicted to threaten marine ecosystems globally. However, current and future levels of dissolved oxygen on coral reefs, the occurrence of low oxygen events, and the effects of low oxygen in combination with other stressors such as warming and acidification remain underexplored. I present here a broad overview of interdisciplinary research leveraging global reef oxygen datasets, aquarium experiments, and naturally variable habitats such as seagrass meadows and mangrove lagoons to better understand the growing threat of deoxygenation on tropical coastal systems. We have found that low oxygen events are already common on coral reefs around the globe, with 85% of reefs surveyed already experiencing moderate ($\leq 153 \mu\text{mol kg}^{-1}$) hypoxia and 15% experiencing severe ($\leq 61 \mu\text{mol kg}^{-1}$) hypoxia under present-day conditions. Further, we show that projected ocean warming will increase the frequency, duration, and intensity of low oxygen events by end of century. From manipulative aquarium experiments, we have found that deoxygenation stress outweighs the sublethal impacts of acidification on Caribbean corals, whereas warming led to the most significant stress response, especially in combination with deoxygenation. From field studies of naturally variable systems, we find that diel exposure to nightly acidification and deoxygenation leads to trade-offs in coral skeletal properties and hypoxia tolerance. This research highlights the importance of continued work investigating how ocean deoxygenation, alongside warming and acidification, are impacting coastal systems across our oceans.

Coral responses to repeated ocean acidification and deoxygenation depend on exposure frequency and species tolerance

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2A: Ocean Deoxygenation: A Twin Threat to Ocean Health in a High CO₂ World, Rongomātāne A,
October 13, 2026, 16:00 - 18:00

Coral reefs face multiple climate stressors, yet while ocean acidification and warming have been widely explored, deoxygenation remains largely understudied to date. Compound low pH and dissolved oxygen (DO) events are projected to intensify, yet whether repeated sub-lethal exposure induces acclimatization to compound stress via phenotypic plasticity – and whether such responses depend on exposure frequency – remains unknown. We tested frequency-dependent conditioning in two Caribbean coral species (*Agaricia tenuifolia*, *Siderastrea siderea*) with different stress sensitivities. During the one-month pre-conditioning phase, corals were exposed nightly to concurrent low DO (2.6 mg L⁻¹) and low pH (pHT 7.75) at high-frequency (HF; six pulses), low-frequency (LF; three pulses), or no pulses (control). This was followed by a one-week acute stress test, in which the corals were exposed nightly to stronger acidification and hypoxia, or ambient conditions. Responses were strongly species-specific, with the longer-term pre-conditioning (1-month) dominating over shorter-term acute stress (1-week). In *A. tenuifolia*, HF imposed substantial physiological costs that persisted to the end of the experiment, including reduced photosynthetic efficiency (–18%), chlorophyll content (–13%), symbiont densities (–46%), and calcification (–33%), suggesting HF exceeded the plasticity capacity of this stress-sensitive species. In contrast, *S. siderea* maintained broad physiological stability across treatments, though LF enhanced biomass retention under acute stress while HF and control corals lost ~24% biomass. Rather than promoting generalized resilience, repeated compound stress exposure can impose cumulative costs or yield narrow, species-specific plasticity. Coral vulnerability will depend critically on how exposure frequency and intrinsic tolerance interact under future multi-stressor environments.

Hidden hypoxia contributes to coral bleaching through a mass transport–metabolism tipping point

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2A: Ocean Deoxygenation: A Twin Threat to Ocean Health in a High CO₂ World, Rongomātāne A, October 13, 2026, 16:00 - 18:00

Declines in dissolved oxygen are typically characterized at ecosystem to global scales, yet marine organisms experience oxygen at much smaller scales where local transport processes govern exposure. This is particularly critical for sessile organisms such as corals, whose metabolic environment depends on the balance between biological oxygen demand and flow-mediated mass transfer. Here, we show that coral bleaching during marine heatwaves (MHWs) is associated with a collapse of oxygen availability within branching coral colony interiors, despite persistently normoxic surrounding waters. Using high-frequency in situ measurements from consecutive Red Sea MHWs, we resolve oxygen dynamics within and around colonies and show that bleached colonies experienced progressive oxygen depletion to near-anoxic conditions prior to visible bleaching, while neighboring colonies maintained stable oxygen conditions under similar thermal forcing.

To explain this divergence, we develop a three-dimensional fluid–thermal–metabolism model coupling metabolic demand with flow-mediated oxygen transport. The model reveals a threshold-like transition in which elevated respiration, reduced photosynthesis, and transport limitation drive a shift from diel oxygen cycling to persistent hypoxia. This transport–metabolism tipping point arises when oxygen demand exceeds flow-mediated resupply within confined colony structures.

Together, these results identify oxygen limitation as an emergent factor of coupled temperature–metabolism–transport interactions and show that deoxygenation can arise intrinsically at the organism scale. Resolving these microscale oxygen dynamics may improve predictions of coral vulnerability under intensifying marine heatwaves.

Amazon River plume control on carbonate chemistry in the western Tropical Atlantic

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2B: Knowledge systems: The River-Ocean Nexus: Freshwater Acidification in a High-CO₂ World,
Rongomātāne B, October 13, 2026, 16:00 - 18:00

The Amazon River Plume (ARP) strongly modulates the carbonate system of the western tropical Atlantic (WTA) through interacting physical and biological processes, including freshwater dilution, biological carbon uptake, and circulation-driven transport of plume waters, yet its basin-scale impact remains poorly quantified. Here, we combine climatological spatial anomalies of sea surface salinity (SSS), carbonate system variables, and biogeochemical indicators to quantify the contribution of ARP waters to carbonate chemistry during wet and dry seasons. We show that ARP-derived freshwater and nutrients drive coherent ~8–10% reductions in sea surface fugacity (fCO₂), total alkalinity (TA), dissolved inorganic carbon (DIC), and carbonate ion concentrations across the WTA during the wet season, closely tracking a ~9% decrease in SSS. These reductions decrease surface fCO₂ and highlight the large-scale influence of the ARP on regional carbon cycling. Physical dilution emerges as the primary driver of carbonate system modulation, while enhanced photosynthesis and substantial N₂ fixation further promote CO₂ uptake in low-salinity waters. The close correspondence between decreases in TA (–9.4%), fCO₂ (–9.8%), and DIC (–9.2%) suggests additional influence from nitrification following N₂ fixation, consistent with recent observational and modelling studies. ARP driven reductions in fCO₂ extend offshore through export by the North Brazil Current and North Equatorial Countercurrent, decreasing fCO₂ by up to 20 µatm near 10°N and modulating carbonate chemistry across the equatorial Atlantic. Together, these findings demonstrate that the ARP is a dominant regulator of surface carbonate chemistry in the WTA, enhancing atmospheric CO₂ uptake through coupled physical–biological processes.

Freshwater-seawater mixing and major phytoplankton groups modulate CO₂ dynamics in a subtropical estuary

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2B: Knowledge systems: The River-Ocean Nexus: Freshwater Acidification in a High-CO₂ World, Rongomātāne B, October 13, 2026, 16:00 - 18:00

Estuarine environments are highly dynamic components of the coastal carbon cycle, yet remain underrepresented in global carbon dioxide (CO₂) budgets, particularly in subtropical regions. Here, we investigate how freshwater–seawater mixing and phytoplankton functional groups jointly regulate surface water pCO₂ in a subtropical estuary (Patos Lagoon, Brazil), using a year long, high-frequency dataset of carbonate chemistry, nutrients, and phytoplankton composition. Surface pCO₂ exhibited strong seasonal variability, ranging from 252 to 9647 µatm, with values on average ~3000 µatm higher during river-dominated conditions. This variability was primarily structured by salinity-driven mixing, but could not be explained by conservative processes alone. Bulk chlorophyll-a showed weak relationships with pCO₂, whereas phytoplankton functional composition better constrained the mechanisms underlying pCO₂ variability. During ocean-dominated conditions, lower pCO₂ (~632 µatm) coincided with higher total alkalinity and dissolved inorganic carbon, and strong diatom dominance (>70% of biomass), indicating enhanced biological CO₂ uptake. In contrast, river-dominated conditions were characterized by elevated pCO₂ (~3706 µatm), driven by riverine CO₂ inputs and heterotrophic respiration, although substantial in situ CO₂ consumption persisted. By separating conservative mixing from non-conservative processes, we show that pCO₂ variability emerges from the combined influence of carbonate system thermodynamics and shifts in phytoplankton community structure, rather than biomass alone. These findings highlight the importance of incorporating phytoplankton functional groups and mixing driven carbonate chemistry into biogeochemical frameworks to improve CO₂ predictions in estuarine systems under a high-CO₂ climate.

The impacts of freshwater acidification on microalgal and cyanobacterial communities in Te Awa o Waikato

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2B: Knowledge systems: The River-Ocean Nexus: Freshwater Acidification in a High-CO₂ World, Rongomātāne B, October 13, 2026, 16:00 - 18:00

Geothermal inputs along Te Awa o Waikato creates a natural gradient that closely mirrors conditions projected under future freshwater acidification, elevating pCO₂ and lowering pH. We will use the river as a large-scale natural analogue to investigate how rising CO₂ levels influence eukaryotic algae and cyanobacteria, with a focus on growth rates, photophysiology, carbon uptake, and community composition. A global synthesis of the literature has been used to identify trends in the data and identify opportunities for future work. Interestingly, little work has been carried out in Australasia in the field. Laboratory assays will expose monocultures and mixed communities to controlled CO₂ and pH treatments, enabling direct tests of physiological thresholds, competitive interactions, and the potential for CO₂/pH effects to be amplified or offset by other factors such as nutrient availability, temperature, and turbidity. Metagenomics will then be employed during mesocosm experiments to catalogue species abundance in situ, combined with transcriptomics to identify the presence and expression of genes linked to CO₂ tolerance. These data will help predict future phytoplankton assemblages in a high CO₂-world and identify traits that may confer resilience under changing conditions, providing a robust framework for understanding the drivers of community change in freshwater systems. The findings will inform targeted restoration, and adaptive water-management strategies.

The river-ocean nexus in a high-CO₂ world: freshwater acidification, carbonate chemistry, and the missing terrestrial bridge

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2B: Knowledge systems: The River-Ocean Nexus: Freshwater Acidification in a High-CO₂ World,
Rongomātāne B, October 13, 2026, 16:00 - 18:00

Ocean acidification is now a central concern of global change science, yet the freshwater half of the carbon cycle—the river corridors that mediate atmosphere–land–ocean exchange—remains largely outside this framework. Rivers integrate catchment-scale CO₂ fluxes and deliver alkalinity, dissolved inorganic carbon, and trace elements to coastal margins, yet the mechanistic basis for how rising atmospheric CO₂ propagates through inland waters and influences their biogeochemical balance is poorly resolved.

I propose a 'Coulombic baseline' framing for freshwater biogeochemistry: atmospheric pCO₂ sets the carbonate equilibrium of soft fresh waters, which in turn governs the surface charge of ubiquitous oxide and carbonate minerals. Because the point of zero charge of ferrihydrite (pH ≈ 8.1) sits close to the pH of soft fresh waters at pre-industrial CO₂, even small CO₂-driven pH shifts reorganise the partitioning of nutrients, trace metals, and colloidal carriers between particulate and dissolved phases. This provides a first-principles expectation against which observed freshwater trends—and deviations from them—can be evaluated, and links inland water-quality change to the same atmospheric driver responsible for ocean acidification.

New Zealand's Emerging Climatic Pressures programme is testing this framework on the Waikato River using high-frequency sonde networks and discrete carbonate-system chemistry. Initial results reveal large reservoirs of disequilibrium CO₂ moving through the system, secondary perturbations imposed by invasive bivalves and catchment loading, and metabolic signals consistent with a regime shift. I argue that an integrated mountains-to-the-sea carbonate framework is essential for interpreting coastal acidification budgets and for situating the river-ocean nexus within high-CO₂ science.

He kaakahi whakairoiro, he kaaeo whakahirahira: How will our taonga evolve with the taiao?

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2B: Knowledge systems: The River-Ocean Nexus: Freshwater Acidification in a High-CO₂ World,
Rongomātāne B, October 13, 2026, 16:00 - 18:00

Te Awa o Waikato is the foremost ancestral river of Waikato people. Many concerns exist regarding impacts on our river's ecosystems and local taonga (treasured) species, especially under projected climate change scenarios. Among these taonga are the kaaeo, *Echryidella sp.*, freshwater mussel species of Aotearoa New Zealand. Once an important mahinga kai (food source), popularly known as ecosystem engineers, and today are listed among our most threatened species. Rising CO₂ levels can directly and indirectly impact freshwater systems, which raises questions about how these taonga will adapt in a dynamic future river system. As part of a wider governmentally funded work programme, multiple investigations are running to examine the river's response to climate change stressors. Our study will employ cutting-edge molecular tools including genomic, transcriptomic, and single-cell sequencing, alongside histological techniques to investigate genetic, phenotypic, and molecular variation within and between kaaeo populations of Te Awa o Waikato. We will examine cellular-level patterns and differentiation across key life stages, focusing on larval (glochidia) and newly settled juvenile phases. These are particularly vulnerable to changing aquatic pH. These findings will provide critical insights into how climate change is shaping freshwater ecosystems in Aotearoa, with particular emphasis on safeguarding our taonga species from the impacts of CO₂-driven freshwater acidification.

Interconnected Dynamics of Plant Growth and Carbon Dioxide Fluxes in Lake Karāpiro under different physical regimes

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2B: Knowledge systems: The River-Ocean Nexus: Freshwater Acidification in a High-CO₂ World,
Rongomātāne B, October 13, 2026, 16:00 - 18:00

This study investigates the causal relationship between chlorophyll-a (Chl-a), a proxy for phytoplankton biomass, and partial pressure of carbon dioxide (pCO₂) under contrasting physical mixing regimes (stratified versus mixed) in Lake Karāpiro. Causal relationships were evaluated using convergence cross mapping (CCM), enabling inference of directional coupling between biological and biochemical variables. CCM analyses revealed strong bidirectional coupling between Chl-a and pCO₂ during stratified conditions (cross-map skill $\rho = 0.42$), whereas coupling was weak during mixed conditions ($\rho = 0.04$), suggesting reduced internal feedback under mixing.

To explain this decoupling, we tested whether variability in Chl-a and pCO₂ is primarily driven by external physical forcing. Temperature showed strong influence on pCO₂ ($\rho = 0.8$) but weak coupling with Chl-a ($\rho = 0.09$) during mixing. Buoyancy frequency (N^2), representing water-column stability, exhibited weak causal links with both Chl-a and pCO₂ ($\rho \approx 0.06$), indicating that stratification strength alone does not explain the breakdown in coupling. These results suggest that weakened Chl-a–pCO₂ feedbacks during mixing reflect multiple turbulence-related processes rather than a single dominant driver.

We further tested whether phytoplankton community composition mediates carbon dynamics using the ratio of phycocyanin to Chl-a (Pc:Chla). During mixed conditions, Pc:Chla showed strong causal influence on pCO₂ ($\rho = 0.75$), in contrast to weak Chl-a–pCO₂ coupling, whereas this relationship weakened under stratified conditions ($\rho = 0.01$). These findings indicate a regime-dependent shift from biomass-driven control of pCO₂ during stratification to composition-driven control during mixing, highlighting the importance of community structure in regulating carbon dynamics in lake ecosystems.

Crowding the Coast: Plume Interactions Reduce CO₂ Uptake from Closely Spaced Alkalinity Outfalls

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2C: Ocean Solutions, Rongomātāne C, October 13, 2026, 16:00 - 18:00

Ocean Alkalinity Enhancement (OAE) is a promising marine carbon dioxide removal (mCDR) approach, with the potential for gigaton-scale CO₂ removal. As coastal regions are increasingly being considered for deployment, the effects of coastal outfall interaction on carbon uptake must be constrained. Using a 3-D hydrodynamic-biogeochemical model, we assess the spatial and rate-dependent effects on the co-location of alkalinity outfalls in southeastern Australia. We find that short separation distances and high addition rates induce strong plume interaction, leading to reduced CO₂ removal (>5 %) and localised increases in pH. In contrast, low rates or wider spacing improve co-located CO₂ removal. This behaviour arises from the nonlinear, diminishing sensitivity of pCO₂ to increasing alkalinity. While this effect is transient, we show that it can persist for months, with any export of unequilibrated waters preserving unrealised CO₂ removal for extended periods. This export leads to increased cumulative radiative forcing relative to the more complete removal achieved from outfalls with reduced plume interaction. Additionally, co-location may have implications for uptake attribution, and therefore monitoring, reporting, and verification. Our results provide practical guidance for scaling OAE, demonstrating that careful planning of outfall spacing, informed by local hydrodynamics and observations, is essential to maximise carbon removal while minimising efficiency losses.

Effect of marine shells on total alkalinity in CO₂-acidified seawater

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2C: Ocean Solutions, Rongomātāne C, October 13, 2026, 16:00 - 18:00

The decrease in ocean pH is primarily associated with the increase in anthropogenic CO₂, which alters the carbon cycle and affects a wide range of marine organisms. Calcifying organisms exhibit a reduction in their calcification rates, along with physiological and morphological alterations in other species. This phenomenon also negatively impacts economic sectors such as fisheries, aquaculture, and tourism.

Given this scenario, it is necessary to implement strategies that mitigate the effects of ocean acidification and enhance the ocean's capacity to remove atmospheric CO₂ by increasing alkalinity, thus improving absorption. One alternative is the use of natural materials capable of increasing water alkalinity. The present study quantitatively evaluated the alkalizing potential of marine gastropod shells, considered a material with low impact on water chemistry. Shells from the families Fissurellidae, Hipponicidae, and Siphonariidae were collected from the intertidal zone of Barbasquillo Beach in Manta, Ecuador, in August 2025. Subsequently, the samples were cleaned to remove organic matter and distributed into six 8 L tanks, 14.895 ± 0.220 g of shells were added to each tank. CO₂ was injected to maintain a pH close to 7.5 (projected for the year 2100), which was continuously monitored using Aquastar equipment. At the end of the experiment, a decrease of 0.09834 g in shell mass was recorded in each tank, along with changes in coloration, indicating degradation processes. Titration analyses confirmed an increase in water alkalinity, highlighting its potential as a mitigation strategy against ocean acidification.

Channeling Expertise: Capacity-Strengthening Pathways to Bridge Ocean Acidification Science and Marine Carbon Dioxide Removal Research

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2C: Ocean Solutions, Rongomātāne C, October 13, 2026, 16:00 - 18:00

As a natural carbon sink, the ocean makes marine carbon dioxide removal (mCDR) central to the effort to meet global climate change mitigation goals. Ocean acidification (OA) scientists are uniquely positioned to lead research on mCDR, through their deep understanding of the marine carbon cycle, expertise in establishing monitoring programs, and proficiency in identifying biological impacts.

Developing an OA to mCDR capacity-building pipeline is essential to produce high-quality mCDR research that spans ocean basins and accounts for regional and local community perspectives. The Ocean Foundation has supported OA scientists and practitioners for over 10 years through an integrated suite of capacity-strengthening services: hands-on technical training, detailed best practices for project implementation, accessible equipment distribution, small grants, and the establishment of regional centers of excellence. This model's success is rooted in centering the feedback and support needs of scientists across all regions, in addition to engaging topical experts, collaborating with equipment developers, and advocating for a holistic approach to capacity building.

The Ocean Foundation is applying this proven capacity-building framework to mCDR, focusing on geographic diversity. After conducting listening sessions with 67 scientists from 31 regions, this approach targets the most salient needs by enabling in-person knowledge exchange, connecting OA scientists across levels of mCDR expertise, and compiling foundational information resources. Furthermore, widely sharing best practices to improve cross-regional collaboration and expand global mCDR research capacity. By mobilizing OA scientists, especially from underrepresented regions, The Ocean Foundation is actively widening the pipeline of skilled mCDR researchers and inviting broader global collaboration.

Influence of suspension-feeding bivalve *Austrovenus stutchburyi* on alkalinity dynamics in a sandy intertidal estuary

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2C: Ocean Solutions, Rongomātāne C, October 13, 2026, 16:00 - 18:00

Intertidal estuaries influence oceanic CO₂ uptake by modulating total alkalinity (TA) delivery from land to the ocean. Alkalinity can be removed by calcification, while seafloor processes such as CaCO₃ dissolution, denitrification, and pyrite formation generate alkalinity. All these processes are influenced by the benthic macrofauna, yet their contribution to net alkalinity production in estuarine systems remains poorly understood. Calcifiers such as bivalves are important for modulating alkalinity production, as they play a central role in sediment biogeochemistry by enhancing bioturbation, organic matter processing, and redox cycling. Here, we investigated how *Austrovenus stutchburyi*, a key bivalve in New Zealand estuaries, modulates the alkalinity transport from the Waitati River and Carey's Creek to the ocean by directly measuring CaCO₃ dissolution and net denitrification at two sites in Waitati Inlet, a sandy intertidal estuary in Otago, New Zealand, and comparing that to estimated CaCO₃ production through calcification. Estimated riverine inputs of TA into Waitati Inlet are around 12.6 Mmol TA yr⁻¹. Our results show that *A. stutchburyi* increases TA flux by ~27% through enhanced sedimentary alkalinity production but decreases it by ~25% due to calcification. Overall, alkalinity production slightly exceeds CaCO₃ formation, resulting in a net increase in TA generation of ~2% relative to riverine inputs. The balance between calcification and sedimentary TA generation is therefore critical in determining the role of bivalves in intertidal alkalinity dynamics in intertidal systems.

Towards constraining the efficiency of ocean alkalinity enhancement: A Canadian Earth System Model study

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2C: Ocean Solutions, Rongomātāne C, October 13, 2026, 16:00 - 18:00

Ocean alkalinity enhancement (OAE) is presently being studied across scales as a proposed geoengineering technology with potential to curb atmospheric CO₂ growth. While many questions remain regarding both the safety and efficacy of OAE, global Earth system models (ESMs) provide the most complete picture of Earth system feedbacks and spatially variable efficiency of OAE, and are thus a useful complement to observational, local and regional studies. To this end, we present results from deploying OAE within the Canadian Earth System Model version 5.1. The experiments presented follow the Carbon Dioxide Removal Model Intercomparison Project (CDRMIP) protocol: 0.15 Pmol of alkalinity is added each year to the entire surface ocean between 60°S and 70°N on the SSP585 emission pathway with interactive CO₂ in the atmosphere. We further apply the CDRMIP protocol to emission pathways SSP126 and SSP245. While this is an idealized experimental set up, it provides an opportunity to compare results with other ESMs that were contributed to the Coupled Model Intercomparison Project Phase 6 (CMIP6) following the same experimental protocol and will thus help elucidate model-based uncertainty in OAE response. Furthermore, the results presented will aim to constrain the efficiency of OAE on different emission pathways and highlight metrics describing the effectiveness of OAE at curbing climate change signals. Overall, the findings of this work will be an important contribution to conversations around the deployment of OAE and underscore key Earth system considerations.

The local alkalinity enhancement of seawater increases shell biomineralization and growth, buffering the effect of Ocean Acidification on shellfish juveniles

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2C: Ocean Solutions, Rongomātāne C, October 13, 2026, 16:00 - 18:00

Ocean acidification (OA) threatens shellfish aquaculture by reducing seawater's buffering capacity and constraining biomineralization during early life stages. Ocean alkalinity enhancement (OAE) has been proposed as a mitigation strategy, but evidence linking alkalinity-driven chemical changes to biological performance and associated trade-offs remains limited. We conducted two complementary 54-day experiments using a natural high-alkalinity seawater analogue to test how elevated total alkalinity (TA) influences the growth and shell structure of juvenile Pacific oysters under ambient and high CO₂ conditions. Elevated TA enhanced cumulative growth and produced more ordered, densely packed shell microstructures. Under high-CO₂, juveniles increased growth in length and height despite an aragonite saturation state below 1, indicating partial buffering of OA impacts under elevated alkalinity and bicarbonate availability. However, enhanced TA alone and in combination with high CO₂ also reduced shell width and organic matrix content, revealing physiological trade-offs associated with altered allocation between inorganic and organic shell components. Our results demonstrate that moderate alkalinity enhancement can mitigate OA-driven impacts on shellfish. However, the benefits are not uniformly positive and depend on the magnitude of exposure and biological thresholds. These findings provide decision-relevant evidence for the cautious implementation of OAE as a mitigation strategy in aquaculture and coastal systems.

The effects of moderate and high ocean alkalinity enhancement on phytoplankton growth and photophysiology using a model diatom and coccolithophore

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2C: Ocean Solutions, Rongomātāne C, October 13, 2026, 16:00 - 18:00

Recent IPCC reports highlight that decarbonisation alone is insufficient to mitigate rising atmospheric CO₂, necessitating marine carbon dioxide removal (mCDR) strategies, such as ocean alkalinity enhancement (OAE). OAE increases seawater bicarbonate (HCO₃⁻) and carbonate (CO₃²⁻) ion concentrations, shifting the seawater carbonate system away from CO₂ through the dispersal of alkaline material, potentially enhancing carbon sequestration. However, the impacts of OAE on marine ecosystems remain poorly understood and existing studies are typically contradictory. In this study, we examined the responses of the coccolithophore *Pleurochrysis carterae* and the diatom *Thalassiosira pseudonana* (including an external carbonic anhydrase-deficient mutant), to moderate (+750 μmol kg⁻¹) and high (+1500 μmol kg⁻¹) alkalinity, alongside natural phytoplankton communities exposed to moderate enhancement (~ +550 μmol kg⁻¹).

P. carterae showed clear sensitivity to enhanced alkalinity, exhibiting reduced growth at high alkalinity despite stable photophysiological parameters, likely reflecting the energetic trade-off between calcification and photosynthesis. *T. pseudonana* maintained growth through flexible photophysiological adjustments, whereas the -eCA mutant showed impaired carbon assimilation, highlighting the critical role of external carbonic anhydrase under elevated alkalinity. Natural communities experienced photophysiological stress and a mid-experiment shift from diatom dominance to the mixotrophic dinoflagellate, *Prorocentrum minimum*, demonstrating that ecological interactions can override single-species plasticity.

These findings suggest that while individual species responses to OAE are variable, ecosystem-level dynamics are critical for evaluating its ecological feasibility as a mCDR strategy.

Ocean Acidification Impairs Survival and Biological Integrity in the Green Mussel (*Perna viridis*)

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2D: Multiple Stressors, Mătiu, October 13, 2026, 16:00 - 18:00

Ocean acidification is an emerging threat to marine calcifiers, but its consequences for ecologically important species at the structural, cellular and elemental levels remain poorly understood. This study investigates the response of the green mussel *Perna viridis*, a major coastal bivalve, to consecutive seawater acidification (pH 7.9, 7.7 and 7.4) during a two month mesocosm experiment. We show that organismal survival, tissue integrity and shell architecture all decline simultaneously under low pH conditions, using energy dispersive x-ray spectroscopy, histopathology, scanning electron microscopy and survival analysis. Acidification progressively weakened the periostracum, exposed the inner calcium carbonate layers and destroyed the nacreous shell structure. Concurrently, vacuolation, loss of structural integrity and epithelial degradation were observed in the tissues of the digestive glands and gills. Elemental analysis showed major changes in the shell composition at low pH, which may indicate decreased biomineral stability. In the survival study a significant decline in survival was observed with the greatest effects on mortality at pH 7.7 and 7.4 ($p < 0.001$). Overall, our results indicate that *P. viridis* suffers from multi-level biological damage due to ocean acidification, threatening both physiological function and structural integrity. These results suggest potential threats to the stability of coastal ecosystems under future high-CO₂ scenarios, given their ecological and aquaculture value.

Using oxidative proteomics to unravel the molecular regulation of coral bleaching in the model organism *Exaiptasia diaphana*

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2D: Multiple Stressors, Mātiu, October 13, 2026, 16:00 - 18:00

The current oxidative model of coral bleaching holds that elevated temperatures trigger the production of reactive oxygen species by algal symbionts, ultimately leading to nonspecific oxidative stress and toxicity in the host coral. Another possibility is that the regulatory pathways involved in bleaching may be modulated through transient protein oxidation. To test this theory, we used an oxidative proteomics approach to track changes in the oxidative state of the cysteine proteome during heat stress in the model organism *Exaiptasia diaphana*. Both symbiotic and aposymbiotic *Exaiptasia* were exposed to a heat ramp from 26 to 34 °C over 10 days, and the oxidative state of cysteines was assessed at the beginning, during, and at the end of the heat ramp. A large diversity of cysteine-containing proteins was identified, and their involvement in regulatory pathways was inferred through homology mapping to the human interactome. Preliminary results show that several proteins associated with the host mitochondria and the endoplasmic reticulum underwent significant changes in their oxidative state between control and heat-stressed individuals. By integrating oxidative protein modifications with the regulatory pathways in which these proteins operate, we aim to determine whether a molecular regulatory cascade could be initiated during bleaching, and to better understand the molecular mechanisms underlying bleaching.

Oyster Immune Response to Multiple Climate Change Stressors: Synthesising Responses with Experimental Applications

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2D: Multiple Stressors, Mātiu, October 13, 2026, 16:00 - 18:00

The impact of ocean acidification, ocean warming, low salinity, and hypoxia on marine systems and marine organisms has been documented across all life stages particularly for calcifying organisms such as oysters (Oestridae & Pteriidae). However, the effects of ocean acidification on oyster immune function have not been comprehensively synthesised. To address this crucial knowledge gap a systematic literature review and meta-analysis was done to investigate the immune response of oysters to multiple and key climate change stressors. Across the 97 analysed studies we evaluated the direction of response (negative, neutral, or positive) for key immune parameters such as hemolymph activity, hemocyte function, enzyme activity, gene expression, antioxidant enzyme activity, and pathogen acquisition and progression, across multiple oyster species. Overall, a range of climate change stressors had a negative effect on oyster immune response, with ocean warming and low salinity being most commonly tested and ocean acidification and hypoxia the least. Our analysis also identified a clear taxonomic and geographic bias in the literature, with a strong emphasis on the genus *Crassostrea*, and studies originating from Asia. This highlights a lack of broader species representation and geographic diversity in current research. In response to these gaps, controlled laboratory experiments are underway to investigate the effect of multiple climate change stressors on immune response in two commercially significant oyster species relevant to Australian aquaculture. These experiments aim to bring clarity to the effect of climate change stressors, especially ocean acidification, on oyster immune response.

Simulated Atmospheric Heatwave Suppresses Immune Function in Sydney Rock Oyster (*Saccostrea glomerata*)

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2D: Multiple Stressors, Mātiu, October 13, 2026, 16:00 - 18:00

Climate-driven atmospheric heatwaves (AHWs) are increasing in frequency and intensity across Australia and exposing intertidal species such as the Sydney rock oyster (*Saccostrea glomerata*) to extreme aerial temperatures. These events have been linked to mortality and disease outbreaks, yet their effects on oyster immune function remain underexplored. This study synthesises findings from two controlled experiments examining the effects of simulated AHWs (42 °C, 6 h day⁻¹ over three days) on oyster immune responses. Haemocyte counts, phagocytosis, and condition index were measured after each exposure as an assay of immunophysiological response. AHW exposure consistently compromised immune performance, characterised by decreased total haemocyte counts and cessation of phagocytic activity while intertidal acclimatisation (low vs high shore emersion) did not buffer oysters against AHW-induced immune decline. Notably, AHW caused immediate and sustained immunosuppression with no cumulative decline over time, suggesting a rapid onset of impairment. Despite stable condition indices and low mortality, suppressed immune function may increase susceptibility to disease under future climate scenarios. These results highlight the vulnerability of *Saccostrea glomerata* populations to short-term extreme heat events and understanding these findings provide valuable insight into how climate stressors may impact the resilience of the ecologically, economically and culturally significant Sydney rock oysters.

Contrasting strategies of cellular pH regulation shape coral calcification responses to ocean warming and acidification

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2D: Multiple Stressors, Mătiu, October 13, 2026, 16:00 - 18:00

Ocean warming and acidification threaten coral reefs by impairing calcification, the process underlying reef accretion. Calcification depends on coral host pH regulation, yet few studies have explored cellular pH-regulatory traits in environmental tolerance. Using live-tissue imaging, we examined calcifying-cell pH regulation in three coral species (*Stylophora pistillata*, *Pocillopora effusa*, and *Porites lobata*) exposed to factorial combinations of seawater pH (7.9 and 7.6) and temperature (25 and 30°C). We assessed whether acid–base regulation corresponded to calcification responses to ocean acidification (OA), ocean warming (OW), and their combination. Light–dark integrated calcification declined under OA in all species (26–42%), with *P. lobata* showing greatest sensitivity. Warming reduced calcification in *S. pistillata* and *P. effusa* but increased it in *P. lobata*. Combined OA and OW caused the greatest losses in *S. pistillata* and *P. effusa* (59 and 58%), whereas *P. lobata* declined by only 18%, as warming partially offset OA effects. Driver interactions were principally additive. Calcification responses were mirrored by distinct patterns of calcifying-cell pH regulation. OA reduced H⁺ removal capacity across species, while warming strongly increased H⁺ loading and generally stimulated removal. In *S. pistillata* and *P. effusa*, increased loading was not matched by removal, particularly under combined exposure, coinciding with their strongest calcification declines. Conversely, in *P. lobata*, removal increased more strongly than loading under warming, potentially contributing to its positive calcification response and partial rescue under combined exposure. These findings highlight the H⁺ loading–removal balance in calcifying-cell function and environmental tolerance, with species-specific regulatory strategies potentially explaining contrasting calcification responses.

Effects of multiple stressors on the low-pH tolerance of the wrinkled rock-borer, *Hiatella arctica*.

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2D: Multiple Stressors, Mătiu, October 13, 2026, 16:00 - 18:00

With ocean acidification and warming threatening marine ecosystems, understanding how multiple stressors affect physiological tolerance to pH stress is paramount for predicting future vulnerability of coastal bivalves. This study explores how organisms perform under acute low-pH stress and how chronic acclimation to multi-stressor conditions may alter these responses. Heart rate is a common metric for organismal stress and exhibits complex and species-specific responses in marine invertebrates to low environmental pH. These differences suggest that modulating heart rate may help maintain acid-base balance by regulating circulatory flow to stabilize pH. Investigating acid-base balance parameters alongside heart rate offers insight to their mechanistic relationship as bivalves undergo low-pH stress.

Wrinkled rock-borers, *Hiatella arctica*, native to Arctic and sub-Arctic regions, were acclimated to four treatment conditions for three weeks: 1) ambient temperature and ambient pH, 2) ambient temperature and low pH, 3) high temperature and ambient pH, and 4) high temperature and low pH. Heart rate was monitored during an acute low-pH reduction from the acclimation pH to a pH of 5. Hemolymph and tissue were sampled at three time points throughout the pH drop. Heart rate performance curves, acid-base balance metrics of carbonic anhydrase and sodium potassium ATPase activity, as well as hemolymph pH and bicarbonate concentration will be discussed. The effect of multi-stressor interactions will be investigated among the treatment groups. This work gives insight into heart rate as an underexplored metric of physiological tolerance to declining pH in bivalve species and its potential role in acid-base regulation during pH stress.

Mapping Potential Multi-Stressor Exposure in Marine Systems: A 4D GIS-Based Approach

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2D: Multiple Stressors, Mătiu, October 13, 2026, 16:00 - 18:00

Understanding the effects of multiple environmental stressors on marine organisms requires not only experimental evidence, but also spatial and temporal insight into where and when these stressors are likely to co-occur. However, at broader planning scales, limited availability of pressure-specific and ecological data often constrains the ability to characterise multi-stressor environments systematically.

This study presents a GIS-based approach to developing a four-dimensional (4D) cumulative activity baseline as a proxy for identifying potential multi-stressor exposure in marine systems. Using Irish coastal waters as a case study, twenty human activities were harmonised within a GIS approach, seasonally weighted according to operational intensity, and mapped across four depth zones (0-165 m). Activities were further interpreted according to their dominant disturbance orientation (benthic or pelagic) to provide insight into likely pressure pathways acting on marine organisms.

Results reveal strong spatial and temporal variability in cumulative activity patterns, with higher levels of co-occurring activities during spring and summer, particularly within shallow euphotic zones. In contrast, deeper zones exhibit more spatially constrained but seasonally distinct activity hotspots, largely driven by fisheries. Seasonal shifts in disturbance orientation suggest changing exposure of marine organisms to benthic- and pelagic-associated pressures year-round.

While not directly quantifying biological responses, this approach provides a structured means of identifying where and when organisms may be exposed to multiple, interacting stressors. As such, the 4D baseline offers a complementary tool to experimental and observational studies, supporting the design of multi-stressor research and improving the spatial relevance of ecological assessments under global environmental change.

HOT FAMILIES: CAN WE USE SELECTIVE BREEDING TO PRODUCE MORE HEAT-TOLERANT GREENSHELL MUSSELS?

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2D: Multiple Stressors, Mātiu, October 13, 2026, 16:00 - 18:00

Climate change is affecting coastlines and marine industries worldwide. In Aotearoa New Zealand, marine heatwaves and extreme weather events are the primary climate change drivers currently threatening the productivity and long term sustainability of aquaculture, highlighting the need for effective adaptation strategies. Selective breeding offers one promising pathway by producing families with greater resilience to heat stress. *Perna canaliculus* (Greenshell mussels; GSM), an endemic species of major cultural and commercial value, have been selectively bred since 2002. This established family-based breeding programme provides a strong foundation for improving heat tolerance and enhancing survival and growth during periods of elevated temperature. Working alongside marine farmers, we have developed a reliable, repeatable survival challenge to compare heat tolerance among mussel families, measuring survival as days to death at 26°C. Current results show that heat tolerance in GSM is moderately heritable ($h^2 = 0.15\text{--}0.54$), indicating sufficient genetic variation to enable meaningful genetic gains if heat tolerance is incorporated into selection indices. Beyond survival testing, we are examining physiological responses to heat stress across families, helping identify biomarkers associated with high and low heat tolerance. We have also observed complex ontogenetic patterns, with heat tolerance shifting across life stages. Collectively, these findings demonstrate that selective breeding for heat tolerance is both feasible and promising for GSM, positioning it as a key tool for strengthening aquaculture resilience in a warming climate. Next steps will be to understand whether heat tolerant mussels are also resilient to other environmental drivers e.g. ocean acidification or low salinity.

Scaling Marine Carbon Dioxide Removal through Coastal Ecosystems: A Multisectoral Approach to Nature-Based Coastal Carbon Removal in the 'Global South'

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2E: Beyond Tipping Points: Financing Ocean Futures: From OA Research to Coastal Safeguards,
Mākarō, October 13, 2026, 16:00 - 18:00

Marine carbon dioxide removal (mCDR) is increasingly recognized as an important strategy to mitigate climate change by enhancing the ocean's capacity to capture and store carbon. However, many technology-driven mCDR methods face ecological, economic, and policy challenges in the Global South, where fragile but highly biodiverse coastal ecosystems sustain millions of people. While national policies emphasize conservation and livelihoods, weak governance and greenwashing often limit genuine climate action, and poorly designed mCDR interventions risk harming both ecosystems and communities.

Natural coastal systems such as mangroves, seagrasses, seaweeds, shellfish aquaculture, and integrated mangrove–aquaculture ponds offer practical, low-risk, and socially inclusive alternatives. Based on published literature and available national-level data, we estimate these ecosystems to be able to collectively remove about 0.16 Gt CO₂ per year across the Global South, highlighting their measurable contribution to global carbon drawdown. Their combined carbon storage, biodiversity, and livelihood benefits establish them as verifiable nature-based mCDR pathways rather than incidental co-benefit systems.

Integrating indigenous knowledge with scientific monitoring and standardized carbon accounting can strengthen their role in climate mitigation. Conserving and restoring these blue carbon ecosystems provide an equitable, low-cost pathway to advance marine carbon removal while promoting sustainable development and climate justice in the Global South.

Vulnerability Assessment of Ocean Acidification in Papua New Guinea's Coastal and Marine Ecosystems

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2E: Beyond Tipping Points: Financing Ocean Futures: From OA Research to Coastal Safeguards,
Mākaro, October 13, 2026, 16:00 - 18:00

Papua New Guinea (PNG) has more than 17,000 km of coastline and supports extensive coral reef, seagrass, and mangrove ecosystems. These ecosystems underpin food security, livelihoods, and cultural identity, yet are increasingly vulnerable to ocean acidification (OA). Despite this risk, OA remains insufficiently reflected in national climate risk and adaptation planning, constrained by limited awareness, technical capacity, monitoring infrastructure, and persistent data gaps. This assessment applies a national OA vulnerability framework structured around exposure, sensitivity, and adaptive capacity. It integrates oceanographic data, satellite-derived indicators, marine ecosystem information, field observations, and community consultations in Milne Bay and Manus to characterize PNG's exposure to OA and inform an assessment of ecosystem and community vulnerability.

The assessment identifies a critical gap in carbonate chemistry monitoring in PNG, including the absence of national pH monitoring stations and OA monitoring within marine protected areas and locally managed marine areas. This limits the ability to detect site-specific conditions and trends. Significant gaps also remain in ecological, socioeconomic, and adaptive capacity data, particularly for remote coastal communities. Nevertheless, the systematic integration of available datasets with local marine governance information provides a practical basis for assessing vulnerability and identifying priority actions. By consolidating fragmented evidence within a unified analytical framework, the assessment strengthens the basis for evidence-informed decision-making on OA in PNG. It identifies priority areas, data gaps, and monitoring needs, and provides actionable information to support government agencies and development partners in targeting adaptation investments, advancing nature-based solutions, strengthening capacity, and mobilizing climate finance.

Advancing Priority Science and Policy Action on Ocean Acidification in the Asia-Pacific Region

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2E: Beyond Tipping Points: Financing Ocean Futures: From OA Research to Coastal Safeguards,
Mākaro, October 13, 2026, 16:00 - 18:00

This is a report-out from the Special Session, "Advancing Priority Science and Policy Action on Ocean Acidification in the Asia-Pacific Region", hosted by the International Atomic Energy Agency and the International Alliance to Combat Ocean Acidification. This special session focused on financing for a regional OA Action for Pacific Islands countries and the development of a Southeast Asian task force on ocean acidification.

Participants in this special session included policy makers, researchers, representatives of financial institutions across the Asia Pacific region and international organizations, to discuss:

- * Status report on the state of OA science in the region.
- * Applicable governance frameworks for the uptake of OA mitigation and adaptation measures including Nationally Determined Contributions, National Adaptation Plans, National Ocean Policies and more.
- * Financial mechanisms that can support the expansion of OA science for policy uptake and action.

Engaging Philanthropy, Development Banks and the UNFCCC on Funding Ocean Acidification Science-to-Policy: Lessons Learned

Jessie Turner¹

¹International Alliance to Combat Ocean Acidification (oa Alliance), Washington, United States

2E: Beyond Tipping Points: Financing Ocean Futures: From OA Research to Coastal Safeguards,
Mākaro, October 13, 2026, 16:00 - 18:00

Securing the adequate funding for ocean and coastal adaptation projects requires strong support from national governments, in addition to significantly improving ocean literacy of climate financial institutions.

The OA Alliance has spent nearly ten years engaging policy makers (subnational to national) on ocean acidification science and policy and local and international scales including specific engagement at the UNFCCC and related constituted bodies such as the Standing Committee on Finance. This presentation will provide a short overview of the lessons learned from the OA Alliance engaging philanthropy, development banks and the UNFCCC on funding ocean acidification science to policy.

While UNFCCC finance mechanisms like GEF and GCF are primarily designed to respond to national applications that demonstrate strong Party support, climate finance regimes also tend to support regionally coordinated projects and initiatives. With proper direction, these financial mechanisms can serve as significant incubators of projects that aim to build technological capacity for long-term observation of climate-ocean change and risks, which ultimately should inform a broad range of ocean and coastal adaptation strategies.

BGC-Argo floats and SOCAT as a pCO₂ Observing System in the Southern Ocean: A Multi-Model Subsampling Assessment

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Welcome & Poster Session 1, Exhibition Area, Level 1, October 13, 2026, 18:00 - 19:30

The Southern Ocean is a key sink for atmospheric CO₂, yet estimates of air-sea CO₂ fluxes remain highly uncertain due to sparse observations and methodological differences. Reconstructions of surface ocean pCO₂ based on SOCAT measurements and BGC-Argo floats often diverge from biogeochemical model outputs, complicating global carbon budget assessments. While previous studies assessed observational sampling using SOCCOM floats or a limited number of models, a comprehensive multi-model evaluation of the full BGC-Argo network combined with SOCAT is still lacking. Here, we address this gap by subsampling five global ocean biogeochemical models at SOCATv2023 and BGC-Argo locations south of 30°S. We evaluate three scenarios: (i) SOCAT-only, (ii) BGC-Argo-only, and (iii) combined, assessing reconstruction skill using correlation and RMSE from detrended fields with and without seasonal-cycle removal. Results show that combining SOCAT and float observations improves reconstruction skill across all models, with the lowest RMSE and highest correlations in the combined case. SOCAT-only or float-only sampling leads to larger errors and stronger model-dependent differences. Skill is strongly modulated by the seasonal cycle, with lower errors in winter and higher RMSE in summer, likely associated with enhanced biological activity. Removing the seasonal cycle reduces RMSE but reveals persistent limitations in capturing interannual variability. While mean pCO₂ is well reproduced across all configurations, long-term trends are underestimated in float-only sampling. Combined SOCAT–BGC-Argo sampling provides the most robust representation of mean state and temporal variability, highlighting the importance of integrating multiple observing systems to constrain Southern Ocean carbon fluxes and reduce global carbon budget uncertainties.

Knowing the Ocean:

Pacific Traditional Knowledge and Coastal Monitoring

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Welcome & Poster Session 1, Exhibition Area, Level 1, October 13, 2026, 18:00 - 19:30

In the Pacific, the ocean is not just a body of water. It is where knowledge is carried — not in books, but in the winds, waves, and the horizon. The stories and practices are passed down across many generations. Traditional knowledge (TK) is accumulated over hundreds of years and can be specific to a particular geographical location. Pacific ancestors utilized traditional knowledge to assist them with ocean observations, stewardship and adaptations. It is primarily orally transmitted between generations through storytellings, chants, songs and in-the-field teachings.

TK forms the basis of customary marine tenure allowing for sustainable marine practices. Tabu (taboo) areas are one of the management systems that selectively restricts access to certain marine species, ensuring long-term sustainability. Traditional indicators are also used to assess the health of the marine and coastal ecosystems. These indicators can be used to complement scientific ocean acidification (OA) and water-quality monitoring.

TK is a crucial part of the Pacific people because it is one of the region's foundations for identity, survival and science. Today, there is a growing recognition of building a synergistic relationship between traditional knowledge and modern science. Therefore, it can help reduce the impacts of climate change in the Pacific.

Carbonate Chemistry at the Top of the World: Observations from a 90°N Trans-Arctic Ship of Opportunity Transit

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Welcome & Poster Session 1, Exhibition Area, Level 1, October 13, 2026, 18:00 - 19:30

The Arctic Ocean is a critical frontier for ocean acidification research, yet the central Arctic Basin and the North Pole remain chronically undersampled due to logistical barriers. Filling these gaps requires utilizing available platforms that can navigate heavy ice cover. This poster presents underway pCO₂ and discrete carbonate chemistry data (pH, Total Alkalinity, and Dissolved Inorganic Carbon) collected during a 2024 trans-Arctic crossing that included sampling at the geographic North Pole (90°N).

The samples were obtained through a collaboration between the Ponant icebreaker Le Commandant Charcot and NOAA. By integrating scientific sampling into the vessel's transit, we were able to capture high-latitude carbonate chemistry data in regions often inaccessible to traditional research cruises. We present the spatial variability of the system along the transect, documenting the chemical signatures observed across the deep Arctic basins and the geographic North Pole. These results contribute to the growing body of high-latitude observations needed to track the chemical evolution of the Arctic Ocean and demonstrate the practical role that non-traditional sampling platforms can play in expanding the spatial reach of ocean acidification monitoring in remote, ice-covered regions.

Riverine flood pulses restructure estuarine pico-sized chlorophyte communities through salinity shifts at a subtropical river–sea interface

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Welcome & Poster Session 1, Exhibition Area, Level 1, October 13, 2026, 18:00 - 19:30

Chlorophytes are important components of marine phytoplankton and contribute substantially to primary production and carbon flow in aquatic ecosystems. Estuaries experience strong hydrographic fluctuations that can rapidly restructure pico-sized chlorophyte communities, yet the contribution of freshwater lineages to these transitions remains poorly resolved. Here, we conducted a year-long dual-platform survey using Illumina MiSeq V4 and PacBio full-length 18S rRNA gene amplicon in the Minjiang estuarine–coastal system to examine chlorophyte succession across salinity gradients. Flood-driven freshening coincided with elevated chlorophyll a, dissolved oxygen, silicate, and nitrate, together with transient dominance of Trebouxiophyceae. MiSeq detected pronounced peaks of Chloroidium, whereas PacBio recovered sustained dominance of Auxenochlorella, highlighting platform-specific taxonomic sensitivity but consistent ecological turnover. In contrast, marine prasinophytes declined under low-salinity conditions and reappeared as salinity returned to euhaline levels. Ordination analyses further showed that freshwater and low-salinity Trebouxiophyceae were associated with dissolved oxygen and silicate, whereas marine prasinophytes were aligned primarily with salinity and temperature. Along the salinity gradient, *Picochlorum* exhibited a U-shaped response, whereas *Tetraselmis* peaked under mesohaline conditions. Together, these results show that flood-driven environmental change strongly regulates estuarine chlorophyte succession and that dual-platform 18S rRNA gene amplicon sequencing provides complementary resolution for detecting freshwater-driven compositional shifts in coastal picoeukaryote assemblages. This framework offers a useful basis for monitoring salinity-driven community transitions at subtropical river–sea interfaces under intensifying hydrological variability.

Sedimentary Alkalinity Production Sustains Low pCO₂ in Seagrass Meadows: Evidence from a Semi-Enclosed Lagoon

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Seagrass meadows are widely recognized as coastal blue carbon ecosystems, yet the role of sedimentary alkalinity production in regulating seawater carbonate chemistry and atmospheric CO₂ exchange remains poorly understood. Here we present a natural case study from the Dongsha Inner Lagoon in the northern South China Sea, where strong sediment–water coupling sustains persistently low pCO₂ in seagrass meadows. Previous observations show that this system is characterized by net community production exceeding net community calcification (NCP > 0; NCC < 0), indicating an autotrophic ecosystem with net CaCO₃ dissolution. The lagoon’s semi-enclosed geomorphology, long water-residence times, and sediments rich in allochthonous CaCO₃ and autochthonous organic carbon create conditions that strongly enhance sedimentary biogeochemical processing. Aerobic remineralization of seagrass-derived organic matter generates CO₂ that drives metabolically mediated carbonate dissolution, while anaerobic pathways—particularly sulfate reduction and sulfide re-oxidation—further increase total alkalinity (TA). This sediment-driven alkalinity production leads to a mechanistic decoupling between TA and dissolved inorganic carbon (DIC): sediment-derived DIC is largely re-assimilated by seagrass photosynthesis, whereas TA accumulates in the water column, enhancing buffering capacity and maintaining suppressed pCO₂ throughout the diel cycle. Measured benthic TA fluxes in the lagoon greatly exceed model predictions for carbonate-rich seagrass sediments, highlighting the importance of organic-inorganic carbon coupling in controlling coastal carbonate chemistry. Together, these results demonstrate that autotrophic seagrass ecosystems with net carbonate dissolution can function as sediment-regulated pCO₂ sinks, revealing a previously underappreciated pathway by which coastal systems contribute to marine CO₂ uptake.

Transcriptomic responses of a bioeroding sponge to interacting ocean change drivers

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Bioeroding sponges are major macroborers in many marine ecosystems and are expected to become increasingly abundant under climate change. Reduced seawater pH can enhance sponge bioerosion, while elevated temperature may have negative effects. However, the combined impacts of ocean warming, acidification, and marine heatwaves (MHWs) remain poorly understood, especially at the molecular level.

Here, we investigated the transcriptomic responses of a bioeroding sponge from the *Cliona* aff. *celata* species complex, collected from a temperate oyster bed. Sponges were exposed in a fully factorial experiment with four main treatments: control (ambient pH, ambient temperature), ocean acidification (future pH, ambient temperature), ocean warming (ambient pH, future temperature), and combined future conditions (future pH, future temperature). Within each treatment, half of the sponges were additionally exposed to a simulated MHW. Transcriptomic samples were collected at pre-MHW, MHW, and post-stress recovery timepoints.

Preliminary differential expression analyses showed that elevated temperature was the principal driver of changes in gene expression, and together with the MHW was strongly biased toward downregulation. Reduced pH alone affected fewer genes overall and induced both the up- and downregulation of genes. In contrast, significant temperature–heatwave and pH–heatwave interactions involved marked increases in both up- and downregulated genes, indicating that heatwave responses were non-additive and strongly dependent on environmental background. This highlights the importance of considering interacting drivers when predicting the future dynamics of bioeroding sponge communities and their impacts on ecosystem-scale carbonate budgets.

Does alkalinity enhancement affect survival and shell integrity of Aotearoa New Zealand mussels?

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Welcome & Poster Session 1, Exhibition Area, Level 1, October 13, 2026, 18:00 - 19:30

Ocean alkalinity enhancement (OAE) is a method being explored for removal of atmospheric CO₂ by the ocean to reduce future global warming. It involves adding an alkaline solution to seawater, with the potential benefit of mitigating ocean acidification impacts by increasing the pH of seawater and should theoretically have positive effects for calcium carbonate utilising organisms. We carried out experiments to assess the response of vulnerable early life stages of two mussel species, the green lipped mussel *Perna canaliculus*, and the blue mussel *Mytilus edulis* to OAE. Both species are important ecologically and culturally, as kaimoana (food) and *Perna canaliculus* is integral to Aotearoa's aquaculture industry. In each experiment, newly fertilised eggs were exposed to two levels of alkalinity (+200 and +500 micromol/kg) by adding sodium bicarbonate and carbonate, and allowed to develop and grow for five days. After this time mussel veligers were assessed for overall survival, size, and shell integrity (explored using Scanning Electron Microscope and micro-Computed Tomography). Results will be analysed to determine any differential effects of the experimental treatments, within and between mussel species, and will be discussed in terms of the broader consequences of OAE on coastal marine ecosystems.

Impact of algal deposition (*Vaucheria* sp.) on DIC and alkalinity fluxes of an intertidal salt-marsh colonized by *Spartina Anglica*

Mr Kentin Plègue¹, Mme Camille Décultot¹, Mme Gwendoline Duong¹, Professor Lionel Denis¹, Mr Nicolas Spilmont¹

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Welcome & Poster Session 1, Exhibition Area, Level 1, October 13, 2026, 18:00 - 19:30

Coastal ecosystems located at the interface between continental, atmospheric and oceanic realms represent a major biogeochemical reactor and play a key role in organic matter degradation and global carbon (C) cycle. In addition to the challenges associated with Carbon budgets establishment, such as emersion/immersion periods alternation, extreme events like algae blooms can disturb associated biogeochemical processes.

This presentation investigated the impact of an algae (*Vaucheria* sp.) on the dissolved O₂ /carbon/alkalinity (between sediment and water) and gaseous CO₂ fluxes (between sediment and atmosphere) within a *Spartina Anglica*-dominated biofacies in Canche salt-marsh (north of France). Fluxes measurement were conducted both during immersion (core incubations) and emersion (benthic chamber measurements) periods on two stations: one with algal deposition and one without.

The two stations firstly showed a significant release of Dissolved Inorganic Carbon (DIC) and alkalinity (TA) during the immersion. However, an important increase of DIC and TA fluxes was observed in the station with algal deposition. The O₂ consumption were also higher (quite the double) than the one observed in the station without algae. DIC/O₂ and TA/DIC ratios suggested a similar contribution of aerobic and anaerobic organic matter mineralization in the two stations. During emersion, a similar carbon release was measured in the two stations during night time, whereas an increase of CO₂ fixation was observed in presence of algae during day time.

These results showed that algae deposition could deeply intensify the benthic biogeochemical processes of coastal areas and by this way also play role in local water acidification.

The energetic cost of long-term exposure to ocean acidification in the commercial scallop *Zygochlamys patagonica*

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Ocean Acidification (OA) has been recognised as a threat to commercial species, including the scallop *Zygochlamys patagonica* from the Southwest Atlantic Ocean. Previous work documented an increase in mortality as a consequence of the experimental exposure to OA and this work explores how this relates to changes in energy budget. We experimentally investigated the impact of prolonged exposure to reduced pH on the biochemical composition of adductor muscle of *Z. patagonica*. Three pH treatments were compared: two within the current range of natural variability (8.10 as high pH and 7.80 as medium pH), and a more acidic condition (7.50 as low pH) simulating future OA. The exposure to low pH was followed by 2-month depuration period. Exposure to the medium pH did not lead to significant changes. Under the lowest pH level, a marked decline in protein and total lipid concentrations were observed, suggesting a reduction in overall energy storage. Glycogen content remained unaffected by exposure to low pH. The fatty acid composition was altered under acidified conditions, with an increase in the PUFA/SFA ratio as well as levels of EPA and DHA. No recovery was observed after 2-month depuration period for the tested biochemical parameters. The physiological and ecological implications of observations will be discussed.

Early life-stage responses to ocean acidification in the invasive estuarine shrimp *Palaemon macrodactylus*

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Assessing species resilience to Ocean Acidification requires understanding how reduced pH conditions affect early life-history traits critical for survival and population persistence. We evaluated the effects of experimental seawater acidification on larval survival, time to reach the juvenile phase, and juvenile size of the invasive shrimp *Palaemon macrodactylus*. Three pH treatments were defined based on natural variability in the study site: 7.90 (high pH, annual mean), 7.80 (intermediate pH, lowest value recorded), and 7.50 (low pH, 0.3 below the observed minimum), with 3 aquarium replicates for each. Larval survival differed among treatments ($p < 0.0001$) showing higher values (78.3%) at high pH than under both intermediate and low pH conditions (60.0% and 57.6%, respectively; $p < 0.0001$ for both comparisons). Development time until the juvenile phase ranged from 13 to 27 days, with differences between high and intermediate pH conditions (16.26 ± 2.12 vs. 15.76 ± 1.19 days; $p = 0.032$), with an intermediate mean development time (16.24 ± 1.72 days) at low pH. Juvenile carapace length (CL) also varied ($p < 0.0001$), individuals reared under low pH were smaller (1.14 ± 0.068 mm), than those under high (1.17 ± 0.066 mm) and intermediate pH conditions (1.16 ± 0.074) ($p < 0.001$ for both comparisons). Low pH constitutes an environmental stressor for this shrimp species, as evidenced by decreased larval survival and smaller juvenile size. These results demonstrate that ocean acidification can impair key aspects of early development in calcifying and environmentally tolerant species, with potential consequences for population dynamics and invasion success under future coastal scenarios.

The Oleander Transect: A Ship-of-Opportunity Platform for High-Frequency Ocean Carbon Observations

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The container ship M/V Oleander operates as a sustained ship-of-opportunity platform for observing surface ocean biogeochemistry and physical oceanography between Bermuda and New Jersey. As part of the Surface Ocean CO₂ Atlas (SOCAT) and within the Research on Commercial Ships (RoCS) framework, this collaboration integrates autonomous measurements into a commercial shipping route to deliver high-frequency observations in the western North Atlantic.

We present an analysis of underway measurements of fugacity of CO₂ (fCO₂), sea surface temperature (SST), salinity, and coincident physical oceanographic context spanning 2024–2026. Data were quality-controlled and mapped onto a fixed latitude grid. Hovmöller diagrams (latitude versus time) resolve seasonal variability and mesoscale structure along the transect.

The Oleander line captures the evolving position and structure of the Gulf Stream and its associated fronts. Strong meridional gradients in temperature and salinity track shifts in Gulf Stream position, while isohaline contours (34–36 ‰) reveal coherent coupling between physical variability and surface carbonate chemistry. Elevated fCO₂ is associated with warmer, saltier waters to the south, with reduced values in cooler, fresher waters to the north. Despite data gaps associated with rapid transit across steep gradients, interpolation preserves dominant spatial and temporal patterns.

This work highlights the value of coordinated ship-based observing systems for resolving short-timescale variability in the surface carbon system. The Oleander transect demonstrates how commercial vessels, augmented with multidisciplinary measurements such as ADCP-derived currents, can serve as scalable platforms for sustained ocean carbon observations and contribute directly to global synthesis efforts such as SOCAT.

Integrating Eddy Covariance and Carbonate Chemistry to Constrain CO₂ Fluxes in a Large Shallow Lake

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Wairarapa Moana, the third largest lake in North Island of Aotearoa New Zealand and a Ramsar-listed wetland of international importance, has been assessed for macrophyte restoration aimed at improving water quality and ecosystem health. However, its role in the carbon cycle, particularly in terms of carbon dioxide (CO₂) exchange with the atmosphere was never studied. Establishing a baseline understanding of CO₂ dynamics is essential to evaluate whether future restoration efforts can deliver measurable climate co-benefits. Wairarapa Moana is hydrologically connected to the coastal ocean via a river channel, creating a continuum through which inland CO₂ dynamics may influence downstream coastal carbon processes.

This study presents a framework to quantify the air–water CO₂ exchange in Wairarapa Moana through a combination of continuous atmospheric measurements and water chemistry observations. An eddy covariance (EC) system will be deployed to monitor high-frequency CO₂ fluxes, capturing diurnal and seasonal variability and their dependence on meteorological drivers such as wind speed and direction. Complementary water sampling will be conducted to determine dissolved inorganic carbon (DIC), pH, and alkalinity, which together constrain the carbonate system and enable calculation of pCO₂, allowing assessment of the processes controlling CO₂ dynamics and air–water exchange. By integrating EC-derived flux measurements with water chemistry, this study will provide the first high-resolution CO₂ budget for a major New Zealand lake prior to restoration. The results will establish a critical baseline against which future restoration outcomes can be assessed and will contribute to improving the representation of inland waters in national greenhouse gas inventories.

Localized acidification in a giant clam ocean nursery highlights the immediate need for carrying capacity studies

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Giant clams are calcifying and functional photosynthetic organisms that play a crucial role in maintaining the health and function of coral reef ecosystems. Despite their importance, giant clams are threatened primarily by poaching and increasing sea surface temperatures that may cause bleaching. The Silaqui Giant Clam Ocean Nursery in Bolinao, Pangasinan, Philippines, hosts about 30,000 giant clams being reared for restocking giant clam populations within the country. Its 58,000 m² area is situated on a shallow reef flat and adjacent to a dense seagrass bed. Discrete carbonate chemistry measurements were performed to understand the water quality conditions amid anthropogenic pressures from a changing climate and booming ecotourism industry. Results of spatial (mean±s.d.) and diel (range) sampling showed that in the dry season, pCO₂ was high (885±89 µatm; 374-1017 µatm), pH was relatively low (7.74±0.04; 7.69-8.04), and aragonite saturation values (2.08±0.17; 1.86-3.74) were below the threshold for marine calcifiers, possibly due to calcification and respiration. In the wet season, pCO₂ was lower (292±30 µatm; 217-540 µatm), pH was relatively higher (8.21±0.06; 7.93-8.26), and aragonite saturation values were above the threshold (3.96±0.31; 2.21-4.58), suggesting the dominance of processes that contribute to a potential buffering effect, albeit with higher sea surface temperatures (31.5±0.5°C; 30.2-31.8°C) than the dry season (28.7±0.3°C; 28.6-30.4°C). The localized acidification (dry season) and possible bleaching (wet season) conditions underscore the need to reassess the giant clam population density within the nursery through carrying capacity estimates that incorporate carbonate chemistry measurements to ensure a healthy ocean sanctuary for these gentle giants.

Living in different tidal niches: acute metabolic response of Adriatic gastropods to low pH

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Ocean acidification can modulate metabolic activity in marine organisms, but responses are often linked to the level of environmental variability experienced in their natural habitats. This study examined short-term metabolic responses to low pH of three gastropod species occupying different niches within the same habitat: *Patella ulyssiponensis*, *Cerithium vulgatum*, and *Phorcus turbinatus*. Specimens were collected from the same location in Mali Ston Bay (southeastern Adriatic Sea), a coastal system characterized by natural pH variability (pHT 8.07–7.74). While *P. ulyssiponensis* and *P. turbinatus* inhabit intertidal rocky substrates, *C. vulgatum* primarily occurs in the shallow subtidal zone. Respiration rate (oxygen consumption; $\mu\text{mol O}_2 \text{ h}^{-1} \text{ g}^{-1}$ wet weight) was measured after a 10-day exposure to four pH treatments (pHT 7.82, 7.42, 7.01, and 6.62) at a constant temperature of 15 °C. The experimental gradient included lower pH levels to examine metabolic response across a broader carbonate chemistry range. Linear models were used to assess the relationship between pH and respiration for each species and to compare responses among taxa. Respiration decreased with declining pH in all gastropods, indicating reduced metabolic activity. Significant relationships were observed in the intertidal species *P. ulyssiponensis* and *P. turbinatus*, whereas the subtidal *C. vulgatum* showed a weaker and non-significant response. Although intertidal organisms showed stronger metabolic responses, pairwise comparisons indicated no statistically significant differences in sensitivity among taxa. These findings suggest that short-term exposure to reduced pH may suppress metabolic activity in some gastropods, while habitat-related ecological traits may influence the magnitude of the response.

Relating subsurface burrow structures and the associated microbial community to seafloor sediment biogeochemistry in a changing world.

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Over 70% of the world's surface is a muddy or sandy seafloor. Many animals that live in the seafloor build burrows which double the reactive surface area and host microbes that catalyse globally important biogeochemical reactions. Burrow microniches are a key component of the benthic ecosystem, hosting specific functional groups of microbes that catalyse benthic biogeochemical cycling and support ocean productivity. However, the importance of burrow shape and size on the rates of these reactions is unknown, and in turn the impact climate may have on their function in the future.

We used an intertidal mudflat as a model system to investigate these relationships. We visualise and quantify bioturbation rates using fluorescent sediment profile imagery and computed tomography (CT) scanning.

To determine the type and abundance of microbial communities that live in different parts of the burrows specific depths and types (e.g., surface connected shaft, connected node, horizontal burrow) were targeted for DNA sequencing. We also determined the associated rates and amplitude of infaunal mediated nutrient cycling (NH₄-N, NO₃-N, NO₂-N, DRP, DSi). Once characterised in current environmental conditions, we incubated replicated sediment cores under future climate conditions (year 2100, temperature +4 °C, pH -0.35 units) to determine how burrow geometry, microbial communities, and biogeochemical cycling were altered. These experimental measurements will enable us to parameterise the micro-scale changes in microbial communities that are caused by changes in infaunal burrow architecture at the mm to cm scale and predict how future climate change might impact New Zealand estuarine and global ecosystems.

Integrating te ao Māori into the regeneration of kelp forests within Te Whanganui a Tara, Aotearoa.

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The connection Māori have to coastlines and the health of the marine environment is intimately intertwined with ones whakapapa (genealogy). As Māori, our whakapapa connects us directly to every aspect of our taiao (natural environment) and as humans with this connection, it means that we are also kaitiaki (guardians) with responsibility to care and nurture our taiao. With the consequences of climate change exponentially worsening, there is a big drive for Māori in the restoration space, fighting to keep our taiao healthy and thriving, using indigenous knowledge systems. As mana whenua (tribe with territorial rights) of Te Whanganui-a-Tara (Wellington), Taranaki Whānui ki te Upoko o te Ika (local tribe) holds this responsibility as kaitiaki to this rohe (region), and this particular marine environment of the Wellington harbour. Through the seaweed restoration project, Love Rimurimu, opportunity was sought to investigate how natural fibres traditionally used by Māori could be used as a substrate to grow *Macrocystis* from spore collection to sporophytes to plant-outs. Two out of five fibres have reached the stage of successfully holding sporophytes and will be planted into the harbour to complete the final stages of this research whilst another two fibres lag behind in the process but show promising signs of healthy substrate and kelp growth. This research along with the relationships formed between the project and mana whenua have allowed for the sharing of two knowledge systems that are working together to regenerate the kelp forests within Te Whanganui-a-Tara, Aotearoa.

Effects of Prolonged Warming on Macroinvertebrates Assemblages in Mesocosms in Sydney, Australia

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Ocean warming (OW) and Marine heatwaves (MHWs) continue to increase in frequency and duration, negatively impacting vital marine ecosystems, which can alter species richness and composition. OW and MHWs can impact species physiology, immune function, and fitness. Settlement plates and Artificial Units of Habitats (AUHs) have been used extensively to measure macroinvertebrate and fouling communities. The aim of this study was to determine the impacts of OW on macroinvertebrate communities at Chowder Bay, New South Wales, Australia. Settlement plates and AUHs were deployed within mesocosms at ambient and elevated +4°C temperature for a period of four months in the Austral summer of 2025 and 2026. Species richness and abundance on settlement plates and AUHs was measured and found to be dependent on temperature and substratum; with sponges and polychaete worms the main taxa driving differences. These results provide evidence that in a high CO₂ world, OW will impact and potentially alter macroinvertebrate marine assemblages in Sydney harbour.

Ocean acidification offsets heatwave-driven recruitment failure and reshapes projected range shifts in the canopy-forming alga *Sargassum macrocarpum*

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Atmospheric CO₂ enrichment drives ocean warming (OW) and ocean acidification (OA), increasing the frequency and intensity of marine heatwaves (MHWs) that threaten thermally sensitive macroalgae. In 2024, an unprecedented MHW along the southern coast of Korea, with seawater temperatures ~5°C above the 20-year average for over 80 days, caused widespread macroalgal loss. *Sargassum macrocarpum*, a foundation species in this region, survives summer as basal holdfasts and recruits as second-year individuals. This study tested whether reduced recruitment under MHW conditions (28°C; +3°C above ambient 25°C) persists under elevated CO₂ (~1000 ppmv) using a three-week microcosm experiment. Simulated MHW conditions significantly reduced photosynthetic performance and growth, accompanied by imbalanced light utilization. In contrast, elevated CO₂ enhanced photosynthesis and growth, and improved light-use efficiency. Under combined MHW and OA conditions, the negative effects of thermal stress were partially alleviated. These results suggest that MHW-induced thermal stress constrains energy acquisition in *S. macrocarpum*, potentially reducing recruitment success, whereas OA may partially offset these effects by enhancing physiological performance. This interaction implies that although warming and recurrent MHWs may drive northward range shifts, OA could modulate this response by mitigating thermal stress.

Regional scale climatology of global change CO₂ flux on the ocean surface flux for North Atlantic and the Arctic

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Calculate climatology of the air-sea flux of CO₂ and ocean sinks of the anthropogenic CO₂ budget is important because there is still a lot of open question on carbon sinks, especially for the northern hemisphere. The CO₂ partial pressure data is used in the monitoring of direction and magnitude of the net air-sea interface ocean carbon flux. We used for calculated a millions of measurements of this pressure. However the regional and temporal means, which we compute in our study, depend on parametrization of gas transfer velocity as well as on the wind/waves fields used for calculations. The aim of this study is to provide ensemble of regional monthly averages of the CO₂ flux climatology for the North Atlantic and Arctic waters using multiple combinations of forcing fields and gas transfer velocity parametrizations. The results of the study are intended in the future to spread to from the regional to the global scale and cover by the results the whole North Atlantic and Arctic waters.

Differential ocean acidification effects on two economically important clams from southern South America

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High-latitude regions are particularly vulnerable to ocean acidification (OA), making studies in areas such as the Beagle Channel, a subpolar ecosystem in southern South America, crucial for understanding its impacts on economically important species and the consequences for ecosystem services. The effects of present-day (400 μatm) and near-future (1200 μatm) pCO_2 levels at the mean summer temperature (10 °C) on the clams *Tawera gayi* and *Retrotapes exalbidus* were analyzed experimentally. The standard metabolic rates (SMR) were estimated using intermittent-flow respirometry in static chambers with polarographic electrodes. The changes in oxidative metabolism were analyzed in the gills and digestive gland of clams by quantifying lipid peroxidation (as the content of 2-thiobarbituric acid reactive substances, TBARS), the activities of superoxide dismutase (SOD), catalase (CAT) and glutathione S-transferase (GST) enzymes, and the content of reduced glutathione (GSH). After 45 days of exposure, only *R. exalbidus* showed significant differences in the SMR, with lower values at near-future pCO_2 levels. Regarding oxidative metabolism in the gills, TBARS levels were significantly reduced in both species at near-future pCO_2 levels. Only the CAT activity varied significantly, decreasing at these pCO_2 levels in *R. exalbidus*. No differences in GSH levels were detected in any of the species. In the digestive glands, only SOD activity decreased significantly in both species at near-future pCO_2 levels. Present results indicate that short-lived (*T. gayi*) and long-lived (*R. exalbidus*) clams respond differently to OA. This information should be considered when developing species-specific conservation strategies in the context of climate change.

Fatty acid response of Antarctic ascidia *Cnemidocarpa verrucosa* to ocean warming and acidification

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Ocean warming (OW) and acidification (OA) are likely to alter the biochemical composition of marine organisms as a physiological response to changing environmental conditions. Given the importance of fatty acids (FA) in energy transfer within marine food webs, we investigated how OW and OA affect the relative FA composition of the gill and mantle tissues of *Cnemidocarpa verrucosa*, an abundant and widely distributed ascidian in Potter Cove (Antarctica). Individuals were exposed to two temperatures (1 and 5 °C) and two pCO₂ levels (350 and 1200 µatm) in a full-factorial design for 45 days. PCA analyses revealed moderate shifts in overall FA profiles across treatments, with clearer separation under warming (5 °C) and combined-stress conditions (5 °C and 1200 µatm). SIMPER analyses identified FAs 18:1 (n-9), 20:5 (n-3), and 22:6 (n-3), key components of membrane structure and energy metabolism, as the main contributors to such differences. When FAs were analyzed separately, relatively minor deviations from the control treatment (1 °C and 350 µatm) were observed in the gills. In contrast, the mantle exhibited greater variability in SFA, MUFA, PUFA, total n-9, the n-6/n-3 ratio and total lipid content across treatments, suggesting that this tissue is more responsive than the gills to OW and OA. Such differences likely reflect distinct physiological roles, with the mantle functioning as a more dynamic metabolic compartment, potentially enabling greater biochemical flexibility under future ocean conditions.

Temperate sponge microbiomes as drivers of holobiont resilience to marine heatwaves

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Marine heatwaves (MHWs) are increasing in frequency, intensity and duration under climate change, threatening marine ecosystems, particularly temperate benthic communities. Sponges are key ecosystem engineers on temperate reefs, yet recent MHWs reveal strong interspecific differences in thermal tolerance, highlighting gaps in our understanding of their resilience. Earlier evidence suggests that sponge-associated microbiomes play a central role in stress tolerance, potentially enabling rapid acclimation through microbial reorganisation. My study investigates how sponge microbiomes contribute to holobiont acclimation during repeated MHW exposure. Temperate sponge species common to New Zealand coasts (*Tethya bergquistae*, *Tethya burtoni*, *Aaptos globosum* and *Darwinella oxeata*) are being assessed under controlled laboratory MHW simulation with an initial 42-day MHW, followed by an eight-week recovery period and a subsequent, more intense heatwave. Host responses will be assessed alongside microbial community shifts across both events to determine whether changes induced by the first heatwave enhance tolerance to subsequent thermal stress. High-throughput 16S rRNA sequencing, metagenomics and genome-scale metabolic modelling will identify microbial taxa, functional pathways and metabolic interactions linked to thermal tolerance. By connecting microbial dynamics with host performance, this study will reveal microbiome-mediated stress memory clarify mechanisms of acclimation and improve predictions of sponge resilience under future ocean warming.

Direct measurements of CO₂ fluxes over the Arctic Ocean: extreme conditions on gas transfer dynamics

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The European Arctic is a highly dynamic, biogeochemically important region and is one of the world's largest carbon sinks. Scientific publications and reports have shown that the long-term trend of global air-sea CO₂ fluxes is mainly driven by constantly increasing CO₂ in the atmosphere, most of which is stored in the ocean. The magnitude of the ocean sink can be determined using air-sea CO₂ flux estimates based on measurements of the oceanic and atmospheric pCO₂ (pCO₂ W and pCO₂ A, respectively) in combination with parameterizations of gas transfer across the sea surface. Despite many years of efforts by researchers and the discovery of novel research methods in situ measurements of pCO₂ W are still sparse in most parts of the world ocean and pCO₂ W surveys are a more complex task. Solving the problems of data gaps and estimating air-sea CO₂ fluxes motivated us to find a reliable method with which to interpolate CO₂ spatially and temporarily. Measurements of CO₂ fluxes between the ocean and atmosphere can be conducted using direct methods, such as eddy covariance (EC). Studies have shown that the uncertainty in hourly averaged EC air-sea CO₂ flux measurements ranges from 1.4 to 3.2 mmol m⁻² d⁻¹, corresponding to a relative uncertainty of approximately 20% during Arctic cruises with high CO₂ flux values. For smaller fluxes, this uncertainty can increase to around 50% Dong et al. (2021). In contrast, indirect methods often exhibit lower uncertainty; however, this depends on the accuracy of ΔfCO₂ measurements and the applied gas transfer velocity parameterization.

The response of giant kelp, *Macrocystis pyrifera*, to simulated Ocean Alkalinity Enhancement (OAE)

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Ocean Alkalinity Enhancement (OAE) is a promising marine CO₂ removal method, where seawater alkalinity is artificially increased to enhance oceanic uptake of CO₂ and mitigate Ocean Acidification. OAE can be implemented through electrochemical processes, or the addition of alkaline substances (sometimes referred to as enhanced weathering or ocean liming). An alkalinity source of interest is the product of Direct Air Capture (DAC), liquid carbonate. Although OAE shows significant promise as a climate change mitigation strategy, the effect of increased alkalinity on fleshy macroalgae is poorly understood. We conducted a 30-day microcosm experiment to test whether Giant Kelp, *Macrocystis pyrifera*, is likely to be impacted by alkalinity enhancement. Five treatments of different alkalinity levels were continuously applied to juvenile *Macrocystis pyrifera* individuals. Alkalinity was reduced by HCl and enhanced by Na₂CO₃ to simulate the coupling of OAE and DAC. Measured responses include relative growth rates (RGR), rapid light curves, and pigment content. We discuss how these results may inform future developments in OAE research and implementation.

Natural alkalinity generation through beach sand weathering and potential feedbacks of olivine addition

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Alkalinity is an essential parameter controlling the ocean's carbon dioxide (CO₂) uptake. Higher alkalinity levels increase the ocean's storage capacity of CO₂ by converting CO₂ into bicarbonate and carbonate ions and thus removing it from the atmosphere. Increasing the ocean's CO₂ storage capacity via Ocean Alkalinity Enhancement (OAE) through the enhanced dissolution of the alkaline mineral olivine has been proposed as a carbon dioxide removal technology.

Sandy beaches comprise 31% of the global coastline and are highly dynamic environments which are conducive for active physical weathering. Quartz, which is a slow-weathering mineral, has been shown to dissolve because of the active movement of sand grains through the actions of waves and currents. Alkaline minerals, such as basalt, olivine and calcium carbonate, are also commonly found in beach environments and could be important contributors to ocean alkalinity, yet the potential alkalinity production has not been assessed.

Here, we present results from continuous grain collision experiments of a series of natural beach sands (carbonate, basaltic, silicate-rich titanomagnetite, feldspar and garnet). We show that the mineralogy of the beach sand determines the alkalinity release rate, with silicate-rich sand producing the highest alkalinity rate per day, followed by garnet sand and basaltic sand. Dunite (olivine) addition to low alkalinity-producing sand greatly stimulated alkalinity production and suggests dunite additions to beach sites with low natural alkalinity production potential could be a viable OAE approach with limited additionality problems.

Establishing and Strengthening Ocean Acidification Monitoring program and Nature-Based Solutions in Kiribati

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Ocean Acidification (OA) remains a relatively under-recognized issue in Kiribati, despite its significant impact on seawater chemistry and vulnerable marine organisms. Corals, which serve as the building block of marine ecosystems, are particularly sensitive to climate change stressors, including OA. The decline of coral reefs has already contributed to the loss of important fishing grounds used by local communities. The Ministry of Fisheries and Ocean Resources (MFOR), through its Coastal Fisheries Division (CFD), is leading efforts to establish a national OA monitoring program. This initiative aims to generate scientific data to support United Nations Sustainable Development Goals (SDG 14) and to raise public awareness of OA impacts on livelihoods. Given the limited local expertise and monitoring capacity, initial efforts have focused on nature-based solutions. In collaboration with the Secretariat of the Pacific Regional Environment Programme (SPREP), Marine Protected Areas (MPAs) were established at the Nanikaai community and later replicated at the Ronton site on Kiritimati Island. Nature base restoration activities include coral planting, seagrass and mangrove rehabilitation, complemented by in-water surveys to assess coral and seagrass health. CFD has strengthened its technical capacity through the acquisition of a GOA-ON toolkit and the establishment of a new laboratory. The two MPAs will serve as primary sites for water sampling and long-term OA monitoring, scheduled to commence in July 2026 as part of MFOR's annual work plan.

Carbonate chemistry insights from a deep-sea octopus nursery

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There are five known deep-sea octopus nurseries worldwide and two of them are located at the Pampa Submarina, about 200 km offshore the Pacific coast of Costa Rica, at about 3000 m depth. All these nurseries are associated with low-temperature (~7-12 °C) hydrothermal vents, as warm water provides favorable conditions for brooding and hatching. Carbonate chemistry information from these sites is scarce, despite its relevance in understanding deep-sea biogeochemical and biological processes. To address this gap, we participated in two expeditions (OctoOddyssey, FKT230602 and FKT231202) aboard the Schmidt Ocean Institute's R/V Falkor(too) and collected water samples using an ROV near the bottom across six sites from Pampa Submarina, to compare the carbonate chemistry conditions in sites with known hydrothermal springs (El Dorado Hill, Tengosed Seamount and La Pulpería Hill) and without them (Caballito Knoll, Fuente Knoll, Mambo Kita Hill). Dissolved inorganic carbon data does not show significant differences between sites, with values ranging from 2270 – 2350 $\mu\text{mol/kg}$. Total alkalinity samples are being analyzed but based on in situ salinity measurements and their linear relationship, total alkalinity is expected to show similarly low variability among sites as dissolved inorganic carbon. Considering the relatively low temperatures of these hydrothermal springs, indicating sluggish fluid-rock reaction rates that would result in carbonate chemistry changes, it is not surprising that there is not a strong signal. This is valuable information in oceanographic studies related to seamount ecosystems and in the context of global carbon budgets.

How can we notice high-CO₂ in the ocean? – A proper indicator for detecting high CO₂ concentration

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CCS is attracting attention as a countermeasure against the global warming. In Japan, CCS operators are legally required to conduct underwater monitoring to ensure that stored CO₂ is stored safely. If high CO₂ concentrations are detected in seawater, re-surveys are legally required, and it is time-consuming and costly. In the CCS demonstration project conducted off the coast of Tomakomai, seawater monitoring has continued even after the injection well was closed in 2019. Since the project began, re-surveys due to false positives have frequently occurred. This is due to the use of DO and only pCO₂ as a CO₂ concentration indicator and the criteria being whether a data point exceeds the upper limit of the 95% prediction interval of data variation. Seawater CO₂ concentration can be determined by two of four parameters: pCO₂, DIC, TA, and pH. Therefore, pCO₂ alone is not sufficient to define seawater CO₂ concentration. Furthermore, these four CO₂ concentration parameters vary significantly across regions and seasons due to biological and physicochemical activities. In this study, we propose a more proper indicator using DIC, TA, and DO to avoid mistaking large natural fluctuations for abnormally high CO₂ concentrations. Furthermore, the 95% figure has no scientific basis. For this reason, we attempt to build a machine learning model that can more accurately detect CO₂ seepage. To do this, we have sampled water from ocean areas where CO₂ has been artificially released and from areas where volcanic CO₂ naturally seeps.

The involvement between seafloor CO₂ eruptions in the Tachibana Bay and the marine environment and organisms

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Welcome & Poster Session 1, Exhibition Area, Level 1, October 13, 2026, 18:00 - 19:30

The Tachibana Bay in Nagasaki Prefecture is a semi-enclosed bay with low anthropogenic nutrient loads. Small-scale eruptions of volcanic gas, mainly composed of CO₂ originating from the Mount Unzen, occur from the seafloor in the central part of the Tachibana Bay. We conducted mapping observations using an AUV equipped with a pH/pCO₂ sensor, sampled and analyzed surface sediments and seawater, performed multi-point vertical observations using a CTD-DO-chlorophyll-pH/pCO₂ sensor, and collected planktons. The TOC content (3.1 wt%) of the surface sediments in the Tachibana Bay was significantly higher than that of the open ocean and was comparable to that of the Tokyo Bay (2.7 wt%). The C/N ratio (5-10) showed phytoplankton origin, and the $\delta^{13}\text{C}$ (-20 ‰ to -24 ‰) indicated marine sediment. The high TOC content in the Tachibana Bay, despite its low anthropogenic nutrient load, is thought to be due to biological production within the bay. Seawater analysis and multi-point vertical sensor observations revealed the distribution of low-pH, high-chlorophyll water masses near the seafloor, below 2m above the seafloor. Near the seabed around the CO₂ emission sites, pH decreased, chlorophyll increased, and phytoplankton density also increased. This suggests that phytoplankton are utilizing the CO₂ emitted from the seafloor to proliferate. Considering these observation results and the fact that the Tachibana Bay is a good fishing ground for anchovies, it is highly likely that the small-scale CO₂ emissions observed in the Tachibana Bay are contributing to the activation of biological production.

Fluorescence and polarised-light microscopy of *Xenia spp.* sclerites reveal resilient biomineralisation under ocean acidification, nitrate enrichment and competitive stress

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Welcome & Poster Session 1, Exhibition Area, Level 1, October 13, 2026, 18:00 - 19:30

Ocean acidification (OA) is expected to alter coral biomineralisation, yet octocorals may show higher resistance to this stressor. *Xenia spp.* has shown resistance to OA while consistently benefiting from nitrate enrichment when exposed to both simultaneously. However, when competing with other hard corals under these conditions, *Xenia spp.* showed negative responses. Whether exposure to acidified conditions leaves persistent structural signatures in calcitic sclerites when competing under concomitant effects of OA and nitrate enrichment remains unknown, although understanding octocoral calcification responses may be fundamental to understanding their contrasting responses to scleractinians under climate change. Here, we revisit preserved *Xenia spp.* colonies from a previous 28-day mesocosm experiment investigating the combined effects of OA (950 $\mu\text{atm pCO}_2$), nitrate enrichment (0, 4 and 8 $\mu\text{mol L}^{-1} \text{NO}_3^-$), and competition with the reef-building coral *Stylophora pistillata*. Sclerites from *Xenia spp.* were isolated from frozen tissue using standard chemical digestion and analysed using light, polarised, and fluorescence microscopy. Morphometric measurements including shape descriptors were obtained, and birefringence patterns were evaluated as a proxy for crystal organisation. In addition, autofluorescence and post-mortem calcein staining were used as exploratory indicators to evaluate differences in mineral surface properties across treatments. We hypothesised that *Xenia spp.* exhibit comparatively minor alterations in sclerite morphology and optical properties supporting the resilience of octocoral biomineralisation despite its negative response under competitive stress, OA and nitrate enrichment, providing mechanistic evidence that contributes to explaining the increasing persistence and competitive advantage of soft corals relative to reef-building hard corals under future ocean conditions.

An initial assessment of marine Carbon Dioxide Removal for Sāmoa

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Welcome & Poster Session 1, Exhibition Area, Level 1, October 13, 2026, 18:00 - 19:30

Scenarios to stabilise global climate and reduce the adverse impacts of climate change require both carbon dioxide emission reductions and active carbon dioxide removal (CDR) from the atmosphere. One of the proposed CDR techniques is ocean-based CDR, which is now attracting greater interest as limitations in land-based methods become more evident. Marine CDR (mCDR) approaches remain untested for large-scale implementation with uncertainty in the ecological consequences and social support for these mCDR methods. Pacific Island countries are at the forefront of climate change impacts and are therefore important to consider for CDR efforts, both in terms of CDR benefits and risks. As mCDR gains traction globally, attention has gradually shifted to the Pacific region. It is crucial to ensure that Pacific perspectives and local ecological contexts are considered and represented at any stage of mCDR conversations and implementation. In this study, a range of mCDR techniques are reviewed against Sāmoa's oceanic, coastal, and bathymetric conditions. Ecological risks and benefits of mCDR methods are evaluated within tropical systems. Social and cultural implications are examined through fa'a-Samoa, recognising that authority over ocean spaces in Sāmoa is collectively held and integral to any consideration of implementation. This study is the first mCDR valuation for Samoa and establishes baseline data important for future assessments of mCDR potential in Samoa and other Pacific Island Countries.

Present and future alkalinity cycling in the east Otago coastal zone

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Welcome & Poster Session 1, Exhibition Area, Level 1, October 13, 2026, 18:00 - 19:30

Continental shelves are crucial for oceanic CO₂ uptake on annual-decadal timescales through generally high rates of primary productivity in the water column, and the production of total alkalinity (TA) in the underlying sediment. Recent evidence has shown that TA is increasing in shelf waters, which has been attributed to an acidification-driven increase in calcium carbonate dissolution in the sediment. However, it is unclear what is driving this increase, nor how this might change in the future.

Here, we present a seasonal TA budget for the east Otago shelf, including calcification, riverine input, and sediment-water fluxes. The main internal source of TA on the east Otago shelf is sedimentary carbonate dissolution. Experiments that mimicked future and past ocean carbonate chemistry revealed a strong dependence of sedimentary carbonate dissolution on the saturation state of the water column. This suggests that future ocean acidification will continue to increase shelf water TA levels and increase shelf CO₂ uptake.

Marine invertebrates are feeling it hot hot hot - multistressor impacts in a heatwave ocean and atmosphere

Dr Maria Byrne¹

¹University of Sydney, Sydney, Australia

Keynote 3: Maria Byrne, Rongomātāne A, October 14, 2026, 09:10 - 09:50

Along its entire 2300 kilometres, the Great Barrier Reef (GBR) experienced mass bleaching in summer 2024. For the first time bleaching was severe in the southern GBR. We work at one of the most protected reef systems, One Tree Island, 90 km off the Australian mainland. This reef is protected from exploitation and is also protected from pollution and development. This protection did not guard the reef from the heatwave. Virtually 100% of coral colonies bleached in the lagoon and in deeper reef slope areas. Twenty years of temperature records at the level of the corals showed that heatwave conditions lasted for four months. The outcomes of bleaching were monitored for 462 colonies across 12 genera over one year in seven health checks. There were marked genus-level differences in mortality, resilience and recovery. As expected, *Acropora* quickly succumbed with 100% mortality of tracked colonies. For massive, long-lived *Goniopora*, bleaching coincided with a black band disease epizootic. This necrotic wasting disease, typically rare on the GBR, appeared along the edge of bleached polyps and contributed to the high mortality (75%). Thermally tolerant genera had lower bleaching and mortality (e.g., *Goniastrea*, *Pavona*, *Porites*). For *Acropora* the emergence of 'sprouts' of live coral in thickets of seemingly dead colonies indicates the importance of regeneration in reef recovery. Many *Goniopora* colonies have been lost with no signs of regeneration. Understanding the connection between the 'evil twins' of bleaching and disease is important as corals are faced with unprecedented thermal anomalies.

From complexity to simplicity: ecosystem reorganisation in a high-CO₂ ocean

Dr Ben Harvey¹

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Keynote 4: Ben Harvey, Rongomātāne, October 14, 2026, 09:50 - 10:30

Ocean acidification is a key driver of ecological change, causing regime shifts that alter both the structure and function of marine ecosystems. A central challenge is linking changes in carbonate chemistry to ecological outcomes in natural systems, where species interactions and environmental variability shape responses. Natural CO₂ analogues, such as volcanic seeps, provide an opportunity to observe these processes under ecologically realistic conditions. Evidence from these systems shows consistent patterns of ecosystem reorganisation. Complex, habitat-forming communities shift toward simplified states, often characterised by turf dominance, resulting in reduced biodiversity and structural complexity. These changes are linked to altered successional trajectories, with communities developing under elevated CO₂ following different pathways and stabilising in low-diversity states. These structural shifts are accompanied by changes in ecosystem functioning, including reduced productivity. Transitions to simplified systems are reinforced by ecological feedbacks through multiple interacting mechanisms. Turf algae can overgrow habitat-forming species, modify local physicochemical conditions, and inhibit recruitment, creating feedback loops that stabilise degraded states. Changes in top-down control are also important: ocean acidification can alter consumer performance and abundance, shifting grazing pressure and reinforcing, or in some cases weakening, control over primary producers. Ocean acidification does not act in isolation. Interactions with warming and tropicalisation reinforce ecosystem transitions and limit recovery, including through shifts in species distributions and novel interactions. Together, these findings suggest that future oceans will be fundamentally reorganised rather than simply degraded. Natural analogue systems, supported by initiatives such as ICONA, provide a critical basis for anticipating and managing these changes.

Biological response to ocean alkalinity enhancement as a multiple stressors problem

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3A: Assessing high-CO₂ and multi-stressor effects on aquatic organisms using natural laboratories of climate change, Rongomātāne A, October 14, 2026, 11:00 - 13:00

Ocean alkalinity enhancement (OAE) is an approach to marine carbon dioxide removal that involves adding alkaline substances to seawater to accelerate the ocean's natural carbon sink. Seawater carbonate chemistry plays a key physiological role, both for intra- and extracellular acid-base regulation and calcification. Consequently, OAE has the potential to drive positive and negative impacts on marine species fitness. In nature, ocean alkalinity enhancement is a multiple stressors problem with different types of exposure depending on the implementation method and altering different aspects of carbonate chemistry (e.g. total alkalinity, pH) as well as other parameters (e.g. trace elements, turbidity, time of exposure). We compared different approaches to manipulate the alkalinity (NaOH, Na₂CO₃, olivine, cement) and implementation methods to identify the main drivers of biological changes and resolve the mechanisms behind the biological response. We tested the impact of a wide range of alkalinity (ranging from 1500 to 4000 $\mu\text{mol kg}^{-1}$) on the early life stages of different species of echinoderms (sea urchins and brittlestars), fish (cod) and corals from different regions (Pacific, North Atlantic and Mediterranean). Several parameters were measured (survival, growth and calcification rate) to evaluate fitness. Our results will be used to discuss pros and cons of OAE for marine calcifiers in the context of ocean acidification.

Engineer of the future: the intertidal mussel *Brachidontes rodriguezii* (Bivalvia: Mytilidae) shows resilience under acidified conditions

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3A: Assessing high-CO₂ and multi-stressor effects on aquatic organisms using natural laboratories of climate change, Rongomātāne A, October 14, 2026, 11:00 - 13:00

Ocean acidification (OA) increases the energetic-cost of acid-base regulation in marine organisms, particularly in marine calcifiers, which allocate a significant proportion of their energy budget to create optimal conditions for biomineralization and prevent dissolution. The impact of OA on species as acting as ecosystem engineers, such as mytilid bivalves, may affect the communities relying on them for survival. We tested the effect of OA exposure on a rocky intertidal ecosystem engineer from Argentina, the mussel *Brachidontes rodriguezii*. Individuals were exposed to three pH conditions for three months in an open continuous seawater flow system to assess the response on shell mass, wet mass and total mass condition indices (CI) as well as shell growth. Target pH treatments were selected taking into account the yearly natural pH variability: 7.90 (high pH, the annual mean), 7.80 (medium pH, lowest pH on the present range) and 7.50 (low pH, 0.3 below the present minimum). pH levels were maintained through controlled CO₂ bubbling. Adjusted models showed no significant effect of pH on growth and CI. These results suggest tolerance to low pH conditions in this mussel species, likely as a local adaptation to predictable daily hypercapnia in the intertidal zone. Further studies addressing physiological mechanisms effects of acidification on this mussel are necessary to resolve the underlying processes.

Ocean Acidification Across Life Stages: Effects on Early Development and Thallus Strength in *Fucus vesiculosus*

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3A: Assessing high-CO₂ and multi-stressor effects on aquatic organisms using natural laboratories of climate change, Rongomātāne A, October 14, 2026, 11:00 - 13:00

Ocean acidification (OA), driven by rising atmospheric CO₂, is a key component of global climate change with important consequences for marine foundation species. While impacts on calcifying organisms are well documented, effects on habitat-forming fleshy seaweeds remain less understood, particularly across life stages and under multiple stressors. The brown macroalga *Fucus vesiculosus* is a dominant ecosystem engineer in temperate coastal systems; here we investigate its responses to OA and warming focussing on variability across populations and environments.

We combined experimental approaches to assess the effects of elevated pCO₂ and temperature on early development and adult thallus integrity in *F. vesiculosus*. We looked at the effect of temperature, ambient (15°C) and elevated (18°C), and OA, present-day (~400 µatm) and elevated (~1100 µatm) pCO₂, on fertilization success and growth of germlings in six populations along a coastal salinity gradient. We found that the responses were highly population-specific and variable. In general, warming reduced fertilization success primarily in low-salinity populations and germling growth increased under OA but was constrained by warming, indicating strong interactive effects.

In parallel, adults exposed to OA showed reduced apical strength and modified tissue structure, linked to structural tissue changes. This weakening decreased survival under field conditions.

Our results demonstrate that OA affects both early life stages and adult performance in *F. vesiculosus*, with implications for population persistence. The strong population variability highlights the importance of local, population-specific adaptation and the need to consider multiple stressors when predicting responses of habitat-forming seaweeds in a high CO₂ ocean.

Dietary plasticity allows a dominant herbivore to persist on simplified reefs under ocean warming and acidification

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3A: Assessing high-CO₂ and multi-stressor effects on aquatic organisms using natural laboratories of climate change, Rongomātāne A, October 14, 2026, 11:00 - 13:00

Ocean warming and acidification are driving rapid simplification of temperate reef communities, shifting benthic habitats from structurally complex macroalgal assemblages toward turf-dominated states. How key herbivores respond to these novel food environments, and whether their responses stabilise or accelerate habitat change, remains poorly understood. Using natural CO₂ vent and warming analogues that capture combined climate stressors in situ, we examined how a range-extending herbivorous parrotfish, *Calotomus japonicus*, adjusts its foraging behaviour and diet across a gradient of increasingly turf-dominated temperate reefs. We also assessed whether physiological condition and abundance are maintained under these altered dietary regimes. *C. japonicus* exhibited strong dietary plasticity, shifting from a macroalgal-dominated diet at the present-day control site to turf-dominated feeding in parallel with increasing turf dominance across the climate gradient. Despite this dietary shift and elevated bite rates at warmer sites (~5-8 higher than at control sites), physiological condition (Fulton's condition factor and oxidative stress markers, malondialdehyde and total antioxidant capacity) remained comparable across all climate scenarios. Of the five benthic algal groups measured, only turf algae showed increased biomass and cover with temperature, and grazing pressure was positively associated with both turf cover and turf biomass. Together, these findings suggest that dietary plasticity enables range-extending herbivores to persist on climate-simplified reefs by tracking abundant, productive turf resources, potentially reinforcing positive consumer-resource feedbacks that stabilise turf-dominated states under future ocean warming and acidification.

Conservation needs for shallow marine vents and seeps?

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3A: Assessing high-CO₂ and multi-stressor effects on aquatic organisms using natural laboratories of climate change, Rongomātāne A, October 14, 2026, 11:00 - 13:00

Shallow-water vents and seeps (SWVS) are increasingly used as natural laboratories to understand how marine organisms and ecosystems respond to high CO₂ and interacting stressors. Beyond their value as analogues for ocean acidification in specific sites, these systems show that biological responses are rarely driven by CO₂ alone. Toxic compounds, warming, metal enrichment, and redox variability can amplify or alter ecological outcomes, making SWVS uniquely valuable for assessing multi-stressor effects across levels of biological organization under realistic, long-term field conditions. SWVS can also contribute to reveal mechanisms of persistence under future ocean conditions, including physiological plasticity, local adaptation, altered metabolic performance, and shifts in primary production and trophic pathways. By cross-referencing open-access vent databases with published studies, we confirmed 269 active SWVS worldwide and assessed their threats and conservation status. Our study shows that SWVS can be exposed to bottom trawling, land-based human pressures, and potential seabed mining, yet they can also support surrounding ecosystems by providing critical habitats, biodiversity, elements, and nutrients that enhance productivity and may stimulate carbon sequestration. The strong environmental gradients of SWVS make them evolutionary and physiological hotspots, and promising sites for discovering ocean-based solutions to climate change. However, only about 5% of known SWVS are highly protected globally, and current conservation measures are sparse and unrepresentative. We argue that SWVS should be fully integrated into conservation planning and environmental impact assessments to help meet 2030 biodiversity and ocean health goals.

Volcanically driven CO₂ emissions in Antarctic coastal systems: insights from Deception Island

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3A: Assessing high-CO₂ and multi-stressor effects on aquatic organisms using natural laboratories of climate change, Rongomātāne A, October 14, 2026, 11:00 - 13:00

Natural CO₂ sources in Antarctic environments remain poorly constrained despite their relevance for regional carbon budgets. Deception Island, in the Southern Ocean, combines active volcanism with diverse aquatic systems, including marine bays, coastal zones and freshwater environments, providing a unique natural laboratory to investigate CO₂ dynamics in polar regions. This study quantifies CO₂ concentrations and air-sea fluxes across these contrasting environments to assess the influence of volcanic activity on carbon cycling. Measurements of partial pressure of CO₂ (pCO₂) were combined with carbonate system parameters (pH and total alkalinity) and hydrographic variables (temperature and salinity), enabling a process-based interpretation of CO₂ variability. Results reveal strong spatial heterogeneity in CO₂ distribution, ranging from undersaturated to highly supersaturated conditions over short spatial scales. The highest CO₂ concentrations and fluxes are consistently associated with volcanic areas, where hydrothermal inputs enhance CO₂ enrichment, promote low pH conditions and drive outgassing to the atmosphere. In contrast, less impacted systems show more moderate variability linked to physical and biogeochemical controls. Overall, most environments act as net CO₂ sources, with particularly intense emissions in volcanically influenced zones. These results indicate that Antarctic coastal systems affected by volcanism can act as significant natural CO₂ sources, challenging the prevailing view of the Southern Ocean as a dominant carbon sink. Accounting for these localized emissions is essential to refine regional carbon budgets and improve the representation of natural CO₂ sources in a high CO₂ ocean.

Are mussel responses to ocean acidification consistent across natural laboratories of elevated CO₂?

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3A: Assessing high-CO₂ and multi-stressor effects on aquatic organisms using natural laboratories of climate change, Rongomātāne A, October 14, 2026, 11:00 - 13:00

Ocean acidification is expected to reshape marine ecosystems, yet predicting organismal responses remains challenging due to environmental variability and intra- and interspecific differences. Bivalves are considered particularly vulnerable to changes in carbonate chemistry due to their calcifying nature, but responses observed under controlled experimental conditions often fail to capture the complexity of natural systems. Natural CO₂ laboratories provide a powerful framework for assessing organismal performance under ecologically realistic, long-term exposure to future ocean conditions. Here, we assess multiple aspects of mussel condition, including growth, shell properties (e.g. structure and isotope content) and trophic ecology across natural CO₂ gradients in two tropical systems, Bouraké (New Caledonia) and Nikko Bay (Palau), characterised by pH variability driven by tidal processes and diel biological cycles. We then compare these patterns with responses previously observed in a temperate CO₂ seep system (Shikine Island, Japan) with chronically reduced pH. Using spatial comparisons across gradients spanning control to elevated pCO₂ conditions, we evaluate how mussel condition varies across contrasting acidification regimes, including chronically reduced and tidally/diel fluctuating pH environments. This approach allows us to assess the extent to which organismal responses are consistently linked to carbonate chemistry, or instead shaped by environmental context, including variability in exposure and resource availability. Together, this study highlights the importance of natural laboratories for capturing the complexity of climate change effects and provides a framework for evaluating organismal responses across contrasting environmental contexts.

eDNA and visual transect examinations of benthic communities in Palau's natural laboratory environments

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3A: Assessing high-CO₂ and multi-stressor effects on aquatic organisms using natural laboratories of climate change, Rongomātāne A, October 14, 2026, 11:00 - 13:00

Many studies have focused on assessing how ocean acidification (OA) affect groups such as scleractinian corals. However, other competitive benthic organisms including sponges, zoantharians, and soft corals remain understudied. Including these groups in surveys is essential for improving understanding of how reef ecosystems could change under OA conditions. Natural laboratory sites, which have low pH levels emulating or exceeding future ocean conditions, have been used to predict how reefs may respond to OA. In this study, we examined the natural laboratory site of Ngerikuul (Nikko) Bay, Palau (pH ≈ 7.8), focusing five benthic groups: hard corals, soft corals, macroalgae, sponges, and zoantharians. Transects were analyzed at 4-5 m depths and environmental DNA (eDNA) water samples were collected from each site. Surveys were also conducted at inner lagoon and outer reef sites outside the bay as reference sites with more ambient pH conditions (pH ≈ 8.0). eDNA samples were analyzed using 12S, ITS2 (Cnidaria & Porifera), and CO1 (eukaryotes) markers. Transect results showed that the dominant group in both low pH sites and the reference sites was hard corals. There was an inverse relationship between sponges and algae, where sponges were more abundant and algae were less prominent in low pH sites, and vice versa, with eDNA markers reflecting those results. Additionally, eDNA showed the absence of calcareous sponges inside the bay. Such findings from natural laboratory sites will help inform which benthic taxa may persist or become more dominant on reefs as pH in the ocean continues to decrease into the future.

From Inventory to Monitoring Readiness: Reassessing Naturally Acidified Marine Sites as High-CO₂ Natural Laboratories.

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3A: Assessing high-CO₂ and multi-stressor effects on aquatic organisms using natural laboratories of climate change, Rongomātāne A, October 14, 2026, 11:00 - 13:00

Naturally acidified marine sites are increasingly used as field analogues of future ocean acidification, yet their scientific value depends not only on location but also on data completeness, temporal continuity, and comparability across studies. Building on an existing geodatabase originally developed to map naturally acidified marine sites worldwide, this study moves beyond inventory-building toward an assessment of monitoring readiness. Our starting dataset identified 15 published sites across Iceland, Italy, Spain, Greece, Portugal, Japan, Taiwan, the Philippines, Papua New Guinea, New Zealand, the United States, Mexico, and Ecuador, and already revealed major geographic gaps in tropical regions. Using published literature and publicly available metadata, we reassess each site according to five criteria: carbonate chemistry completeness, temporal continuity, presence of control or reference conditions, ecological coverage, and data accessibility. Preliminary results suggest that geographic representation alone overestimates global monitoring capacity, as many sites are still known only from isolated studies or incomplete datasets. This framework allows us to distinguish between robust natural laboratories and sites that remain promising but methodologically limited. Within this context, tropical systems such as Roca Redonda in the Galápagos gain strategic importance because they combine naturally low pH conditions with baseline oceanographic information in an otherwise underrepresented region. This contribution provides a practical pathway for moving from site inventories to monitoring priorities and improving the global comparability of high-CO₂ natural laboratories.

Temperate coral populations naturally occurring in high pCO₂ environments

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3A: Assessing high-CO₂ and multi-stressor effects on aquatic organisms using natural laboratories of climate change, Rongomātāne A, October 14, 2026, 11:00 - 13:00

Natural volcanic CO₂ vents cause local acidification of seawater and are used as natural analogues for future ocean acidification (OA) conditions. These high pCO₂ environments, along with their populations, provide an unparalleled opportunity to assess the mechanisms of acclimatization and adaptation to climate variability and extremes. Here, we investigate two CO₂ vent systems along the coast of Ischia (Italy) and how elevated seawater pCO₂ exposure influences coral populations that naturally occur in these acidified environments. The studied corals are two Mediterranean long-lived scleractinian corals of key relevance for conservation as habitat-forming species: the zooxanthellate *Cladocora caespitosa* and the azooxanthellate *Astroides calycularis*. We compare populations living near the vents (pHT = 7.6 -7.8) to reference areas with ambient pH (pHT= 8.0). Our research addresses questions related to physiology, ecology, and adaptive responses of corals to ocean warming and acidification. To achieve this, we integrate carbonate chemistry, ecological field surveys and laboratory experiments, encompassing population demographics, skeletal characteristics, and transcriptomic approaches. Moreover, unexpectedly, we witnessed the spawning of the coral *A. calycularis* in the field. This allows us to investigate the effects of acidification on the early life stages. Combined, through the study of these high pCO₂ environments and their populations, we aim to gain new insights into how natural coral populations survive, their adaptive strategies, and resilience to high pCO₂ environments.

Shifts in benthic trait diversity and ecosystem functioning at natural CO₂ vents: an ecosystem property perspective

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3A: Assessing high-CO₂ and multi-stressor effects on aquatic organisms using natural laboratories of climate change, Rongomātāne A, October 14, 2026, 11:00 - 13:00

Global environmental change drives biodiversity loss and shifts in community structure. However, linking these changes to ecosystem functioning remains a major challenge. CO₂ vents locally acidify seawater and serve as natural analogues for future OA conditions, enabling a mechanistic understanding of ecological responses at the whole-ecosystem level over long time scales. Here, we combine field surveys and experimental approaches at CO₂ vent systems along the coast of Ischia (Italy), spanning multiple benthic habitats across different depths (from 1 to 40 m). First, we quantified changes in species composition and trait diversity across CO₂ venting and ambient pH sites, using benthic cover data and species traits (e.g. morphology, trophic strategy, and calcification). Second, we conducted community transplant experiments to assess how declining pH influences community composition, biomass, and key community metabolic processes, including calcification, primary production, and nutrient uptake.

We find that species and trait diversity decrease under acidified conditions. Furthermore, shifts in trait categories such as autotrophs, filter feeders, herbivores, and habitat-forming species are habitat-specific, indicating that OA may produce divergent responses across habitats and depths. Importantly, these structural and functional changes are associated with reduced community biomass and calcification rates, alongside enhanced photosynthesis and nutrient uptake. By leveraging natural CO₂ vents and linking species and trait diversity with measurements of ecosystem functioning, this study provides new insights into how OA-induced biodiversity loss reshapes the structure and functioning of temperate coastal marine ecosystems. Ongoing work integrating intraspecific trait variability will further link individual-level responses to ecosystem functioning under global change.

Modeling the spatiotemporal effects of ocean acidification and warming on Atlantic sea scallop growth to guide adaptive fisheries management

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3B: Beyond tipping points: From Data to Decisions, Operationalizing Interdisciplinary Ocean Acidification Knowledge, Rongomātāne B, October 14, 2026, 11:00 - 13:00

Climate-ready fisheries management requires reliable predictions of species responses to changing conditions across large-scale environmental gradients. Bioenergetic frameworks, such as Dynamic Energy Budget (DEB) models, relate physiological processes to environmental conditions, enabling predictions of organismal growth under projected climate change conditions. We developed the first large-scale coupling of a DEB model to downscaled regional oceanographic simulations to resolve spatiotemporal changes and reveal how climate stressors emerge at relevant biogeographic, economic, and oceanographic scales. We calibrated our DEB model for the Atlantic sea scallop (*Placopecten magellanicus*) with forcing from a realistic oceanographic and biogeochemical model for the Northeast U.S. continental shelf to predict the effects of ocean acidification (OA) and warming on individual growth historically and over the next century. Our model reproduced observed historical patterns in scallop age at harvest size and maximum size. At mid-century (2035–2050), scallop growth was projected to increase in most areas except the southern Mid-Atlantic, and OA effects were limited to the deep Gulf of Maine. By the end of the century (2080–2095) under a high emissions scenario, scallops were predicted to grow faster but attain smaller sizes. Our results highlight that warming stress is more acute than previously accounted for, particularly in the southern Mid-Atlantic. While warming stress emerges in the south first, OA stress emerges before warming in the north. Together, these emerging stressors compress the spatial range for optimal growth. Our findings demonstrate the utility of the spatially coupled DEB model as a tool to inform adaptive fisheries management.

Taking a dive into El Veril: Constraining coastal carbonate system variability through citizen science at a coastal site in Argentina

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3B: Beyond tipping points: From Data to Decisions, Operationalizing Interdisciplinary Ocean Acidification Knowledge, Rongomātāne B, October 14, 2026, 11:00 - 13:00

In coastal environments, high natural variability complicates the detection and attribution of ocean acidification (OA) signals, particularly in data-limited regions. A citizen science-based monitoring initiative at El Veril (38°10.5'S - 57°25.4'W), a rocky reef off Mar del Plata (Argentina) provides a successful OA assessment, developed by INIDEP researchers and recreational scuba divers from CASE within the NANO/NF-POGO DOAP project. Since December 2018, over 50 divers have conducted 48 sampling visits, collecting seawater at 5 m depth and documenting in situ conditions. Samples were analyzed for pH and total alkalinity (TA), salinity, dissolved oxygen (DO), macronutrients, chlorophyll-a, and microbial plankton communities (MPC). Seasonal variability was evident, with temperature-driven patterns reflected in pH. TA and salinity remained relatively stable, and were positively correlated ($r^2 = 0.77$, $n = 33$), suggesting a physical control over carbonate chemistry. DO, macronutrients, and chlorophyll-a showed episodic variability without clear seasonal patterns. MPC exhibited seasonal succession in terms of biomass, with microphytoplankton dominating year-round with peaks in March, May, and November. Dinoflagellates prevailed during warm periods while diatoms were most prominent in cooler months. Nanophytoplankton and picophytoplankton remained minor but persistent. Bacterioplankton biomass was highest in April, and protozooplankton tracked phytoplankton blooms, suggesting trophic coupling. This multi-year record provides valuable insight into carbonate system variability in the Southwestern Atlantic, emphasizing the importance of sustained observations in dynamic coastal environments. They further demonstrate how citizen science can advance OA monitoring in support of the SDG 14.3, while fostering ocean literacy through INIDEP-CASE outreach.

Carbonate Chemistry Variability and Air Sea CO₂ Fluxes on the Ghana Shelf in a Coastal Upwelling System

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3B: Beyond tipping points: From Data to Decisions, Operationalizing Interdisciplinary Ocean Acidification Knowledge, Rongomātāne B, October 14, 2026, 11:00 - 13:00

The Gulf of Guinea remains under sampled for carbonate chemistry observations, limiting our ability to quantify ocean acidification exposure and air sea CO₂ exchange in a region supporting major coastal livelihoods. We present new carbonate system observations from the Ghanaian continental shelf within a seasonal coastal upwelling setting, combining ship based hydrography with discrete measurements of total alkalinity, dissolved inorganic carbon, and pH to derive pCO₂ and aragonite saturation state. We assess spatial and seasonal variability across inner to outer shelf transects and interpret patterns in relation to physical drivers including stratification, mixing, and upwelling favorable winds, supported by satellite and reanalysis indicators such as sea surface temperature and winds. The dataset provides an initial baseline for Ghana shelf carbonate conditions and reveals pronounced variability consistent with episodic ventilation and mixing that can shift CO₂ flux direction and magnitude over short time scales. We outline an uncertainty aware workflow for carbonate calculations and flux estimation to ensure transparent, reproducible reporting from sparse observations. These results help identify potential hot spots and hot moments of acidification risk and provide guidance for monitoring design, including priority seasons and shelf zones for repeat sampling. Establishing defensible baselines and process based interpretation in the Gulf of Guinea is essential for regional OA monitoring, model evaluation, and science to action discussions relevant to fisheries and coastal management.

Ocean acidification and blue food security: mapping two overlapping regime complexes

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3B: Beyond tipping points: From Data to Decisions, Operationalizing Interdisciplinary Ocean Acidification Knowledge, Rongomātāne B, October 14, 2026, 11:00 - 13:00

The dual challenges of blue food security and ocean acidification (OA) are increasingly urgent for global sustainability. Blue foods provide essential nutrients but are threatened by OA, posing risks to biodiversity, fisheries, and dependent livelihoods. Addressing blue food security through the lens of OA is therefore critical. However, existing literature largely treats OA and blue food security governance separately, leaving their interaction underexplored. This talk examines whether and how international governance regimes intersect in addressing this nexus by mapping their regime complexes. It finds substantial overlap, particularly in fisheries, marine resources, and climate change. Despite this, governance remains fragmented. While many actors and instruments reference both issues, integration is limited. Case studies on the Food and Agriculture Organization (FAO) and the United Nations Framework Convention on Climate Change (UNFCCC) reveal that neither institution provides a comprehensive framework for governing the nexus of OA and blue food security. The FAO lacks an explicit mandate for OA governance. If mentioned, OA is relegated to a list of stressors. The UNFCCC addresses OA only indirectly through CO₂ mitigation efforts, and its instruments, while referencing food production, generally do not link it explicitly to OA. This results in fragmented authority, unclear responsibility, and limited integration across policy domains. Furthermore, a discrepancy exists where blue food security is acknowledged as a legal and political priority, while OA often receives only scientific attention. Further joint integration of OA and blue food security in legal and policy frameworks is necessary to enhance coherence across these regimes.

A synthesis of data products for ocean carbonate chemistry

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3B: Beyond tipping points: From Data to Decisions, Operationalizing Interdisciplinary Ocean Acidification Knowledge, Rongomātāne B, October 14, 2026, 11:00 - 13:00

As the largest active carbon reservoir on Earth, the ocean plays a crucial role in the global carbon cycle, modulating ocean health and the Earth's climate system. Understanding these roles requires access to a broad array of data products documenting the changing chemistry of the global ocean as a vast and interconnected system. This review article provides an overview of 68 existing ocean carbonate chemistry data products and data product sets, encompassing compilations of cruise datasets, derived gap-filled data products, model simulations, and compilations thereof. It is intended to help researchers identify and access data products that best align with their research objectives, thereby advancing our understanding of the ocean's evolving carbonate chemistry. The list will be updated periodically to incorporate new data products. The most up-to-date list is available at <https://oceanco2.github.io/co2-products/> (Gregor and Jiang, 2026).

Real-Time Coastal Ocean Monitoring with Portable Mini-Mooring Network Enabling OA Event Reporting for Southern California

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3B: Beyond tipping points: From Data to Decisions, Operationalizing Interdisciplinary Ocean Acidification Knowledge, Rongomātāne B, October 14, 2026, 11:00 - 13:00

A timely and effective response to acute impacts of OA on coastal communities requires real-time reporting of physical and chemical properties to identify hypoxic events posing risks for fishers' livelihood and human health. A network of second generation mini-moorings have been designed and deployed along the Southern California inner-shelf, telemetering pH, oxygen, temperature and salinity data to detect hypoxic or low pH events responsible for dissolution of shell-based organisms and behavioral changes in marine life. With this data we can also work on identifying the relative contribution of different processes to OA across event and seasonal scales within the Southern California Bight. Upwelling, primary production, internal tides and ocean-atmosphere gas flux modulate acidity along the coast. Coupled physical-chemical measurements recorded on sub-daily timescales provide information to decouple high frequency biological signals in the mixed layer from deeper, long period upwelling events. Results from a two year time-series of pH and temperature recorded on a first generation mini-mooring, offshore mooring and pier station in Southern California identified seasonal and spatial variability in acidity and temperature. While pH variability along the 30 m isobath is mostly in phase with both semidiurnal tides and upwelling events, the correlation between the magnitude of pH and temperature variations differs seasonally. Cross-shore pH gradients also express seasonal variation. The extension of this OA time-series with additional nodes just deployed will improve understanding of coupling between the shore and inner-shelf regions and of the climatological rate of OA within the Southern California Bight.

Developing information products to inform ocean change adaptation and resilience planning by tribal and state managers of Washington's Olympic Coast

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3B: Beyond tipping points: From Data to Decisions, Operationalizing Interdisciplinary Ocean Acidification Knowledge, Rongomātāne B, October 14, 2026, 11:00 - 13:00

We seek to address the need for understanding how ocean acidification and other climate stressors will affect the marine biota of the Olympic Coast of Washington state, USA. Through a locally-relevant, step-wise, interdisciplinary process developed previously, we have co-produced actionable information. Using synthesized chemical and biological data from open ocean to intertidal areas, a forecast model, and assigned thresholds, researchers estimated the risk of ocean acidification impacts to key biological resources important to tribal partners.

Our previous work indicated that managers wanted projections sooner than end-of-century, and that focused on practical information relevant to key species like Dungeness crab. These lessons learned are guiding our new work, which will focus on co-designing new data products, synthesizing the information with each Tribe, and working to assure the information is accessible and useful. The outputs will directly support tribal climate adaptation planning and regional marine conservation strategies.

We offer our approach as inspiration for other place-based studies. This work is a use case for Ocean Acidification Research for Sustainability (OARS), a programme endorsed by the UN Ocean Decade. Via seven OARS outcomes, including ones on co-designing observing strategies and societally relevant future projections, OARS seeks to bridge the gap between cutting-edge research and practical applications on local through global scales.

Integrating Social Science with Natural Science to Inform Society

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3B: Beyond tipping points: From Data to Decisions, Operationalizing Interdisciplinary Ocean Acidification Knowledge, Rongomātāne B, October 14, 2026, 11:00 - 13:00

Ocean and coastal acidification (OCA) threatens food security, economies, and ways of life because of its potential impacts on coastal ecosystems and societies. The NOAA Ocean Acidification Program (OAP) examines the ways in which coastal communities and industries are vulnerable to OCA and fosters research and partnerships that promote resiliency and adaptation. As part of OAP's research portfolio and now in its third cohort of funded projects, Regional Resiliency and Vulnerability Assessments (RVAs) are interdisciplinary projects that supplement the physical, chemical, and biological dimensions of OCA with social science to assess regional vulnerability and resilience. RVA projects inform pathways that build resilience and adaptation to ocean change that are responsive to community values, needs, and priorities. This information is intended to provide national-to-local marine resource decision-makers with information in order to support the development of adaptation strategies to OCA and related drivers of change affecting ocean and coastal ecosystem services and the human communities that depend on them. In this presentation we will give a high level overview of the RVA program, the projects funded to date and future directions.

Defining ecological vulnerability to ocean and coastal acidification in the Mid-Atlantic region of the United States

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3B: Beyond tipping points: From Data to Decisions, Operationalizing Interdisciplinary Ocean Acidification Knowledge, Rongomātāne B, October 14, 2026, 11:00 - 13:00

To support climate-informed management of ocean and coastal resources and ecosystems, exposure-sensitivity frameworks are needed to integrate biogeochemical and biological data into metrics suitable for decision-making. We are developing a single ocean and coastal acidification (OCA) in situ ecological vulnerability metric (ISEVM) for the Mid-Atlantic region of the United States (US). The ISEVM will be a combination of an OCA Exposure index and an OCA Sensitivity index. We will develop and test the OCA Exposure index using output from existing regional oceanographic models. We will use a compilation of biological impacts of OCA for US Mid-Atlantic species held by the US Mid-Atlantic Coastal Acidification Network (MACAN). We seek input from the High-CO₂ community on the value and limitation of different indices as well as the approach for merging the selected indices of exposure and sensitivity into the final ISEVM. The final product, designed for use by natural resources managers and decision makers, will be a metric GIS-based data layer of ISEVM values for the US Mid-Atlantic Ocean Data Portal, calculated using MACAN's carbonate chemistry and biological databases.

Advancing Towards Adaptation in the Chesapeake Bay Region: The Trajectory of Three Resiliency and Vulnerability Assessment Projects

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3B: Beyond tipping points: From Data to Decisions, Operationalizing Interdisciplinary Ocean Acidification Knowledge, Rongomātāne B, October 14, 2026, 11:00 - 13:00

Building from efforts to characterize regional trends in ocean and coastal acidification (OCA), to predict impacts on oyster production and producers, and to explore the intersection of community vulnerability and OCA impacts on shellfish aquaculture, our legacy of Resiliency and Vulnerability Assessments in the United States' Chesapeake Bay region is advancing strategies that support community and industry adaptation. The first project synthesized carbonate system observations to identify long-term trends and generated the first model-based estimates of past, present, and near-future acidification conditions in Chesapeake Bay. The second project produced the first predictions of biological impacts of OCA and multiple stressors in the context of shellfish aquaculture. Oyster production is most sensitive to species-specific exposure metrics. Field interviews identified social factors that compound OCA effects on shell production and the perception of limited adaptation pathways. The third project, recently funded, characterizes vulnerability to OCA impacts at the community level and examines how community vulnerability interacts with OCA exposure. Exposure risk and community vulnerability will be compared among eastern oyster and hard clam aquaculture areas. The influence of community vulnerability on the responses of people to predictions of future exposure and production will be assessed. An interactive dashboard will integrate adaptive response options, community vulnerability metrics, and modeled OCA impacts on exposure and production. Lessons learned across eight years of effort will be shared, including the importance of sustained end-user engagement. This work provides a model for end-user engagement and science-industry collaborations that can be applied in other regions.

Embedding climate risk modelling in pāua quota valuation to uphold socio ecological and financial values in Aotearoa New Zealand

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3B: Beyond tipping points: From Data to Decisions, Operationalizing Interdisciplinary Ocean Acidification Knowledge, Rongomātāne B, October 14, 2026, 11:00 - 13:00

Ocean warming and acidification, and sedimentation, are altering coastal ecosystems and habitats and, subsequently, population dynamics for pāua (New Zealand abalone), with implications for fishery quota values, livelihoods and kaitiakitanga. We co developed a risk management and valuation framework for a wild pāua fishery area (PAU2), that explicitly links climate and acidification related stressors to bio economic trajectories and financial risk. The Pāua Quota Valuation Bio Economic Model integrates projections of changing temperature, pH and associated habitat stress with stock productivity, catch, revenue and quota price under alternative management and climate scenarios. We coupled this with a “PAU2 climate related risk” tool, codesigned with quota owners and a major lender, to explore how multiple stressors (including ocean acidification, sedimentation and marine heatwaves) propagate through to asset values, debt servicing capacity and nature related financial disclosures. Scenario analysis shows that pathways which anticipate acidification driven shifts in productivity and distribution, and embed ecosystem based management and adaptation investments, can materially reduce downside financial risk while supporting ecological resilience. Our work demonstrates how organism and ecosystem scale understanding of high CO₂ impacts can be operationalised in fisheries valuation, banking, and policy decisions, helping move from “knowing” to “doing” in line with the High CO₂ VI focus on actionable, interdisciplinary ocean solutions.

Coastal sediment alkalinity fluxes and their implications for mineral-based ocean alkalinity enhancement (OAE)

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3C: Ocean Solutions: Alkalinity cycling in a changing ocean, Rongomātāne C, October 14, 2026, 11:00 - 13:00

Ocean alkalinity enhancement (OAE) through the dissolution of alkaline minerals (e.g., olivine, brucite) shows promise for scalable carbon dioxide removal. However, alkalinity dynamics at the sediment water interface are complex and poorly constrained even in the absence of OAE. Here, we use a novel reactor system to constrain alkalinity fluxes from natural sediments with and without added alkaline minerals. The reactor system facilitates porewater advection via stirring, and reactors are supplied with a continuous flow of temperature-controlled seawater to realistically simulate field conditions.

We conducted two 6+ week experiments using the reactor system. First, we used natural sediment from the US Atlantic coast with and without olivine-rich Sibelco dunite (Åheim, Norway). Second, we used natural sediment from the US Pacific coast with and without olivine-rich Hardie Pacific dunite (Greenhills, New Zealand). Across both experiments, porewater total alkalinity (TA) and dissolved inorganic carbon (DIC) increased over time in natural sediments without added dunite. These increases were likely driven by microbial redox processes, which we contextualize with porewater oxygen, trace metal, nutrient, and hydrogen sulfide data. Added dunite disproportionately increased TA relative to DIC, suggesting that dunite contributes buffering capacity to overlying water, despite potentially higher alkalinity fluxes from natural sediments. Dunite from New Zealand dissolved more rapidly than that from Norway, likely in part due to the fact that it features a brucite component.

These findings emphasize the importance of evaluating OAE within the context of natural alkalinity sediment fluxes and of assessing site- and feedstock- specific alkalinity dynamics.

Empirical models of total alkalinity in the Southwestern Atlantic: A regional approach to carbonate system estimation

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3C: Ocean Solutions: Alkalinity cycling in a changing ocean, Rongomātāne C, October 14, 2026, 11:00 - 13:00

The ocean is crucial for storing anthropogenic CO₂. Total alkalinity (TA), a key carbonate system variable, reflects the ocean's buffering capacity. In the Southwestern Atlantic (SWA), TA distribution is poorly known due to limited data. However, as TA is conservative with temperature and varies linearly with salinity (S), empirical models can estimate surface values and regional distributions.

This study estimates the carbonate system on the Northern Continental Shelf of the Southwestern Atlantic, including the Argentine-Uruguayan Common Fishing Zone, using in-situ S and temperature data from INIDEP's BaRDO database, alongside TA and fCO₂ measurements from DiPlaMCC ecological time series (2017-2024). Regionally adjusted TA-S relationships fill data gaps.

The Lee et al. (2006) Southern Ocean model was validated locally ($r^2=0.96$, bias=-22.5 $\mu\text{mol/kg}$, RMSE=28.0 $\mu\text{mol/kg}$). Three regionally adjusted variants were developed, with the "Lee-Mixed" model performing best ($r^2=0.91$, bias=-0.11 $\mu\text{mol/kg}$, RMSE=15.2 $\mu\text{mol/kg}$). A mixing model (Tomczak et al. 1981) was also used to estimate TA and its biogeochemical variation, providing insight into non-conservative processes.

Finally, TA estimates were integrated with continuous fCO₂ observations to generate regional distributions of dissolved inorganic carbon (DIC) and surface pH. This approach yielded mean carbonate system values for the region's characteristic water masses: the Río de la Plata plume (DIC = 2002 $\mu\text{mol/kg}$, pH = 8.08) and Subantarctic Shelf Waters (DIC = 2033 $\mu\text{mol/kg}$, pH = 8.12). These estimates establish a critical baseline for carbon cycling, enabling the assessment of future marine carbon dioxide removal scenarios and their potential to mitigate ocean acidification in this historically under-sampled region

Advancing our understanding of Ocean Alkalinity Enhancement natural analogs in the Gulf of Tehuantepec, Mexico

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3C: Ocean Solutions: Alkalinity cycling in a changing ocean, Rongomātāne C, October 14, 2026, 11:00 - 13:00

Ocean alkalinity enhancement (OAE) is an emerging marine carbon removal technique that increases the ocean's capacity to absorb CO₂ and potentially mitigates the effects of ocean acidification (OA). OAE is being implemented in other countries, and OAE credits have already been issued for the first time; however, its feasibility and possible impacts in Mexico remain unknown, as does which ecosystems might serve as OAE analogs (by contributing carbonates). This study evaluates the potential of the Copalita River, located in Oaxaca, Mexico as OAE analog, monitoring discharge, the carbonate system, and carbonate content in sediments at the river mouth and the adjacent coastal zone to assess ocean-atmosphere and land-ocean carbon fluxes, as well as the increase in alkalinity due to river inflows. Preliminary results indicate that the river plume significantly increases alkalinity in the coastal zone, with peak inputs during the rainy season, thus providing important evidence of an OAE potential. On the other hand, during summer, CO₂ fluxes were positive nearest the river discharge area and changed direction at the farthest end of the river plume. This is probably due to a large amount of organic matter. This indicates that the OAE potential of the river will depend on whether carbonate ions exceed the supply of organic matter, underscoring the importance of water quality evaluation and control in river plumes for OAE purposes. Further studies are needed to evaluate the alkalinity inputs on an annual cycle.

A biophysical modelling framework for evaluating potential OAE in Aotearoa New Zealand's Exclusive Economic Zone

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3C: Ocean Solutions: Alkalinity cycling in a changing ocean, Rongomātāne C, October 14, 2026, 11:00 - 13:00

Ocean Alkalinity Enhancement (OAE) is an emerging strategy to mitigate climate change by increasing surface ocean alkalinity and thereby enhancing the capacity of seawater to store atmospheric CO₂. However, prior to considering any deployment, it is critical to develop the capacity to verify CO₂ removal, to quantify the net climatic benefit of OAE and potential ecosystem-level impacts. Despite recent advances in autonomous observing platforms, in situ observations – particularly of biogeochemical variables - remain spatially and temporally sparse, limiting capability to provide a comprehensive assessment of OAE outcomes. Numerical models, informed and validated by observations, are therefore essential for guiding OAE deployments and for supporting robust measurement, reporting, and verification of carbon uptake.

Here, we present a coupled physical-biogeochemical modelling framework developed to evaluate potential OAE within Aotearoa New Zealand's Exclusive Economic Zone. The model is based on a nested configuration of the Regional Ocean Modelling System (ROMS), enabling high spatial resolution in targeted coastal regions while maintaining basin-scale context. To demonstrate the capability of the modelling framework, a high-resolution nest of the North Taranaki Bight (west coast, North Island), is validated against multiple observational datasets and used to explore the impact of OAE across a range of spatial scales.

Using a natural analogue to assess Ocean Alkalinity Enhancement: An Aotearoa New Zealand case study

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3C: Ocean Solutions: Alkalinity cycling in a changing ocean, Rongomātāne C, October 14, 2026, 11:00 - 13:00

Ocean Alkalinity Enhancement (OAE) is being considered as a potential approach for increasing CO₂ uptake by the ocean, but research has been limited to some extent by concerns regarding deliberate alkalinity addition to the ocean. A new research programme in Aotearoa New Zealand is employing an alternative approach of using natural analogues to develop monitoring and verification and determine ecosystem effects without the need for deliberate alkalinity addition. Initial sampling in the Hawke Bay region (north-east North Island) identified two rivers draining limestone catchments with elevated alkalinity concentration exceeding that of coastal waters. This natural source of alkalinity will be tracked as it disperses in coastal waters by nearshore surveying, using an autonomous surface vehicle and sensor buoy, and also parallel offshore mapping on a research vessel. The field data will be incorporated in a hydrodynamic model to assess the impact on the regional alkalinity budget of Hawke Bay and compared with natural alkalinity supply from sediments and groundwater and also proposed OAE in other regions.

South Atlantic Ocean surface acidification in a high atmospheric CO₂ world

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3C: Ocean Solutions: Alkalinity cycling in a changing ocean, Rongomātāne C, October 14, 2026, 11:00 - 13:00

The increase of anthropogenic CO₂ in the atmosphere is driving changes in the global ocean, including the increase in sea temperature, acidification, and others. Ocean acidification is a particular concern for marine ecosystems as it affects the planktonic communities and consequently the biological pump efficiency. Using ecoGENIE, a mid-complexity Earth System Model, with atmospheric CO₂ concentrations from the IPCC AR5 Representative Concentration Pathways (RCP) 4.5 and 8.5 scenarios, we investigated the changes in the surface acidification process in the South Atlantic Ocean from 2000 up to 2100. The DIC/TA ratio was used to identify the acidification process, as higher ratio values indicate a larger DIC content and less buffered seawater conditions. Therefore, the model results suggest that DIC/TA ratio would be 0.90 for both RCP 4.5 and RCP 8.5 scenarios in year 2000. The two scenarios start to diverge from the year 2020 onwards, reaching values of 0.93 and 0.97 by 2100, respectively, indicating an increase in the acidification process. This is consistent with the pH and Ω_{arg} values, which decreases from 8.06 and 3.07 in year 2000 to 7.92 and 2.49 in year 2100 for the RCP 4.5, and to 7.72 and 1.76 in year 2100 for the RCP 8.5, respectively. These results also corroborate with the increasing acidification tendency suggested by the CMIP5 models and as observed in the subtropical North Atlantic. However, uncertainties associated with the acidification process in the South Atlantic Ocean remain difficult to validate due to the lack of long-term in situ observations.

Natural shelf seafloor feedbacks to changing ocean carbonate chemistry

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3C: Ocean Solutions: Alkalinity cycling in a changing ocean, Rongomātāne C, October 14, 2026, 11:00 - 13:00

The ocean alkalinity (TA) content determines how much carbon dioxide (CO₂) can be stored as dissolved inorganic carbon. The shelf seafloor is crucial for regulating ocean TA levels on shorter timescales, mainly through the recycling of ~22 Tmol TA per year through CaCO₃ dissolution. Both increasing atmospheric CO₂ concentrations and proposed marine CO₂ removal approaches like ocean alkalinity enhancement ('OAE') alter the calcium carbonate (CaCO₃) saturation state, which can trigger feedbacks through changes in CaCO₃ dissolution rates in the shelf seafloor. Yet the impact of anthropogenically induced changes on shelf seafloor biogeochemistry is poorly understood.

Here, we present time-series data from the last 25 years in shelf and Subantarctic surface water along the Munida timeseries in Aotearoa New Zealand, which we combined with experimental sediment incubations. We show that CaCO₃ dissolution in the shelf seafloor is enhanced in response to higher atmospheric CO₂ and concurrent reduction in CaCO₃ saturation state. At the same time, OAE greatly limits seafloor CaCO₃ dissolution. Our results suggest there is a "fast climate feedback" in the shelf seafloor, and that OAE will reverse this feedback and reduce natural alkalinity generation.

Adaptive remodelling of cell membranes and energy substrate use under ocean warming and acidification in a ubiquitous marine copepod

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3D: Modulating role of time, Mătiu, October 14, 2026, 11:00 - 13:00

Organisms' ability to rapidly adapt to changing environmental conditions is key to their persistence in a rapidly changing ocean. In particular, the simultaneous impacts of ocean warming (OW) and ocean acidification (OA) are expected to strongly affect marine life negatively. Our understanding of fitness responses and the genetic mechanisms underpinning adaptation has recently improved. Differently, the functional implications of adaptation, particularly at the cellular level, remain poorly investigated. We characterised the metabolome and lipidome adaptive responses in laboratory strains of the marine copepod *Acartia tonsa* exposed for approximately 130 generations to OW and OA conditions in isolation or combined. We report profound remodelling in copepods' metabolome and lipidome profiles, with the strongest changes observed in copepods adapted to combined conditions (OWA). Metabolic adaptations included a transition in energy-substrate use, from carbohydrates to amino and fatty acid sources, to sustain ATP production, along with an increase in antioxidative capacity. In addition, we observed a strong remodelling of fatty acid classes composition and lipid unsaturation levels, particularly following adaptation to OW and OWA. These changes are consistent with the homeoviscous adaptation of cellular membranes under OW, and with membrane restructuring to mitigate acidosis-induced damage under OA. Our findings shed light, for the first time, on the cellular functional consequences of adaptation to OA, OW and OWA in a marine metazoan. Understanding the functional implications of marine organisms' rapid adaptation to combined anthropogenic global change drivers is paramount to inform adaptive environmental management and support biodiversity conservation and ecosystem functioning.

Cross-generational plasticity and the interaction between environmental stressors

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3D: Modulating role of time, Mātiu, October 14, 2026, 11:00 - 13:00

Tropical fishes generally exhibit high thermal sensitivity and are negatively impacted by ocean warming. However, with development and cross-generational exposure to warming thermal plasticity can occur and improve performance. While we understand the impacts of cross-generational plasticity to thermal performance, we know little about how the phenotypic changes in response to temperature affect performance under other environmental change conditions. This research exposed coral reef damselfish (*Acanthochromis polyacanthus*) to various F1 and F2 generation warming scenarios to allow for cross-generational thermal plasticity. Subsequently, F3 generation offspring underwent a series of experiments that tested the phenotypic outcomes when juveniles developed in elevated temperature and ocean acidification, elevated temperature and suspended sediment, and elevated temperature and reduced resource availability. Differences due cross-generational performance was observed in response to suspended sediment and resource availability, but not in response to ocean acidification. This work allows greater understanding of how cross-generational plasticity manifests, and under what conditions we expect it to be adaptive.

REVISITING THE MECHANISMS OF ADAPTATION AFTER 200 GENERATIONS OF SIMULTANEOUS OCEAN WARMING AND ACIDIFICATION IN A WIDESPREAD MARINE COPEPOD

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3D: Modulating role of time, Mătiu, October 14, 2026, 11:00 - 13:00

To fully comprehend how organisms will persist under climate change, we need to consider synergistic stressors over multiple generations. Experimental evolution allows us to manipulate long-term selection regimes, making it a powerful tool to interrogate the relative contributions of adaptation and plasticity. For marine invertebrates, the combined effects of ocean warming and acidification (OWA) have already begun to detrimentally impact natural populations. Microbiome dynamics are an important response mechanism for marine invertebrates. However, few studies assess how multigenerational stressors shape host-microbiome interactions. The copepod *Acartia tonsa* is a fortuitous system to explore this question, as these animals have rapid generation times (14 days) and can be cultured for multiple generations in the lab. By experimentally evolving *A. tonsa* for over 200 generations under OWA conditions, we elucidate how microbiome dynamics are shaped by long-term exposure to future environmental regimes. Our preliminary data presents how non-additive responses to thermal and pH stress can result in distinct microbiome configurations, which in some cases can become canalized due to sustained abiotic stress. In pairing these results with forthcoming transcriptional and genomic data, our work represents an unprecedented opportunity to not only capture the development of fitness trajectories in real time, but also ascertain the potential role of the microbiome in shaping said outcomes, ultimately providing insights into the resilience of copepods under climate change.

Transgenerational maternally-provided lipid composition & quantification in early-life stages of *Perna canaliculus* under differing OA conditions

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3D: Modulating role of time, Mātiu, October 14, 2026, 11:00 - 13:00

In aquaculture, parental priming, the intentional exposure of broodstock to stressors during gametogenesis, is increasingly explored as a complementary or alternative strategy to selective breeding for producing stress-resilient offspring. Under ocean acidification (OA) stress, changes in maternal energetic demands may generate transgenerational responses mediated through egg provisioning, where lipids are critical for the survival and performance of early life-stages in broadcast-spawning bivalves. We examined whether maternal exposure to ambient (pHT~8.1), year-2050 (pHT~7.74), and year-2100 (pHT~7.65) OA conditions for 4- then 14-months influenced lipid composition and quantity in unfertilised eggs and pre feeding larvae of three selectively bred family lines of the New Zealand green lipped mussel, *Perna canaliculus*. Lipid classes were quantified in post-spawning eggs and D-larvae reared under ambient or high (pHT~7.65) OA conditions using thin-layer chromatography with flame-ionisation detection (TLC/FID). Across both exposure durations, OA did not alter total lipid content or the relative proportion of energetic and structural lipids in eggs, although egg lipid composition differed significantly among family lines. In contrast, D-larval lipid reserves were affected by OA. Irrespective of parental OA exposure, D-larvae reared under high OA had significantly lower lipid reserves, indicating increased developmental energetic costs or reduced developmental performance under acidified conditions. These findings provide limited support for parental priming of maternal lipid provisioning under OA in *P. canaliculus*. Larval reserves appear to be driven primarily by developmental conditions. For aquaculture, aligning broodstock conditioning and spawn timing to periods maximising egg energetic lipids may improve larval quality despite parental OA exposure.

Transgenerational plasticity responses differ across genetically distinct families in the Sydney rock oyster, *Saccostrea glomerata*

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3D: Modulating role of time, Mătiu, October 14, 2026, 11:00 - 13:00

Across the globe, marine organisms need to rapidly respond to climate change. Acclimation through the mechanism of transgenerational plasticity (TGP) is now at the forefront of research, providing hope that some marine organisms may persist into the future. To date, however, because most studies have focussed on the average phenotypic species response to climate change, we do not know whether phenotypic responses vary among genotypes. Here, we take a next critical step in TGP research to assess whether TGP responses to ocean acidification (OA) differ among genotypes of the culturally significant and iconic Sydney Rock Oyster (SRO), *Saccostrea glomerata*. Adults of four genetically distinct families of the SRO were exposed to ambient (410 μatm) and elevated (1000 μatm) pCO_2 for 9 weeks during reproductive conditioning. Following this exposure, we performed a within family cross of each family and measured the percentage development, abnormality, shell length and respiration rate of D-veliger larvae after 48 h in the same ambient and elevated pCO_2 treatments. We found significant variability in TGP responses among families to elevated pCO_2 , with positive, negative, and neutral responses in larval offspring. How well we understand the adaptive potential of oysters and their capacity to mount fast responses through TGP to climate change will determine our ability to ensure the sustainability of SRO populations, marine food security and the cultural heritage of this iconic species. Combined approaches quantifying both genetic and non-genetic TGP responses are needed to determine the total adaptive potential of other marine organisms to climate change.

Both parent exposure to elevated pCO₂ and genetics influence embryo resilience to ocean acidification in the greenlipped mussel, *Perna canaliculus*

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3D: Modulating role of time, Mātiu, October 14, 2026, 11:00 - 13:00

Coastal pCO₂ levels in New Zealand are expected to outpace oceanic means, reaching ~1100µatm by 2100, raising concerns for calcifying organisms. The endemic mussel, *Perna canaliculus*, is an ecological and economic keystone species with a vulnerable pelagic embryonic phase. Well-developed aquaculture practices for this species also facilitate experimental manipulation under controlled conditions, underpinning its emergence as a model species for environmental studies. To explore embryo vulnerability and adaptive capacity to OA, adult mussels from three genetically distinct commercially-bred families were exposed to constant 400, 850 or 1100µatm pCO₂ seawater at 17°C and fed ad libitum on cultured microalgae. After three months of exposure, mussels were induced to spawn using thermal shock; gamete fertilization and subsequent embryogenesis was then carried out at 400 or 1100µatm pCO₂. All offspring raised under 400µatm performed well, with ~87% of eggs reaching shelled larval stage after two days, irrespective of parental history. Incubating embryos at 1100µatm pCO₂ reduced net embryo survival by ~25%; however, prior adult exposure to 850 or 1100µatm incrementally improved offspring performance. A parallel experiment utilized selective-bred adults to create 96 full-sibling offspring families. Embryos were again raised under ambient or elevated pCO₂ conditions. Net embryo survival displayed a significant maternal effect, while the size of the shell secreted during the 2-day embryonic phase was significantly influenced by genetics, with a moderate heritability (0.3-0.4). While *P. canaliculus* embryos are certainly vulnerable to near-future acidification, there is genetic potential within standing stocks, as well as transgenerational plasticity that could support rapid population-level adaptation.

Genetic variation and phenotypic plasticity in the response to ocean acidification

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3D: Modulating role of time, Mătiu, October 14, 2026, 11:00 - 13:00

The impacts of ocean acidification will depend on the ability of marine organisms to tolerate, acclimate and eventually adapt to changes in ocean chemistry. We performed unique transgenerational experiments to determine the molecular response of a coral reef fish to short-term, developmental and transgenerational exposure to elevated CO₂. This aids in teasing apart plastic responses due to developmental plasticity and reveals within-generation specific reactions to be driven by epigenetic regulators. Importantly, we find that altered gene expression for the majority of within-generation responses returns to baseline levels following parental exposure to elevated CO₂ conditions. What remains uncompensated across generations is the gene expression involved in glucose homeostasis. Furthermore, responses of offspring depended largely on the parental phenotype measured by behavioral tolerance to elevated CO₂. We show that the transgenerational signal of tolerance is connected to the circadian rhythm and suggests adaptive potential of impaired behaviors from high CO₂ to be due to existing natural variation. We therefore re-sequence 75 genomes of behaviorally tolerant and sensitive parents and their offspring and identified variants and genomic regions linked to the behaviorally tolerant phenotype. This will allow for the further understanding of this tolerance to elevated levels of CO₂ and aid future predictions of resilience and population persistence in the light of rapidly increasing acidification of the oceans.

Mesoscale environmental mosaics modulate phenotypic plasticity under multi-scale environmental variability in coastal upwelling systems

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3D: Modulating role of time, Mătiu, October 14, 2026, 11:00 - 13:00

Coastal upwelling systems are inherently heterogeneous, generating environmental mosaics over tens of kilometers that expose marine animals to highly dynamic regimes of temperature, pH, and dissolved oxygen (DO). While ocean acidification research has traditionally focused on mean conditions, emerging evidence highlights the ecological relevance of variability across multiple temporal scales. Here, we integrate diel (hours) and upwelling-driven (days to weeks) variability to assess how multi-scale environmental forcing shapes phenotypic plasticity in the kelp crab *Taliepus dentatus*, a species with limited larval dispersal (<15 days). Using information from deployed T², pH and DO sensors, we designed field-informed laboratory experimental designs, where we simulated natural diel cycles of pH–oxygen variability characteristic of contrasting habitats within an upwelling seascape—an active upwelling site and an upwelling shadow. These environments differ markedly in variability regimes, including the decoupling of pH and oxygen under persistent upwelling conditions. We then imposed inter-daily variability through upwelling cycles of increasing duration and intensity, mimicking present and future climate-driven scenarios. Across scales, environmental heterogeneity drives divergent physiological responses between populations separated by <30 km. Crabs from active upwelling habitats exhibit elevated metabolic rates, enhanced acid–base regulation, and constitutive reliance on anaerobic pathways, consistent with persistent plasticity to recurrent stress. In contrast, individuals from upwelling shadows show reduced metabolic performance under fluctuating conditions and activate compensatory mechanisms only under prolonged upwelling. Extended low pH and hypoxia expose constraints in physiological compensation in both populations. These findings highlight the importance of incorporating multi-scale variability into predictions of organismal resilience under future ocean change.

Tolerance Throughout Time: Can Coralline Algae Acclimate to Future Ocean Acidification and Ocean Warming?

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4A: Multiple Stressors, Rongomātāne A, October 14, 2026, 16:00 - 18:00

Crustose coralline algae (CCA) play a crucial role in marine reef ecosystems globally, acting as reef builders, settlement substrate, and seed banks. However, they are highly susceptible to the effects of ocean acidification. The impact of ocean warming and its interaction with ocean acidification on CCA is less certain. Many questions remain regarding long-term effects of these drivers and the potential for tolerance change across multiple generations of exposure. Previous studies indicate that CCA tolerance to ocean acidification may relate to shifts in dissolved inorganic carbon (DIC) use. Specifically, shifts from energetically expensive bicarbonate (HCO_3^-) to readily available CO_2 , could provide long-term energetic savings. Tolerance in CCA has also been attributed to their ability to maintain stable internal calcifying fluid conditions, particularly high internal CaCO_3 saturation state (Ω). In this study, we exposed four generations of temperate coralline algae to a shared socioeconomic pathway (SSP) 5-8.5 projection of ocean acidification and warming. We investigated changes in growth and recruitment, DIC uptake and $\delta^{13}\text{C}$ values, and internal calcifying fluid Ω and %Mg. We hypothesise that: (1) acclimation potential is species-specific; (2) species capable of acclimation will exhibit greater control of calcification physiology (high internal CaCO_3 Ω and low %Mg), and/or preferentially take up CO_2 for photosynthesis; and (3) species exhibiting these changes will experience metabolic benefits, including increased growth and recruitment rates. Here, I will discuss the results of this experiment, focusing specifically on changes to DIC uptake and $\delta^{13}\text{C}$ values, and CaCO_3 Ω and %Mg data.

Impacts of multiple stressors on a reef-building coralline alga

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4A: Multiple Stressors, Rongomātāne A, October 14, 2026, 16:00 - 18:00

This study examined both the independent and interactive effects of global and local stressors by assessing how elevated seawater pCO₂, increased nutrient availability, and reduced light levels influence the growth and photosynthetic performance of the branching crustose coralline alga *Lithophyllum cf. pygmaeum*. Our results revealed complex interactions among these drivers affecting both algal growth and photosynthesis. Despite this complexity, enhanced pCO₂ consistently stimulated linear growth across all light and nutrient treatments. Conversely, growth was markedly suppressed under conditions combining low irradiance with high nutrient concentrations, reflecting degraded water quality scenarios. These findings indicate that declines in water quality may negate potential CO₂ driven growth enhancement under ocean acidification. This has important implications for coral reef conservation, highlighting the critical role of water quality management in sustaining reef ecosystem functions. Overall, our results demonstrate the value of multifactorial experimental designs for resolving how global change drivers interact with local environmental pressures to shape coralline algae responses.

Multiparameter experiments constrain the sensitivity of coralline algae to environmental change

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4A: Multiple Stressors, Rongomātāne A, October 14, 2026, 16:00 - 18:00

Coralline algae are marine calcifiers and critical foundational species in the photic zone of higher latitude coastal regions, but also significantly contribute to carbonate production in coral reef structures. Here we present some highlights of calcification rate, internal pH regulation, raman spectroscopy, photophysiology, carbon and nitrogen isotope data collected from a series of experiments on both articulate and encrusting species and species complexes from New Zealand. One experiment explores the influence of changing light levels on the geochemistry of four coralline algae complexes, finding no overall change in $\delta^{11}\text{B}$ but other geochemical results reflected significant differences in the carbon utilization between articulate and encrusting complexes. In a second experiment we performed a comparative analysis of the sensitivity to elevated pCO_2 in seven different species – finding a wide variation in calcification fluid pH 8.4-8.9 and complexes that showed no change with external acidification and those that showed high sensitivity. Some but not all these complexes also showed signs of compromised photophysiology and calcification under acidification. In a third experiment, we tested the individual and interactive effects of pCO_2 , light, and temperature across four species. All species exhibited pronounced vulnerability, particularly in terms of calcification, although responses diverged with respect to driver dominance and interaction type. These differences appear to reflect species-specific capacities to balance increased energetic demands under constrained resource acquisition and to effectively allocate energy among competing processes. Therefore, we find evidence for physiological diversity in coralline response to changing ocean pH, temperature, and carbonate chemistry.

An integrated framework for evaluating reef persistence under multiple stressors

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4A: Multiple Stressors, Rongomātāne A, October 14, 2026, 16:00 - 18:00

Coral reef ecosystems are economically and culturally important, yet they remain severely degraded and increasingly vulnerable to changing ocean conditions. Here we present results from a large-scale, multidisciplinary effort to assess how multiple stressors affect reef persistence, focusing on the largest U.S. coral reef restoration project to date, Mission: Iconic Reefs (M:IR). We leveraged 28 years of bimonthly water-quality monitoring throughout south Florida and satellite remote sensing data to validate a regional high-resolution biogeochemical model (MOM6 + COBALT) and project ocean conditions under different scenarios. We built on these outputs, along with seagrass cover data and hydrodynamic models (SLIM2D), to evaluate how local seagrass restoration in upstream flowsheds may mitigate changes in carbonate chemistry at priority M:IR sites. Next, we created a novel multistressor aquarium control system to simultaneously manipulate acidification, hypoxia, and temperature in real time and evaluated the performance of a suite of benthic calcifiers and eroders. We built on more than 100 high-resolution 3D photomosaics, representing multiple reef zones and biogeographic regions, and integrated species sensitivity data to construct dynamic carbonate budget models that predict trajectories of reef habitat under different multistressor scenarios. Finally, we incorporated these scenario-dependent outputs into a user-friendly web tool that allows stakeholders to explore the impacts of environmental change on their reefs. Together, these data present an integrated framework by which the impact of future multistressor distributions can be applied at the species and ecosystem levels to ultimately evaluate habitat persistence in the context of restoration and management.

Multiple drivers of change: Simple experimental approaches for a complex problem

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4A: Multiple Stressors, Rongomātāne A, October 14, 2026, 16:00 - 18:00

Multiple global environmental factors are changing simultaneously in our increasingly high CO₂ world: Ocean acidification, ocean warming, marine heat waves and altered nutrient (e.g. nitrogen, iron) supply in addition to local drivers of change including anthropogenic nitrogen additions from land use change and animal aquaculture. Designing experiments to test for the effects of multiple drivers on marine life is often perceived as complex or 'too hard' but attention to experimental design and the development of precise hypotheses can overcome perceived challenges. Here I will illustrate the utility of three experimental approaches – physiological performance curves, scenario testing and collapsed factorial designs using algal examples from laboratory physiological experiments on phytoplankton (*Emiliania huxleii*) and macroalgae (*Macrocystis pyrifera*, *Phyllospora comosa* and *Ecklonia radiata*). In addition, transcriptomics is a powerful tool to identify biochemical indicators of stress that are apparent in multiple driver experiments but not apparent when traditional physiological/growth metrics are examined. For example, the marine macroalga *Ecklonia radiata* can show signs of severe stress at the biochemical level that are masked at the organismal level. Taken together, careful experimental design and application of 'omics' to traditional physiological metrics can provide relatively simple and interpretable data that enable understanding of algal responses to the ongoing complex environmental changes in marine systems.

Does Ocean Acidification Exacerbate Bleaching? Multistressor Insights from Corals and Coralline Algae

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4A: Multiple Stressors, Rongomātāne A, October 14, 2026, 16:00 - 18:00

Scleractinian corals and crustose coralline algae (CCA) underpin the structure and function of coral reefs, yet both are increasingly threatened by climate-driven stressors. Marine heatwaves are well-established triggers of bleaching, but ocean acidification (OA) has historically been reported to induce bleaching under certain conditions. However, the physiological pathways through which decreased seawater pH influence bleaching are complex and largely unknown. This study investigates whether OA directly induces coral and coralline algal bleaching, and whether bleaching is instead driven by exposure to elevated temperature and high light. An eight-week multistressor experiment was conducted at the AIMS National Sea Simulator (SeaSim) facility, in which four pH levels spanning near-future projections to extreme low-pH conditions were crossed with high- and low-light regimes and maintained at either ambient or elevated temperatures. This design enabled us to evaluate whether OA can induce bleaching independently of thermal stress or in combination with high light across multiple coral and CCA species. We assessed bleaching and stress physiology using high-resolution photophysiological measurements, calcification-related analyses (including Raman spectroscopy), and a novel application of NDVI to quantify bleaching in both corals and CCA. Together, these complementary approaches provide a mechanistic perspective on how these taxa respond across gradients of temperature, light, and pH, with a focus on distinguishing stressor-specific versus shared bleaching responses. These findings refine our understanding of the environmental conditions that initiate bleaching and alter key physiological functions in corals and CCA, providing context for interpreting early shifts in reef condition and offering actionable insight for reef management.

Impacts of the sunscreen oxybenzone on the oxidative proteome of the coral model *Exaiptasia*

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4A: Multiple Stressors, Rongomātāne A, October 14, 2026, 16:00 - 18:00

Sunscreens, including oxybenzone, have been identified as potential contributors to localized coral reef decline by exacerbating coral bleaching. Oxybenzone has been proposed to have phototoxic effects on corals during ultraviolet (UV) light exposure through its metabolism to the photosensitizer oxybenzone-glucoside, and accumulation of oxybenzone-glucoside has been demonstrated in the anemone model *Exaiptasia diaphana*. Here, we investigated the effects of oxybenzone on the oxidative state of the host proteome in the *Exaiptasia*–dinoflagellate symbiosis. Reversible cysteine oxidation is a widespread means of protein activation, regulation, and signalling. Consequently, analyzing the cnidarian oxidative proteome in the presence of oxybenzone can reveal the cellular components and protein networks underlying the physiological response.

We assessed the reversible oxidative state of cysteine-containing peptides via liquid chromatography-mass spectrometry. *Exaiptasia diaphana* either hosting *Breviolum minutum* or lacking symbionts (aposymbiotic) were exposed to 8.8 μ M oxybenzone in seawater at 26 °C, with or without the presence of UV light. Protein samples were processed by solid-phase extraction followed by resin-assisted capture of cysteine-containing peptides.

We quantified the reversible cysteine oxidative state in thousands of *Exaiptasia* proteins exposed to oxybenzone with and without UV light. We found shifts in the redox state of host mitochondrial and cytoplasmic proteins that are consistent with host oxidative stress and stress responses. Oxybenzone in the absence of UV light induced relatively limited changes to the host proteome. By better understanding the metabolic and signalling pathways affected by UV-absorbing compounds, we can better understand and select for effective but less-toxic sunscreens.

The OA2O Project: Integrating Short-Term Ocean Acidification into NOAA's Operational Ocean and Weather Forecasting Systems

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4B: Beyond tipping points, Rongomātāne B, October 14, 2026, 16:00 - 18:00

There is a significant opportunity to establish an operational forecasting system for ocean acidification (OA) at NOAA, which will greatly benefit coastal communities and industries reliant on marine ecosystems. Building from more than 15 years of biogeochemical modeling research sponsored by NOAA's Ocean Acidification Program (OAP), the Ocean Acidification to Operations (OA2O) initiative seeks to transition mature, community-developed BGC and OA forecast models from research-based systems into NOAA's 24/7 operational infrastructure. This transition addresses a critical gap in reliability and accessibility of research-funded models.

The OA2O initiative will leverage existing operational hydrodynamic models from NOAA's National Ocean Service (NOS) as a foundation for new, dependable OA forecast products. The initiative has a two-pronged implementation path: first, adapting existing research BGC and OA models for integration with NOS operational systems; and second, developing a generalized, hydrodynamic-core-agnostic BGC/OA module that can interface with various hydrodynamic cores used by the Unified Forecast System (UFS) and NOS ocean forecast systems. Ultimately, the OA2O initiative empowers the ocean acidification community to better address the needs of stakeholders in coastal industries, fisheries, and aquaculture sectors with timely, actionable forecasts, fostering a robust Research-to-Operations-to-Research (R2O2R) feedback loop.

A risk-based assessment of biodiversity changes from ocean acidification along the UAE's east coast.

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4B: Beyond tipping points, Rongomātāne B, October 14, 2026, 16:00 - 18:00

The UAE's east coast, including the Fujairah–Khorfakkan region, contrasts strongly with the Arabian Gulf due to Indian Ocean monsoon driven upwelling. This process brings cooler, nutrient rich waters, enhancing productivity and biodiversity, while also causing periodic decreases in pH. The area supports a unique mix of coral reefs, mangroves, seagrass patches and pelagic fisheries, making it one of the most diverse coastal ecosystems in the UAE. However, this ecological richness is paired with high sensitivity to chemical changes, particularly ocean acidification intensified by CO₂ rich upwelling.

A risk-based assessment was carried out to evaluate biodiversity changes linked to ocean acidification along the Gulf of Oman's east coast. The assessment incorporated regional oceanography, ecosystem sensitivity and socio-economic reliance on marine resources, covering both commercially important species and conservation focused habitats. Corals, molluscs and echinoderms were identified as especially vulnerable because reduced carbonate availability limits calcification and weakens skeletal structures. Documented coral bleaching has already caused mortality, reduced reef growth and loss of structural complexity, increasing the likelihood of habitat degradation for associated species. A shift towards algae dominated communities is expected, alongside declines in biodiversity, resilience and fisheries productivity. Risk scoring classified coral reefs as facing very high impacts, while seagrass meadows, mangroves and pelagic and commercial fish habitats were rated high to medium risk. Benthic invertebrates, particularly shellfish, also showed very high vulnerability. Overall, ocean acidification represents a medium to very high ecological threat to the area, underscoring the need for resilience centred marine management, conservation planning and monitoring.

Identifying priorities of the ocean acidification research community of the Pacific to minimize and address the impacts of ocean acidification

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4B: Beyond tipping points, Rongomātāne B, October 14, 2026, 16:00 - 18:00

Five key priority actions for the Pacific ocean acidification (OA) community were identified using a survey and interactive polling approach: 1) Incorporate OA into national policies and develop a science-to-policy interface; 2) Establish national monitoring programs in nations that don't have them; 3) Undertake more research into the effects of OA and related topics; 4) Undertake direct action such as conserving or restoring marine ecosystems that absorb CO₂; and 5) Ensure comprehensive country-based baseline dataset collection (at current sites) and program continuation. Potential pathways and feasibility of achieving these goals were identified and implementation of these will require a phased approach supported by concurrent progress on several lower ranked but foundational activities. We describe the approach to the study and the implications for Pacific OA policy and management.

A strategic plan to address and minimize the impacts of ocean acidification in Iceland

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4B: Beyond tipping points, Rongomātāne B, October 14, 2026, 16:00 - 18:00

Ocean acidification (OA) is now considered a major threat for marine species, ecosystems and associated services. With more than 10,000 scientific articles, the inclusion in key policy frameworks (e.g. Sustainable Development Goals, Global Biodiversity Framework), and coordination networks (e.g. Global Ocean Acidification Observing Network, International Ocean Acidification Coordination Center, Ocean Acidification Research for Sustainability), the field of OA sends a clear message: the time for action is now. Solutions include global mitigation of carbon dioxide and stakeholder co-creation of local and regional solutions that increase ecosystem resilience through protection, restoration, and adaptive management and practices. However, changes are slow and implementation of solutions often lack follow through and accountability.

The threat of OA could be viewed through the framework of collective action. A collective action problem is a situation in which the short-term self-interest of individual actors conflicts with longer-term collective benefits. This can be improved through stakeholder engagement.

In this presentation, we will summarize the state of the art of OA research in Iceland and present our approach to co-create a realistic and timely strategic plan that prioritizes science toward positive actions to address and minimize the impacts of OA. Iceland is an ideal case study as their egalitarian culture valuing independence, science, strong family ties, nature, and creativity, as well as progressive values and gender equality. Emphasis on self-sufficiency and community make it an exceptional environment for such implementation.

One coast, two stories? pH trends and dynamics in an urbanized bay and a pristine seagrass habitat

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4B: Beyond tipping points, Rongomātāne B, October 14, 2026, 16:00 - 18:00

Ocean acidification in coastal environments is shaped by rising atmospheric CO₂ but also by local biological and physical processes that can amplify or buffer its signal. Here we present a pH time series from two contrasting coastal sites in the Balearic Sea (Western Mediterranean), building on data from the Bay of Palma (since 2018) and the Cabrera Archipelago (since 2019) using high-resolution autonomous sensor measurements.

Host to monitoring stations of physicochemical parameters, the two sites offer a compelling natural contrast. The Bay of Palma is a semi-enclosed, anthropogenically influenced embayment, where biological modulation of carbonate chemistry is limited and the pH signal is dominated by physical drivers and atmospheric CO₂ uptake. Cabrera, on the other hand, is a shallow, pristine MPA where dense seagrass (*Posidonia oceanica*) meadows exert a strong influence on the local carbonate system through photosynthesis and respiration, producing pronounced diel and seasonal pH variability.

Data gaps — inherent to long-term autonomous sensor deployments — were addressed using Recurrent Neural Networks trained on co-located temperature, salinity, and dissolved oxygen records, following a previously established methodology. This approach allowed reconstruction of continuous pH hindcasts and calculation of long-term acidification trends at both sites.

The extended dataset now provides sufficient temporal coverage to rigorously characterize and compare the pH dynamics, drivers, and acidification trajectories at these two sites, quantifying the role of *Posidonia oceanica* meadows as a modulator of ocean acidification in shallow Mediterranean coastal waters, and highlighting the divergence between anthropogenized and pristine coastal environments under increasing CO₂ pressure.

Toward Informed Action: A Systematic Review of Ocean Acidification Research in India

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4B: Beyond tipping points, Rongomātāne B, October 14, 2026, 16:00 - 18:00

Ocean acidification, a consequence of climate change, is emerging as a serious threat to marine ecosystems. Although its impacts have been widely studied globally, research from India is still limited but growing rapidly. This highlights the need to systematically compile existing knowledge to better guide future studies. In this study, we synthesized ocean acidification research in India using Scopus, Web of Science, and the Ocean Acidification–International Coordination Centre bibliography. A bibliometric analysis was conducted using the Biblioshiny package in R to assess research trends, publication growth, and key knowledge gaps. Using relevant keywords and restricting results to Indian affiliations, we identified 353 publications after applying PRISMA-based screening criteria. Our findings show that nearly one-third of these were non-primary studies. Among research articles, only 71 examined the responses of marine organisms to ocean acidification. Most studies focused on single stressors, short-term experiments, and a narrow range of species. Critical gaps include limited molecular-level investigations, lack of multifactorial approaches, and insufficient long-term studies. This analysis provides a consolidated overview of ocean acidification research in India and offers insights to support researchers and policymakers in developing future research priorities and effective adaptation strategies.

Tipping points beyond single stressors: spring floods advance hypo-salinity vulnerability thresholds in subarctic estuarine molluscs

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4B: Beyond tipping points, Rongomātāne B, October 14, 2026, 16:00 - 18:00

Subarctic estuaries receive turbid, acidic freshwater pulses each spring, intensified by catchment-level deforestation, agriculture and soil erosion. These disturbances will grow more frequent as climate change intensifies the hydrological cycle. However, these multi-stressor realities are rarely considered when identifying environmental thresholds, which are often derived from single-stressor studies. Using a gradient-based laboratory approach, we exposed three dominant mollusc species from subarctic estuaries (*Littorina saxatilis*, *Macoma balthica*, and *Mytilus spp.*) to freshwater pulses of increasing duration (0–9 d), either alone (pH 7.7, turbidity 0 mg L⁻¹) or combined with simulated spring flood conditions (pH 5.7, turbidity 325 mg L⁻¹), over five weeks. Shell dissolution and strength (the latter only on *M. balthica* and *Mytilus spp.*) were measured after 2.5 and 5 weeks.

The co-occurrence of multiple spring flood-associated stressors consistently amplified the negative effects of hypoosmotic stress across all species. Spring flood conditions lowered mortality thresholds across all three species, unveiling new thresholds for *M. balthica* and *Mytilus spp.* and shorter pulse tolerance in *L. saxatilis*. All three tolerated pulses shorter than 3 d only under non-spring flood conditions. Shell dissolution increased under spring flood conditions only in *L. saxatilis*, particularly with longer pulse durations, while only *Mytilus spp.* shells weakened structurally after five weeks despite no detectable external dissolution.

These findings demonstrate that tipping points are highly context-dependent and occur at lower stress levels when co-occurring stressors are considered, underscoring the need to manage catchment-level land use and erosion to preserve estuarine biodiversity under intensifying climate change.

Ocean acidification monitoring in Suva harbor, Fiji

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¹Pacific Community, Suva, Fiji

4B: Beyond tipping points, Rongomātāne B, October 14, 2026, 16:00 - 18:00

Coral reef health underpins food security and livelihoods for many Pacific Island communities, yet ocean acidification (OA) increasingly threatens these systems. While the Pacific is highly vulnerable, long term carbonate chemistry observations remain limited. In response, Fiji established an ocean acidification monitoring program in 2022, with support from the Pacific Islands Ocean Acidification Centre (PIOAC), to better understand local OA conditions in Suva Harbour.

The program is led by the Pacific Community, with monitoring activities carried out following the Practical Best Practices guide for ocean acidification research using the Global Ocean Acidification Observing Network (GOA ON) in a Box kit. The program is designed to translate data into actionable knowledge by building in country capacity for sampling, data quality control, interpretation and reporting, and by engaging end users of the information

Preliminary results include the establishment of baseline OA conditions, improved understanding of site-specific variability, strengthen in country capacity for OA sampling, data quality control, and reporting. This presentation outlines the program's design and early outcomes, and discusses key challenges encountered during implementation and the approaches used to address them in order to sustain long term monitoring.

Time series of carbonate system variable in the coasts of Savaia and Mulinuu, Upolu Island, Samoa

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4B: Beyond tipping points, Rongomātāne B, October 14, 2026, 16:00 - 18:00

I will present an analysis of temporal variability in the carbonate chemistry of seawater in the coastal area within the Marine Protected Area of Savaia village, and of Mulinuu Apia, in Samoa. This study assesses total pH (pHT) and total alkalinity (AT) using data collected over the year 2020 and 2026 using methods in the guide to best practices for ocean CO₂ measurements. We are currently conducting seawater samples collection with data analysis for the 2026 data set finishing in September. We plan to analyze the data using a single anova test and linear model function to identify key correlations and confirm statistical significance. The preliminary analysis of the first set of data collected in 2020 for Savaia indicates a declining AT and corresponding low pHT in this area, which are likely due to nutrient and organic matter enrichment, and freshwater flow from small freshwater springs and rivers in the vicinity of the coastal area. These results raise the possibility of a potential source of acidification to downstream coastal ecosystems with potential implications for coral reefs, biodiversity and fishery livelihoods for these communities. Our ongoing ocean acidification monitoring and analysis of new data set will validate our findings from 2020 and contribute to a new time series of carbonate system for Samoa reef ecosystems.

Evaluating the effect of ocean alkalinity enhancement in natural phytoplankton communities of New Zealand.

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4C: Ocean solutions: Understanding ocean-based climate solutions: Ecological implications, monitoring needs, and financing pathways, Rongomātāne C, October 14, 2026, 16:00 - 18:00

Ocean alkalinity enhancement (OAE) has been proposed a low-risk marine carbon dioxide removal technique with benefits that include increasing the buffering capacity of the ocean and reducing ocean acidification. So far, most of the studies evaluating environmental impacts have focused on the addition of clean alkalinity at high concentration, but there are uncertainties on the potential negative effects of low alkalinity addition as well as of delivering alkalinity with nutrients. Here, we conducted three minicosm experiments using natural phytoplankton communities from two New Zealand regions to test the effect of two approaches for delivering alkalinity. Experiment one tested clean alkalinity addition (carbonate and bicarbonate) in coastal waters in Wellington at two levels: low (200 $\mu\text{mol kg}^{-1}$) and high (500 $\mu\text{mol kg}^{-1}$). Experiment two and three tested the combined and individual effect of nutrient addition (NO_3 and PO_4) and alkalinity enhancement (500 $\mu\text{mol kg}^{-1}$) in coastal and off-shore waters in Hawkes bay, simulating delivering alkalinity with sewage. All experiments were conducted at ambient temperature and light conditions over 7 days, with biomass, taxonomic community composition, community size structure and total DMSP assessed in all experiments. Additional C^{14} incubations for determination of net primary production were included in Minicosm 2 and 3. Preliminary results show no effect of alkalinity at low or high concentration in Chlorophyll- a and total DMSP production in Wellington coastal waters. Results from these experiments will inform biogeochemical models and provide advice for development of Environmental impact assessment framework in New Zealand

Sea urchin larval sensitivity to low pH varies among nearby seagrass meadows, highlighting the need for fine-scale monitoring

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4C: Ocean solutions: Understanding ocean-based climate solutions: Ecological implications, monitoring needs, and financing pathways, Rongomātāne C, October 14, 2026, 16:00 - 18:00

Ocean acidification is a major threat to marine ecosystems, with well-documented impacts on many species. Recent studies suggest that sensitivity to low pH is shaped by local adaptation and may be linked to the lowest pH conditions organisms naturally experience. We tested this hypothesis using larvae of the sea urchin *Tripneustes gratilla* from two neighbouring seagrass meadows at Inhaca Island (southern Mozambique): a subtidal site (EBMI) and an intertidal site (Banguá), which experience different pH regimes. Larvae were reared under four pH treatments (8.04, 7.67, 7.46, 7.29) for seven days. Lower pH negatively affected larval survival, growth, and symmetry. Unexpectedly, larvae from the intertidal site—where pH fluctuates more—were more sensitive to acidification than those from the more stable subtidal site. This suggests that tolerance mechanisms may differ between habitats and that exposure to variability does not always confer resilience. These findings challenge the assumption that physiological tipping points align with the lowest natural pH conditions and highlight the limits of this concept in highly variable environments. They also emphasize the importance of fine-scale monitoring to better understand local responses and inform conservation strategies.

Ocean Alkalinity Enhancement Pelagic Intercomparison Project (OAEPIIP): Results from the New Zealand Experiment

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4C: Ocean solutions: Understanding ocean-based climate solutions: Ecological implications, monitoring needs, and financing pathways, Rongomātāne C, October 14, 2026, 16:00 - 18:00

Ocean alkalinity enhancement (OAE) is a proposed carbon dioxide removal strategy that increases the ocean's capacity to absorb and store atmospheric CO₂. While promising, its potential impacts on marine ecosystems, including planktonic communities, remain poorly understood. Assessing these impacts is critical before OAE can be considered for safe and responsible large-scale deployment. The Ocean Alkalinity Enhancement Pelagic Intercomparison Project (OAEPIIP) is the first globally synchronised experimental study of its kind. Spanning 19 countries and a wide range of marine environments, the project runs standardised microcosm experiments to assess how plankton communities respond to equilibrated and unequilibrated OAE. By applying a common methodology, OAEPIIP enables direct comparison of studies from different regions and seasons, laying the foundation for a comprehensive global intercomparison analysis that no single-site study could achieve.

Here we present the results from the New Zealand OAEPIIP experiment, conducted in the waters of Otago Harbour, and discuss our findings in the context of results from the broader network of OAEPIIP experiments worldwide. Together, these results advance our collective understanding of how OAE may affect pelagic ecosystems across contrasting environments and seasons, moving us closer to an evidence-based global assessment of OAE as a viable and responsible climate intervention strategy.

Toward robust quantification of carbon uptake and CO₂ removal in seaweed ecosystems

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4C: Ocean solutions: Understanding ocean-based climate solutions: Ecological implications, monitoring needs, and financing pathways, Rongomātāne C, October 14, 2026, 16:00 - 18:00

Seaweed ecosystems are increasingly recognized for their potential contribution to carbon neutrality, driven by their high productivity and scalability through both restoration and aquaculture. Unlike other coastal vegetated ecosystems, seaweeds offer unique opportunities to achieve additional carbon uptake and removal. In this study, we present a methodological roadmap for quantifying carbon uptake and CO₂ removal in seaweed ecosystems. We synthesize existing approaches and propose efficient methods for estimating net primary productivity (NPP) and tracking long-term carbon storage. In addition, we outline complementary frameworks for estimating carbon dioxide removal, incorporating monitoring, reporting, and verification (MRV) strategies. By integrating methodological advances across biological, biogeochemical, and observational approaches, this roadmap provides a foundation for improving the accuracy, consistency, and comparability of seaweed carbon assessments. Furthermore, this framework supports the development of scientifically robust methodologies for evaluating the climate mitigation potential of seaweed ecosystems and their inclusion in carbon accounting and policy frameworks.

Spatial distribution of seawater pH and alkalinity across five sites on the North coast of Upolu, Samoa

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¹National University of Samoa, Apia, Samoa

4C: Ocean solutions: Understanding ocean-based climate solutions: Ecological implications, monitoring needs, and financing pathways, Rongomātāne C, October 14, 2026, 16:00 - 18:00

Ocean acidification, driven by the dissolution of approximately 30% of atmospheric carbon dioxide (CO₂) into seawater, poses a significant threat to marine ecosystems. This process reduces seawater pH and depletes carbonate ions essential for calcifying organisms such as corals. Despite its importance, the spatial variability of seawater carbonate chemistry in Pacific island coastal regions, including Samoa, remains poorly characterized.

To address this gap, this study investigated seawater carbonate chemistry at five sites along the north coast of Upolu Island, Samoa. Seawater pH was measured spectrophotometrically using m-cresol purple, while total alkalinity (AT) was determined through titration with standardized 0.101970 mol/kg HCl. Absorbance values at 730 nm (non-absorbing wavelength) and at 578 nm and 434 nm, corresponding to the base and acid forms of the indicator dye, together with electromotive force (EMF) values from titration, were used to calculate pH and AT.

Results indicate significant spatial variability across the sites. Mean pH values ranged from 7.944 ± 0.090 to 8.087 ± 0.069 , generally lower than the open ocean average of 8.1. In contrast, mean AT values remained within the normal range of 2100–2500 $\mu\text{mol kg}^{-1}$, suggesting relatively stable buffering capacity. These findings provide important baseline data for Samoa and highlight the need for continued monitoring to better understand coastal ocean acidification dynamics in small island environments.

Monitoring carbonate chemistry in coral restoration projects in Costa Rica

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4C: Ocean solutions: Understanding ocean-based climate solutions: Ecological implications, monitoring needs, and financing pathways, Rongomātāne C, October 14, 2026, 16:00 - 18:00

Tropical coral reefs face severe threats from ocean warming and acidification, yet baseline data on coastal carbonate chemistry remains scarce. To address this gap, the NGO Raising Coral Costa Rica (RCCR) and the University of Costa Rica (CIMAR-UCR) established a collaborative monitoring program in Golfo Dulce in August 2023. CIMAR-UCR analyzes samples and trains coral gardeners in sampling best practices, while RCCR integrates regular water sampling into their coral restoration activities. Over two years, 237 samples were collected across six sites at two depths, surface and close to the reef. Preliminary results reveal high local variability, with total alkalinity ranging from 1779.33 - 2341.16 $\mu\text{mol/kg}$ and dissolved inorganic carbon from 1566.48 - 2287.86 $\mu\text{mol/kg}$. Seasonal shifts (dry vs. rainy) and other local processes seem to drive variability in surface waters, while reef metabolism likely influences fluctuations near the coral reef. Understanding this variability will guide the seasonal timing of coral restoration activities, including new innovations such as assisted larval recruitment. Although monitoring programs are costly, the CIMAR-UCR / RCCR collaboration illustrates how such partnerships can streamline collection of environmental data that form the baseline for understanding long-term changes in carbonate chemistry.

Buffering capacity of *Ulva* sp. on oyster larval survival and development under enhanced alkalinity and elevated CO₂ conditions

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4C: Ocean solutions: Understanding ocean-based climate solutions: Ecological implications, monitoring needs, and financing pathways, Rongomātāne C, October 14, 2026, 16:00 - 18:00

Ocean acidification is adversely affecting the shellfish industry. In regions exposed to increasing CO₂, larval production is becoming challenging. It is necessary to develop mitigation strategies from the hatchery. Recent studies indicate that co-cultivating shellfish with algae may serve as a nature-based solution to buffer the effects of ocean acidification on shellfish productivity while enhancing the system's carbon sequestration capacity. Furthermore, global change is expected to increase the antioxidant activity of algae, thereby enhancing their potential for cosmeceutical production while supporting the circular bioeconomy. This study aimed to evaluate the effects of ocean acidification on egg fertilization, hatching, and larval development of the Portuguese oyster (*Magallana angulata*) when co-cultivated with the green macroalga *Ulva* sp. The study also examined whether polyphenol and protein concentrations, as well as the antioxidant activity of algae, varied under different CO₂ concentrations. After two hours of fertilization, the percentage of fertilized eggs was 10% lower under high CO₂ conditions compared to control oocytes. However, after nine days of exposure to varying CO₂ concentrations, no significant differences were observed in larval survival rates or in the phenolic compounds, protein content, and antioxidant activity of algae across treatments. Notably, larvae cultivated without algae exhibited the largest surface areas independently of the CO₂ concentration. These findings suggest that additional factors, such as the locally elevated total alkalinity of seawater, may exert a greater buffering effect on larval development under ocean acidification conditions than the presence of algae.

Physical-biological processes regulating summer sea-air CO₂ exchanges and marine carbonate system along the Drake Passage and northern Antarctic Peninsula

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4D: Modulating role of time, Mătiu, October 14, 2026, 16:00 - 18:00

The Southern Ocean plays a central role in regulating global carbon fluxes and buffering anthropogenic CO₂. However, the interplay between physical and biogeochemical processes controlling sea–air CO₂ exchange and carbonate system variability remains poorly constrained. The Drake Passage and the northern Antarctic Peninsula are key transition zones linking subantarctic and polar environments, where frontal systems, eddy activity, upwelling, and ice–ocean interactions generate strong spatial gradients in carbon dynamics. Here, we synthesize two companion studies investigating surface CO₂ variability and carbonate chemistry during the austral summer of 2019. Using high-resolution measurements of pCO₂, O₂, and hydrographic properties, we quantified air–sea CO₂ fluxes and assessed dominant physical–biological drivers. The Drake Passage acts as a weak net CO₂ source ($\sim 0.1 \text{ mmol m}^{-2} \text{ d}^{-1}$), with marked contrasts across fronts: north of the Polar Front, photosynthesis drives CO₂ uptake ($\sim -3 \text{ mmol m}^{-2} \text{ d}^{-1}$), whereas southward, respiration-driven outgassing prevails. In the northern Antarctic Peninsula, CO₂ exchange ranges from moderate outgassing ($\sim 1.3 \text{ mmol m}^{-2} \text{ d}^{-1}$) to strong uptake ($\sim -2.4 \text{ mmol m}^{-2} \text{ d}^{-1}$), modulated by sea-ice and glacial melt and elevated primary production. A pronounced outgassing event ($\sim 5 \text{ mmol m}^{-2} \text{ d}^{-1}$) associated with an anticyclonic eddy at the Antarctic Slope Front highlights the role of mesoscale processes. Upwelling of Circumpolar Deep Water increased pCO₂ ($> 400 \text{ } \mu\text{atm}$) and lowered pH (< 7.99), whereas photosynthesis and meltwater inputs reduced pCO₂ ($< 350 \text{ } \mu\text{atm}$) and increased pH (> 8.00) in coastal areas.

Dynamics of surface CO₂ in the equatorial Pacific from satellite remote sensing: from seasonal to interannual and decadal scales

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4D: Modulating role of time, Mătiu, October 14, 2026, 16:00 - 18:00

The equatorial Pacific is the largest oceanic source of CO₂ to the atmosphere, yet how its CO₂ dynamics respond to global change remains poorly constrained—particularly across the contrasting environment between the eastern upwelling region and the western warm pool. The Surface Ocean CO₂ Atlas (SOCAT) provides invaluable in situ measurements, yet its spatiotemporal coverage still limits the ability to resolve the CO₂ variability from seasonal to decadal scales. Here, we develop a novel algorithm to estimate sea surface partial pressure of CO₂ (pCO₂) from ocean color satellite (MODIS). Independent validation yields a root mean square error of 10 μatm and an R² of 0.94, demonstrating its robust retrieval accuracy. This high-performance data product allows, for the first time, a consistent investigation of pCO₂ dynamics across seasonal, interannual, and decadal timescales over the past two decades, providing new insights into the multi-scale variability of the CO₂ outgassing in this critical region.

One year of continuous pCO₂ measurements at the Antarctic glacier front: addressing a critical gap in Southern Ocean carbon budgets

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4D: Modulating role of time, Mătiu, October 14, 2026, 16:00 - 18:00

The coastal waters of the Antarctic Peninsula are among the most data-sparse regions in the global ocean carbon budget, especially at the interface between tidewater glaciers and the marine environment, where accelerating ice retreat is changing carbon cycling. Here we present the first year-round continuous record of dissolved carbon dioxide (CO₂) from a mooring deployed near Johnson Glacier (Livingston Island, South Shetland Islands), filling a critical temporal and geographic gap in Southern Ocean observations. The mooring, equipped with a SAMI-CO₂ sensor and a HydroCAT-EP multiparameter CTD, provided simultaneous high-resolution measurements of pCO₂, oxygen, chlorophyll, salinity, and temperature across a full annual cycle.

Data quality control followed QARTOD standards, and annual flux estimates were evaluated using Monte Carlo uncertainty propagation and multi-scenario sensitivity analysis with five established gas transfer velocity parameterizations, ensuring robust and reproducible results.

The site acts as a net annual CO₂ sink across all tested methods. A distinct austral spring bloom, confirmed by simultaneous oxygen supersaturation, causes significant seasonal biological CO₂ removal. Increased chlorophyll and turbidity signals during summer indicate that glacial meltwater fertilizes local phytoplankton growth with micronutrients, supporting carbon uptake beyond the initial bloom.

This dataset significantly adds to the limited collection of year-round air-sea CO₂ flux measurements in glacier-adjacent Antarctic regions, directly helping to improve understanding of Southern Ocean carbon budgets in the context of ongoing climate change.

How do nutrient stores and CO₂ levels affect diatom responses to warming?

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4D: Modulating role of time, Mătiu, October 14, 2026, 16:00 - 18:00

Diatom responses to warming have the potential to impact primary production both locally and globally. Here, we investigate how other environmental conditions that precede warming affect diatom responses to increases in temperature. In particular, we test the hypotheses that first, nutrient stores facilitate more rapid responses to warming and second, that additional CO₂ may mitigate the effects of low nutrient stores during warming responses. We varied the environment of the model diatom *Thalassiosira weissflogii* prior to warming by growing them at two temperatures (T) within their thermal niche, under either CO₂ limitation or saturation, and then manipulated internal nitrate stores (N) by controlled nitrate starvation. This produced populations under all combinations of environments (TxCO₂xN, 2x2x4), reflecting different environmental conditions that lead to differences in intracellular nitrate stores, and the ability to redirect energy by downregulating the carbon concentrating mechanism (CCM). These populations were then transferred to a stressful (above T_{opt}) higher-temperature environment. The main hypothesis we tested was whether elevated CO₂ reduced the need for the costly CCM, allowing the diatoms to reallocate resources towards nitrate acquisition, thereby offsetting some negative effects of low internal nitrate due to warmer environments. To capture how internal nitrate stores mediate phenotypic memory via transgenerational plasticity we estimated growth over the initial 48-hour period in the stressful warm environment, alongside reactive oxygen species production, lipid content, cell size, and particulate organic carbon and nitrogen content. We discuss how these initial constraints on acclimation could drive subsequent evolutionary responses, based on links to previous studies.

Seasonal Variability Dominates Spatial Patterns of Particulate Organic Carbon Export in the Southern Ocean

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4D: Modulating role of time, Mătiu, October 14, 2026, 16:00 - 18:00

The Southern Ocean is a key component of the global carbon cycle, yet large uncertainties persist in quantifying particulate organic carbon (POC) vertical flux and its variability. Here, we investigate whether temporal variability exerts a stronger control than basin-scale spatial gradients on POC export across the Southern Ocean. To address this, we combine multi-decadal sediment trap observations (1992–2013; 100–200 m; $n = 361$) with hydrographic data and outputs from state-of-the-art biogeochemical reanalyses (e.g., ECCO-Darwin). Our preliminary analyses of sediment trap data reveal a pronounced seasonal cycle in POC sinking (ANOVA, $F = 6.56$, $p < 0.001$), with fluxes ranging from 76 to 145 $\text{mg C m}^{-2} \text{ d}^{-1}$ and consistently higher values during austral spring and summer. In contrast, spatial differences along ocean basins are not statistically significant (Kruskal–Wallis, $H = 4.52$, $p\text{-value} = 0.11$), despite slightly higher mean fluxes in the Pacific (136.4 $\text{mg C m}^{-2} \text{ d}^{-1}$) and Atlantic (125.5 $\text{mg C m}^{-2} \text{ d}^{-1}$) in relation to the Indian sector (96.5 $\text{mg C m}^{-2} \text{ d}^{-1}$). These patterns may reflect regional differences in primary productivity and large-scale circulation, particularly the longer residence times and enhanced nutrient availability characteristic of Pacific waters. Overall, this indicates that temporal variability dominates over basin-scale spatial gradients in controlling carbon export, emphasizing the need for models to better resolve seasonal dynamics. The next steps include further investigating the role of physical drivers (e.g., mixed-layer depth variability and freshwater inputs from ice shelf melt) in modulating export efficiency using biogeochemical reanalyses.

Reconstructing the ocean carbon budget from observations with machine learning and an inverse method

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4D: Modulating role of time, Måti, October 14, 2026, 16:00 - 18:00

The ocean absorbs ~30% of anthropogenic CO₂ (Canth) emissions annually, mitigating atmospheric warming but driving ocean acidification that threatens marine ecosystems. This uptake is spatially uneven, and regions of carbon absorption differ from regions of storage due to ocean circulation redistributing carbon on multiyear timescales. However, direct observations of interior ocean Canth accumulation and surface pCO₂ - that constrains air-sea fluxes - remain sparse.

To address this, machine learning approaches can infer carbon distributions from better-observed proxies such as temperature and salinity, whose coverage has expanded rapidly through autonomous profiling floats (e.g., Argo) and remote sensing. Here, we present the application of the first global, full-depth, four-dimensional reconstruction of ocean interior carbon to investigate the ocean carbon budget. Our reconstructions use ResNet-DIC, a deep neural network trained to predict biogeochemical variables from temperature, salinity, location, depth, and atmospheric CO₂.

We reconstruct dissolved inorganic carbon (DIC), alkalinity, oxygen, and nitrate using shipboard and float-based observations from the GLODAP database. From these fields, we compute C*, a quasi-conservative tracer representing the preformed component of interior ocean carbon. We then integrate these reconstructions with a water-mass inverse model that simultaneously constrains heat, salt, and carbon budgets, diagnoses ocean circulation, and adjusts air–sea fluxes and interior changes for dynamical consistency.

Applying this framework to the 1990s and 2000s reveals that an increase in the global Canth sink was primarily driven by the North Pacific and Southern Ocean. Circulation changes diagnosed by the inverse model help explain the mechanisms underlying these decadal carbon budget shifts.

Resilience against the impacts of climate change in an ecologically and economically significant native oyster

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4D: Modulating role of time, Mătiu, October 14, 2026, 16:00 - 18:00

Climate change is acidifying and warming our oceans at an unprecedented rate posing a challenge for marine invertebrates vital across the globe for ecological services and food security. To survive in this changing ocean, marine organisms will need to improve their resilience. Unfortunately, for most marine organisms tested to date, resilience in one trait often comes at a “trade-off” in another. Attempts to breed resilience in the edible oyster, *Saccostrea glomerata* have come at a trade-off in their energy budget, with resilient oysters having lower metabolic scope. The aim of this study was to determine whether it is possible to breed resilience in *S. glomerata* to climate change, without detrimental trade-offs in their energy budget. We exposed 24 pair-mated genetically distinct families of *S. glomerata* to ocean acidification and warming for 4 weeks and measured their resilience. Resilience was identified as the capacity to defend their acid-base balance without a loss of energy available for Scope for Growth (SFG). Of the 24 families, 13 were better able to defend their acid-base balance while eight had no loss of energy availability with a positive SFG. This study has found oyster families with resilience against climate change without a loss of SFG, is an essential mitigation strategy, in a critical mollusc. Understanding instances of trade-offs in marine organisms that are resilient to climate change, and the capacity to overcome them, is an essential aspect to consider in aquaculture breeding programs.

Creating evidence for action: bridging knowledge gaps and identifying opportunities for ocean acidification in the United Kingdom

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4D: Modulating role of time, Mătiu, October 14, 2026, 16:00 - 18:00

Since its recognition by the United Nations as a global area of concern in 2005, Ocean Acidification (OA) has become an unavoidable subject within climate change research. Countries and organisations with the capacity to monitor carbonate chemistry (CC) have already detected OA signals in their waters. From monitoring by Plymouth Marine Laboratory (PML) since 2008, the UK has detected a decrease in pH up to the present day. Although temporally sound, this monitoring lacks spatial resolution, meaning that the true CC variation experienced by marine species is at risk of under-representation. As a substantial proportion of economic and social activities occur within a few nautical miles of the coast, it is imperative to understand the CC dynamics in these waters. From 2024-2025 water samples were collected from 7 intertidal and estuarine locations around the UK to monitor the CC in marine areas impacted most by land-use and human activity. Short-term seasonal pH profiles have been developed from these samples for comparison with the time-series data collected off-shore to understand how much CC variability the current monitoring is able to capture. Throughout 2026, UK marine user-groups identified as at risk from the effects of OA are being surveyed to understand their concerns and understanding of OA and their activities. Accompanying short-term OA mitigation experiments, the above research is being combined to propose a framework for an OA action plan for the UK Department for Environment, Food, and Rural Affairs to get monitoring and mitigation of OA recognised as a national responsibility.

Decadal Trends in Surface Ocean and Coastal Carbonate Chemistry from Time-Series Data: Insights into Drivers of Change

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4D: Modulating role of time, Mātiu, October 14, 2026, 16:00 - 18:00

The ocean absorbs a substantial fraction of anthropogenic CO₂ annually, driving long-term changes in surface carbonate chemistry. However, the magnitude and expression of these changes vary widely across regions because global forcing is modified by local processes such as ocean warming and biological activity. Here we synthesize decadal trends from 25 publicly available surface-ocean time series spanning open-ocean and coastal environments using a consistent best-practices trend framework. We quantify trends in seawater pCO₂, pH and hydrogen ion concentration on the total scale ([H⁺]_{total}), aragonite saturation state (Ω_{arag}), and dissolved inorganic carbon (DIC).

Open-ocean sites show trends relatively consistent with global mean trends and have relatively low variability, providing a solid baseline for comparison. In contrast, coastal systems exhibit substantially greater heterogeneity, including long-term trends that diverge from the global mean, suggesting strong local modulation. Furthermore, we find indications of decadal variability in long-term trends at sites with two or more decades of time series observations.

Ongoing work evaluates the sensitivity of decadal carbonate changes to potential drivers including rising CO₂, temperature, and freshwater shifts, providing a pathway to interpret regional departures from the global mean. These long-term observational constraints support improved monitoring and region-specific approaches to anticipating and managing ocean acidification in a high-CO₂ world. Determining the drivers of long-term surface carbon change is critical for understanding implications for species sensitive to ocean acidification, as local conditions may amplify or buffer biological exposure beyond global trends.

Bass Strait Ocean Alkalinity Enhancement Scenarios Reveal the Fate of Potential Carbon Uptake

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Poster Session 2, Exhibition Area, Level 1, October 14, 2026, 18:00 - 19:30

Ocean Alkalinity Enhancement (OAE) is a promising marine carbon dioxide removal (mCDR) method. While global ocean and Earth system models are necessary to track air-sea CO₂ equilibration and far-field alkalinity transport on extended timescales, OAE efficiency is strongly influenced by local oceanography and climate. Regional ocean modelling is a powerful tool for capturing the influence of these processes on near-field plume dispersion and CO₂ uptake. Here, using a 3-dimensional hydrodynamic-biogeochemical model (2 km), we evaluate the effects of deployment location and interannual climate on OAE in the Bass Strait, southeast Australia. We add 113.21 Gmol of alkalinity (theoretical uptake capacity of ~4.2 Mt CO₂) over one month, via four infrastructure-constrained pathways: desalination outfalls, shipping lanes, ferry tracks, and a series of coastal outfalls. These are repeated over three Southern Annular Mode (SAM) phase end-member winters: 2017 (positive SAM – low winds), 2021 (neutral SAM – moderate winds), and 2023 (negative SAM – strong winds). CO₂ uptake efficiency variability (mol CO₂/mol TA) is primarily influenced by delivery method and location (95.2 %) rather than by interannual climate variability (3.9 %). At the shelf-break, 70.67 ± 10.53 % of added alkalinity is subducted below the mixed layer before equilibration with the atmosphere. This reduces the realised CO₂ uptake and contributes to efficiencies (0.11–0.27) that are lower than those simulated by a global model in the same region (0.31). To resolve these scale-dependent mismatches, we recommend integrated monitoring, reporting, and verification frameworks of observational networks, regional models, and global models.

The Third Decadal U.S. Carbon Cycle Science Plan

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Poster Session 2, Exhibition Area, Level 1, October 14, 2026, 18:00 - 19:30

The U.S. Carbon Cycle Science Program (U.S. CCSP) is a community-focused program with a research portfolio that encompasses carbon and pertinent biogeochemical cycles across land, water, air, and society. Over the last three decades, the U.S. CCSP has led and coordinated community input from the U.S. and the international carbon cycle community and captured them in two seminal U.S. Carbon Cycle Science Plans (1999, 2011). The U.S. CCSP is now completing the development of an updated, new science plan for U.S. carbon cycle science, identifying challenges and priorities for the next decade (~2026-2035). The Third Decadal U.S. Carbon Cycle Science Plan will build on the two previous plans, identify new priorities and directions for the U.S. carbon cycle community and aim to increase engagement between the research, U.S. federal agency partners, and stakeholder communities. In this presentation, we will outline the overall scope and strategy for the plan, current status and allow the community to provide feedback on the first draft of the plan. We will also highlight steps that have been taken to capture the growing role of the private sector, the urgent need for decision-making support related to carbon management and lay out our vision for the next decade of U.S. carbon cycle science research.

Can Surface Salinity Predict Alkalinity in Data-Scarce Tropical Shelf Regions? A Western South Atlantic Case Study

Ms Manoela Barbosa de Oliveira¹, Dr Cíntia Albuquerque¹, Dr Raquel Oliveira², Dr Jannine M. Lencina-Avila¹, Mr Ricardo Keim¹, Ms Sabrina Santos¹, Prof. Dr. Luana Pinho¹, Prof. Dr. Leticia Cotrim da Cunha¹

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Poster Session 2, Exhibition Area, Level 1, October 14, 2026, 18:00 - 19:30

In the Western South Atlantic Ocean (WSAO), significant limitations remain in biogeochemical data availability to support the understanding of ocean acidification. In the WSAO, the availability of surface ocean physical data still exceeds the availability of ocean carbon data. Therefore, the main goal of this study was to predict the surface total alkalinity (TA) using SSS. The study area is the WSAO continental shelf off Rio de Janeiro (Brazil), using data collected during a cruise in austral Autumn (April 2025). Discrete surface water samples were analysed for TA, pH and nutrients (n=32), and SSS was measured underway using the ship's thermosalinograph (TSG). The measured TA ($\mu\text{mol kg}^{-1}$) range was 2332.16 to 2597.21 $\mu\text{mol kg}^{-1}$, with a median 2478,84 $\mu\text{mol kg}^{-1}$.

We found a separation between waters where SSS > 36.5 and SST > 25, and lower salinities and temperatures. The observed “in situ” TA-SSS correlation was poor i.e. $\text{TA} = 32.10 \cdot \text{SSS} + 1343.5$ ($r^2 = 0.095$), suggesting that there are other processes controlling TA in the area. When splitting these 2 “water masses” we found an empirical TA-SSS equation closer to the pre-existing regional model $\text{TA} = 63.15 \text{ SSS} + 57.67$ ($r^2 = 0.76$), but only for the cooler and less saline surface water.

These discrepancies highlight the need for more observations so that a robust climatology can be established. Continental shelf variability drivers such as seasonality, freshwater balance and upwelling should also be considered.

Carbonate system observations during a capacity-building expedition across the Tropical Atlantic (March 2025)

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Poster Session 2, Exhibition Area, Level 1, October 14, 2026, 18:00 - 19:30

Oceanographic training expeditions offer a unique opportunity to generate high-quality biogeochemical data in undersampled regions while simultaneously strengthening human capacity. During the Walvis Bay (Namibia) - Mindelo (Cape Verde) transit aboard the R/V OceanXplorer, conducted within the framework of the POGO OceanQuest OceanX Shipboard Training Fellowship, we leveraged an intensive training approach to produce new carbonate system observations across the eastern tropical Atlantic. A total of 16 oceanographic stations were sampled at ~250 nautical mile intervals, coordinated with the PACE satellite overpass. At 14 stations, seawater samples for total alkalinity (TA) and dissolved inorganic carbon (DIC) were collected and analyzed onboard using a LI-COR provided LI-5800A TA titrator and LI-5300A DIC analyzer, following best practices. Findings highlight the combined influence of water mass distribution and oxygen minimum zone conditions on carbonate system variability. This UN Ocean Decade aligned approach, centered on ECOP capacity exchange, demonstrates how opportunistic science embedded within training frameworks can significantly expand the spatial coverage of carbonate chemistry observations in data-sparse regions. ECOPs were actively engaged in end-to-end workflows, from sampling to data analysis, visualization and manuscript drafting, fostering expanded technical expertise in ocean acidification research. We advocate for integrating scientific data collection into training initiatives as a scalable strategy to accelerate global ocean observing efforts.

Nutrient-Activated Biochar Cultch: Improving Shellfish Larval Settlement and Habitat Resilience in British Columbia Under Combined Climate Stressors

Mr Bruce Bradley¹

¹BC Timber Goats, Kelp and Biochar, Campbell River, Canada

Poster Session 2, Exhibition Area, Level 1, October 14, 2026, 18:00 - 19:30

Coastal shellfish in North America, including Pacific oysters, geoducks, and scallops in British Columbia, face compounded threats from ocean acidification (OA), warming, and hypoxia, which impair larval settlement, shell formation, and recruitment success. Single-stressor studies often fail to capture these interactive effects, creating an urgent need for practical, field-applicable resilience strategies.

We describe a novel functionally activated biochar produced from local forest residues in a flame-cap kiln and soaked in a marine nutrient solution of homemade seaweed extract (Bee Sea Kelp), saltwater, nigari (magnesium-rich bittern), and sea calcium by-products from sea salt production. Microscopic analysis shows dense microbial biofilms and distinct nutrient–calcium–magnesium signatures within the high-porosity capillary network, enabling slow-release nutrients and complex microhabitats.

Supporting the 2025 North Island College Biochar Kelp Growth Report, which found faster sporophyte establishment and larger early gametophyte sizes with similarly nutrient-loaded biochar compared to controls, we hypothesize enhanced biofilm-mediated settlement cues will improve spat retention and juvenile performance when deployed as loose-packed cultch in scallop lanterns or low-rate (1–3% volume) sediment amendments in post-harvest geoduck beds.

Conclusions: This circular innovation integrates forestry and aquaculture wastes to mitigate multiple stressors—promoting oxygenating microbes (hypoxia), buffering pH and supporting calcification (OA), and delivering biostimulants (warming)—while advancing blue-carbon sequestration and restorative aquaculture. Small-scale field trials will quantify settlement rates, growth, and sediment biogeochemistry, offering a scalable tool for sustainable shellfish management under high-CO₂ conditions.

Incubation-derived Biogeochemical Fluxes of Macrophytes: Implications for Seaweed Aquaculture Carbon Sequestration

Ms Cheyenne Bridge¹, Dr. Lihini Aluwihare¹, Dr. Satoshi Mitarai², Dr. Reggie Spaulding⁴, Ms. Tran Nguyen¹, Dr. Loretta Roberson³, Dr. Brandon Stephens⁵, Dr. Adrienne Sutton⁶, Dr Yuna Zayasu¹, Dr Andreas Andersson¹

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Seaweed aquaculture has been proposed as a scalable carbon dioxide removal (CDR) strategy and as a means of locally mitigating ocean acidification (OA) and deoxygenation. However, the diversity in biogeochemical fluxes across species remains poorly characterized, yet determines CDR efficacy, OA/deoxygenation mitigation, and ecosystem effects. Using bottle incubations with five Okinawan macrophytes: cultivated and wild mozuku (*Cladosiphon okamuranus*), sea grapes (*Caulerpa lentillifera*), sea lettuce (*Ulva* sp.), and seagrass (*Thalassia hemprichii*), we quantified dissolved oxygen, carbon, and inorganic nutrient fluxes in 9-hour light and dark experiments. All species were net carbon sinks and net oxygen producers on diel timescales. Daytime net primary production (NPP) ranged from 8–119 $\mu\text{mol gDW}^{-1} \text{ h}^{-1}$ and nighttime NPP ranged from -4–-18 $\mu\text{mol gDW}^{-1} \text{ h}^{-1}$, resulting in NPPlight:NPPdark ratios of 2–10, indicating substantial variability in local OA and deoxygenation mitigation potential. Consistent with the overflow hypotheses, more productive/N-limited species released more dissolved organic carbon (DOC), yielding light DOC release rates of 1–25 $\mu\text{mol gDW}^{-1} \text{ h}^{-1}$ and percent extracellular release (PER) of 1–25% of GPP; dark DOC release was similar across most species. Percent recalcitrant DOC (RDOC) production in dark incubations ranged from 14–60%. Extrapolating these rates, RDOC production over a five-month cultivation period was comparable to or exceeded sequestration via sinking, demonstrating that seaweed cultivated for food or biomass retains meaningful carbon sequestration potential. These findings highlight key parameters: PER, %RDOC, NPPlight:NPPdark, NPP:nutrient-uptake, displaying species' variability in biogeochemical cycling and suitability for carbon sequestration, local OA/deoxygenation mitigation, and minimizing ecosystem effects.

Survival and lipid content of *Calanus pacificus* under dynamic Ocean Alkalinity Enhancement exposure scenarios

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Ocean Alkalinity Enhancement (OAE) sequesters atmospheric CO₂ and mitigates localized ocean acidification by increasing total alkalinity (TA). Following TA addition, carbonate chemistry evolves dynamically. Consequently, organisms experience temporally structured conditions—an initial elevated pH "overshoot" phase followed by a stabilizing "variable" phase—rather than a single equilibrium state. Because OAE's impact on zooplankton remains understudied, we assessed its effects on the mortality and lipid content of *Calanus pacificus* copepodites (stage CV). We conducted two independent experiments simulating the (A) overshoot (8 days) and (B) variable (4 days) phases. Copepods were exposed to ambient seawater (control) and two OAE treatments with increasing TA concentrations (TA₁, TA₂). Surviving overshoot copepods were preserved for lipid extraction. Results showed negligible mortality during the variable phase across all treatments. In contrast, the overshoot phase significantly increased mortality risk in both TA₁ (Hazard Ratio=2.79, p<0.05) and TA₂ (HR=3.00, p<0.05) relative to controls. Mortality dynamics were non-linear and dose-dependent: TA₁ caused an early hazard peak (day 1.75), whereas TA₂ induced a delayed peak (day 6.51), indicating mortality under highly elevated alkalinity is driven by cumulative physiological stress rather than immediate chemical shock. Furthermore, no significant differences in lipid content were observed among treatments. These findings highlight that acute biological responses to OAE depend heavily on exposure trajectories, underscoring the need to account for dynamic carbonate chemistry when evaluating the ecological risks of marine carbon dioxide removal.

Red Seaweed Aquaculture in a Changing Ocean: Growth and Biochemical Responses to Ocean Acidification

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Ocean acidification (OA), driven by rising atmospheric CO₂ concentrations, is expected to alter the physiology and productivity of marine macroalgae, with important implications for aquaculture. High-value red seaweeds such as *Palmaria palmata* and *Chondrus crispus* are widely cultivated for food and phycocolloid industries, yet their responses to near-future OA conditions remain insufficiently understood.

This study investigates the effects of projected OA scenarios on the performance of *P. palmata* and *C. crispus* under controlled aquaculture conditions. We expose both species to current and future projected pCO₂ concentrations representative of current and future oceanic pH levels, and measure a range of physiological and biochemical parameters including growth rates, photosynthetic performance, pigment composition, and fatty acid profiles.

By integrating these metrics, we aim to evaluate species-specific sensitivities and potential shifts in biomass quality under acidified conditions, considering the impacts on of OA on both productivity but also the nutritional and commercial value of these economically important seaweeds. The findings are expected to inform sustainable aquaculture practices including long-term, strategic investments, as well as contribute to predicting the resilience of red seaweed cultivation in a changing ocean.

Seagrass-Derived DOC Enhances Bacterial Growth and Reveals a Potential RDOC Carbon Sink

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Seagrass ecosystems are important coastal carbon sinks, yet the contribution of seagrass-derived dissolved organic carbon (DOC) to microbial processes and long-term carbon sequestration remains poorly constrained. We conducted diel incubation experiments in Penghu, Taiwan, to examine bacterial dynamics associated with two seagrass species, *Halodule uninervis* and *Halophila ovalis*, compared to unvegetated sandy sediments.

Bacterial abundance showed no significant difference between seagrass treatments (1.13 ± 0.30 and $0.94 \pm 0.40 \times 10^5$ cells mL⁻¹) and the bare sand control ($1.16 \pm 0.31 \times 10^5$ cells mL⁻¹). In contrast, bacterial production was significantly higher in seagrass treatments (100 ± 23 and 88 ± 31 mg C m⁻³ d⁻¹) than in the sand group (57 ± 23 mg C m⁻³ d⁻¹), resulting in approximately twofold higher bacterial specific growth rates (4.62 ± 1.09 and 4.96 ± 1.47 d⁻¹ vs. 2.40 ± 0.76 d⁻¹). Growth rates peaked at midday, indicating strong coupling to photosynthetically derived organic carbon, yet no diel variation in abundance was observed, suggesting regulation by viral lysis and grazing.

Based on bacterial carbon demand, DOC release rates were estimated as 179.5 and 121.9 µg C shoot⁻¹ d⁻¹ for *H. uninervis* and *H. ovalis*, respectively. Scaling to a density of one shoot per 10 cm² yields refractory DOC (RDOC) sequestration potentials of -12.0 and -8.15 tCO₂e ha⁻¹ yr⁻¹. These values are comparable to traditional sediment-based estimates, suggesting that DOC-mediated pathways may represent a substantial, previously overlooked component of seagrass blue carbon.

Metabolic Dynamics of an Offshore Coral Reef in the Central Red Sea: Observations from Autonomous Sensors

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Coral reefs are on the front line of climate change, exposed simultaneously to ocean warming, acidification, deoxygenation, and intensifying local stressors. Yet our ability to assess how reefs are functioning in a high-CO₂ world remains limited by monitoring approaches that often capture reef condition visually or at discrete moments in time. Because ocean acidification directly alters the carbonate chemistry that governs coral calcification, reef persistence depends not only on what reefs look like, but on whether they continue to produce, calcify, and maintain carbonate structure over time.

This work presents a new autonomous biogeochemical observing approach to examine reef metabolism on an offshore coral reef in the central Red Sea, a naturally warm and saline region often considered an analogue for future ocean conditions. We report the first multi-month deployment of an autonomous standalone total alkalinity sensor on a coral reef, integrated with autonomous pH, pCO₂, and dissolved oxygen measurements across contrasting back-reef and fore-reef environments. These high-frequency observations reveal dynamic diel variability and distinct metabolic signatures between reef habitats, reflecting differences in benthic communities, hydrodynamic exposure, phase shifts, and biological control of carbonate chemistry.

By resolving carbonate system variability at timescales inaccessible to traditional sampling, this work demonstrates how autonomous sensor networks can improve our understanding of reef function under acidification and climate stress. The results provide an important baseline for Red Sea reef metabolism and highlight the role of emerging technologies in tracking whether coral reefs can continue to grow, calcify, and persist in a rapidly changing ocean.

Bayesian modelling of growth phase transitions in phytoplankton cultures

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In multi-driver phytoplankton growth experiments, chlorophyll concentration is commonly measured over time as a proxy for biomass, facilitating the characterisation of population dynamics under varying environmental conditions. These dynamics typically follow a multi-phase growth structure: a lag phase of physiological acclimation to new environmental conditions, an exponential phase with an approximately constant specific growth rate, and a deceleration leading to a slow-growth and/or stationary phase. Identification of the exponential growth phase and estimation of the growth rate are of key interest and are often done via manual identification of a change in the log-linear slope. However, in some cases, it is unclear whether to include or exclude points near the beginning or end of the exponential phase, and the choices made can affect both the precision and accuracy of the estimated growth rate. We propose a Bayesian modelling framework for automated identification of phase transitions in phytoplankton growth curves. The model is based on smooth transitions in growth rates between phases, which is a realistic representation of underlying dynamics. The model jointly estimates phase-specific growth rates and phase durations using all data, avoiding the need for manual selection and enabling automated analysis of large numbers of growth curves. This allows us to answer the key question, “How fast did they grow?”, in a consistent and reproducible manner, while also providing secondary information on phase duration and growth rates during slow-growth phases.

Nitrogen-Driven Changes in Internal C:N Stoichiometry Influence Organic Carbon Release and Ocean Acidification Responses in the Giant Kelp *Macrocystis pyrifera*

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Kelp forests are among the most productive coastal ecosystems and play a fundamental role in global carbon cycling through high rates of dissolved inorganic carbon uptake. However, the fate of this fixed carbon remains poorly understood, particularly the physiological mechanisms regulating dissolved organic carbon (DOC) release. Nitrogen availability influences internal C:N, thereby regulating carbon allocation. Here, we investigate whether nitrogen-driven changes in internal C:N influence the physiological response of *Macrocystis pyrifera* to elevated CO₂ and regulate DOC release. We evaluate how contrasting nitrogen availability modifies carbon assimilation, DOC release, and photosynthetic and respiration rates under ambient (400 µatm; pH 7.9) and elevated CO₂ (1200 µatm; pH 7.6). Juvenile sporophytes from populations with contrasting life-history strategies (perennial and annual), previously acclimated for three months under common-garden conditions, were exposed to N-limited and N-sufficient treatments for 10 days. Our preliminary results indicate that both respiration and photosynthetic rates increased under N-sufficient conditions at elevated CO₂ compared with N-limited treatments and ambient CO₂, regardless of population origin. Nevertheless, annual populations consistently exhibited higher carbon assimilation rates than perennial, suggesting population-specific differences in carbon metabolism. Ongoing analyses of DOC release and internal C:N and nitrate and ammonium internal pools will determine whether enhanced carbon assimilation under elevated CO₂ and N-sufficient is accompanied by greater DOC release or increased carbon storage. These findings will provide new mechanistic insights into how nutrient availability regulates carbon allocation in kelps and will improve our understanding of the role of giant kelp forests in coastal carbon cycling.

Breaking Bad Curves: ocean acidification shifts multiomics dose responses to a pollutant in an Arctic copepod

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Rising atmospheric CO₂ leads to ocean acidification (OA), with rates that vary across regions. The Arctic Ocean is acidifying particularly rapidly due to enhanced CO₂ uptake, cold waters, reduced sea ice cover, and increased freshwater input. Simultaneously, Arctic waters are contaminated by polycyclic aromatic hydrocarbons (PAHs), a problem that is expected to intensify with expanding marine traffic and oil industries. When combined, multiple stressors arising from global changes may interact, causing additive, synergistic or antagonistic effects. We investigated whether OA alters the response of cold-adapted species to pyrene, a PAH. We focused on the Arctic shelf copepod *Calanus glacialis*, due to its central ecological role and its high lipid content, which may facilitate bioaccumulation of lipophilic contaminants such as PAHs. We characterised the lipidome, metabolome and metabolic rates of stage CIV copepodids exposed for seven days to a pyrene gradient (0, 10, 100 and 200 nM) under present-day versus future OA conditions. At the whole-organism level, exposure to treatments did not cause acute mortality or affect oxygen consumption, yet it triggered sublethal molecular changes. At the present-day pH, only the highest pyrene dose elicited a molecular response. Conversely, this molecular response was induced at even lower doses under future OA conditions, while metabolite-lipid connectivity was altered. By potentially increasing zooplankton sensitivity to pollutants, OA may have cascading effects on Arctic trophic webs. Our findings highlight the need to integrate multistressor and multiomics perspectives to identify actionable molecular biomarkers and align conservation practices to species-specific biology in a changing ocean.

Bioturbation is a key driver influencing alkalinity release from coastal and shelf sediments

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The ocean's alkalinity balance regulates atmospheric CO₂ concentrations, with coastal and shelf sediments contributing about 40% of the global oceanic alkalinity input. The main processes generating net alkalinity in these sediments are the dissolution of calcium carbonate (CaCO₃) and precipitation and burial of pyrite (FeS₂), which occur in geochemically distinct environments. Dissolution of CaCO₃ takes place in oxygenated, surficial sediments, while FeS₂ precipitation occurs in deeper, anoxic layers. Both CaCO₃ dissolution and FeS₂ precipitation are influenced by bioturbation, the mixing and flushing of sediments by animals. While bioturbation can enhance CaCO₃ dissolution by increasing the O₂ availability in the sediment, O₂ introduced to anoxic layers can reoxidise FeS₂ and consume alkalinity. However, the overall impact of bioturbation on net alkalinity production via these opposing mechanisms remains unclear.

Here, we investigated alkalinity generation in sediments with and without bioturbation. To this end, we took advantage of a unique coastal site: the Blakeney salt marshes (Norfolk, UK), where ponds with and without bioturbation occur naturally a few meters apart. While bioturbation substantially decreased the burial of FeS₂, the ponds with bioturbation often showed the highest alkalinity effluxes, likely due to CaCO₃ dissolution. Additionally, the presence of O₂-producing benthic microalgae and the production rate of reduced compounds – factors affected by bioturbation – influenced the alkalinity release. Hence, shifts in benthic faunal communities can greatly impact alkalinity generation in coastal sediments and should be considered when evaluating how environmental changes affect marine carbon sequestration.

Quantifying farmed kelp atmospheric carbon dioxide uptake and release through localized air-sea flux measurements in the Northern Gulf of Alaska

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Farmed kelp has been proposed as an ecosystem-based tool to enhance coastal carbon sinks and locally buffer ocean acidification, yet quantitative constraints on how kelp farms alter air–sea CO₂ exchange remain limited, particularly in high-latitude systems. We quantified hourly air–sea CO₂ fluxes (FCO₂) across the 2023–2024 growing season at two commercial kelp farms in the Northern Gulf of Alaska (Kalsin Bay, Kodiak, Alaska, and Windy Bay, Cordova, Alaska) using paired “inside” (within farm) and “outside” (upstream reference) moorings at ~3 m depth. Sensor arrays measured pH or pCO₂, temperature, salinity, and oxygen from winter seed-line outplanting through spring harvest. Both bays transitioned from wintertime net heterotrophy and CO₂ efflux to springtime net autotrophy and CO₂ uptake, but the farm effect on cumulative FCO₂ was strongly site-specific. In Windy Bay, the farm slightly enhanced net atmospheric CO₂ drawdown (net integrated farm signal: $-9.2 \pm 3.6 \text{ mol m}^{-2}$). In contrast, in Kalsin Bay the farm reversed the natural sink and became a net source, releasing $800.1 \pm 145.8 \text{ mmol m}^{-2}$ over the deployment, largely via biological modification of DIC, including respiration associated with early-season biofilms on farm structures. Aragonite saturation remained mostly above 1, but kelp presence reduced Ω_{arag} inside farms at times, underscoring complex, non-uniform OA effects. These results demonstrate that kelp mariculture does not universally function as a CO₂ sink or OA refuge and underscore the need for site-specific evaluation when incorporating kelp farms into coastal carbon management and ocean acidification mitigation strategies.

Effects of ocean warming and acidification on an ecologically important echinoderm in its southernmost distribution limit

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The sea urchin *Loxechinus albus* is a benthic coastal herbivore and represents one of the exploited natural marine resources in southern South America. Here, we evaluated the effects of ocean warming (OW) and acidification (OA) on small adults of this species. Forty-eight individuals were exposed to two temperatures (~ 6 and ~ 9 °C) and two pCO₂ levels (~ 400 and ~ 1200 μ atm), corresponding to present-day and near-future conditions, in a full-factorial design. After two months, we estimated self-righting success and time, as the ability and time required for each urchin in each treatment to fully return to its normal upright position when placed upside down. We quantified the grazing rate as the amount of *Macrocystis pyrifera*. consumed by each urchin over the entire exposure period, and also the force required to cause failure of the urchins' structural integrity. The self-righting success rate was consistently >65% and differed significantly across temperatures, with higher values at near-future temperatures. However, among individuals that self-righted, faster self-righting times were observed at present-day temperatures. Grazing rate increased with near-future temperatures. No significant effects of pCO₂ alone or the interaction between factors were observed on any of these traits. Moreover, the 2-month exposure period was insufficient to detect changes in the test structural integrity associated with temperatures, pCO₂ levels, or their interaction. Overall, these results indicate that OW, rather than OA, may disrupt certain species' traits, with potential ecological and economic consequences for local fisheries.

The Surface Ocean-Lower Atmosphere Study (SOLAS) 3.0: from science towards solutions

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The Surface Ocean-Lower Atmosphere Study (SOLAS) has spent two decades at the forefront of international research, coordinating the atmospheric and oceanographic communities to quantify the biogeochemical-physical interactions at the air-sea interface. Formally launched in 2004, SOLAS has evolved into a global network of thousands of scientists across 34 countries, providing the essential expertise required to understand how the air-sea coupled system regulates and is regulated by the Earth's climate. As the project enters its third decade, the SOLAS 3.0 Science Plan (2026–2035) marks a strategic evolution from pure discovery science toward societal impact. While maintaining its core commitment to fundamental process studies—specifically focusing on long-term trends and extreme events—SOLAS 3.0 introduces an expanded mandate. This new phase aims to leverage air-sea expertise to provide a balanced, scientific assessment of the feasibility and effectiveness of climate and environmental solutions. Central to this mission is a renewed focus on community and skill development. SOLAS 3.0 seeks to educate, engage, and connect the next generation of ocean-atmosphere researchers, advocate for equitable access to data and tools, and promote the integration and global coordination of science across the air-sea interface.

The effects of marine carbon dioxide removal (mCDR) carbonate chemistry conditions on zoea stage Dungeness crab (*Metacarcinus magister*)

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Marine carbon dioxide removal (mCDR) encompasses a suite of climate change mitigation strategies to enhance carbon dioxide sequestration. Data on how marine organisms respond to the high pH/low pCO₂ conditions that can be created by mCDR activities is limited. We conducted a set of experiments exposing Dungeness crab (*Metacarcinus magister*) zoea to high alkalinity or low pCO₂ conditions to evaluate effects on survival, behavior and development rate. In one experiment, we estimated the Lethal Concentration 50 (LC50) for NaOH (i.e., the NaOH concentration at which 50% of the organisms died). Zoeal mortality and abnormal behavior were evaluated daily for three days. The LC50 NaOH level was ~60 mmol/kg, which is higher than would typically be generated by mCDR activities and at a level that led to precipitation of brucite and calcium carbonate, with complex equilibrium dynamics. The fraction of zoea displaying “functionally dead” behavior was substantially elevated above 5 mmol/kg NaOH. In a second experiment we explored less extreme treatments than the LC50 study and manipulated both alkalinity (NaOH or HCl addition) and pCO₂ levels. During 33 day exposures, we observed only very weak effects of the carbonate chemistry conditions on zoea survival and molting rates. Overall, the experiments suggest that mCDR-driven carbonate chemistry changes would have little effect on acute or moderate-term survival of Dungeness crab zoea. Additional research is needed to evaluate sublethal effects or responses under different chemistry conditions expected with mCDR.

Environmental variability in pH and temperature drives reef carbonate dynamics in the Mexican Caribbean

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Coral reefs face increasing stressors such as ocean acidification and warming, but their combined effects in natural settings are not well understood. Here, we examine a natural climate variability system in the Puerto Morelos Reef System (Mexican Caribbean), where submarine groundwater discharges create strong pH and temperature gradients, to assess how environmental changes influence reef carbonate processes.

We integrated high-frequency (hourly) pH and temperature monitoring from 2020 to 2022 with in situ measurements of coral and crustose coralline algae (CCA) calcification, along with macro- and microbioerosion across backreef and forereef zones. Discrete seawater samples helped define the carbonate system (DIC, TA, Ω_{ar}) and calibrate pH loggers. The backreef showed significantly greater variability in pH and temperature on diel to seasonal timescales, driven by groundwater input, limited circulation, and benthic metabolism. Despite these fluctuating conditions, both coral and CCA exhibited higher calcification rates in the backreef compared to the forereef, indicating local adaptation or tolerance to environmental fluctuations. However, this zone also experienced significantly increased macrobioerosion, while microbioerosion levels remained similar between zones. These findings reveal a dynamic balance between carbonate production and erosion, where increased calcification under variable conditions may be countered by heightened bioerosion. Under future stress events like bleaching or disease-induced mortality, this balance could shift toward net erosion. Our results underscore the value of high-resolution biogeochemical monitoring combined with process-based measurements in understanding and predicting reef responses to multiple stressors in natural ecosystems.

Impact of improved Marine Atmospheric Boundary CO₂ measurement on regional sea-air CO₂ fluxes

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The $\Delta p\text{CO}_2$ in the open ocean can fluctuate by $\pm 200 \mu\text{atm}$, yet a disequilibrium of just 7–14 μatm is enough to drive the annual sequestration of 2.5 billion tons of anthropogenic carbon. Capturing this subtle difference requires highly precise, high-resolution measurements of both oceanic and atmospheric $p\text{CO}_2$. While most sea-air CO₂ flux estimates use the smoothed zonally resolved Global View Marine Boundary Layer (GV_MBL) product extracted from a smooth curve fitted to actual data, this proxy does not reflect the local variability of the marine boundary layer, resulting in regional flux biases. Furthermore, enhanced shipboard measurements can support atmospheric inverse modeling by filling data gaps in under-sampled regions. Here, we evaluate the current and potential state and accuracy of ship-based atmospheric CO₂ data and describe a new quality control method tested on SOCONET platforms that have the potential to improve the regional sea-air CO₂ fluxes.

Genetics and ontogeny are key factors influencing thermal resilience in a culturally and economically important bivalve

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Increasing seawater temperatures coupled with intense and frequent heatwaves pose an increasing threat to marine species. In this study, the New Zealand mussel, *Perna canaliculus*, was used to investigate the effect of genetics and ontogeny on thermal resilience. Six selectively-bred families and four different ages, from juveniles (6, 8, 10 weeks post-fertilisation) to sub-adults (52 weeks post-fertilisation), were used for experimentation. At each age, each family was exposed to a three-hour heat challenge, followed by recovery, and survival assessments. Gill samples from sub-adults were collected to quantify hsp70 gene expression. Results showed that genetics, ontogeny and size influence thermal resilience in *P. canaliculus*, with LT50 values between 31.3-34.4°C for all studied families and ages. Juveniles showed greater thermotolerance compared to sub-adults, while the largest individuals within each family/age class tended to be more heat sensitive than their siblings. Sub-adults differentially upregulated hsp70 in a pattern that broadly correlated to net family survival following heat challenge, reinforcing the perceived role of inducible HSP70 protein in molluscs. This study provides insights into the complex interactions of age and genotype in determining heat tolerance of a key mussel species. As marine temperatures increase, equally complex selection pressure responses may therefore occur in the wild.

A decade-long reconstructed pH time series at the Strait of Gibraltar: gap-filling strategies for continuous ocean acidification monitoring

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Mooring sensors have proven essential for long-term monitoring of seawater carbonate chemistry, yet logistical constraints on instrument deployment and recovery routinely introduce temporal gaps that fragment the record and complicate trend detection and seasonal analysis.

Here, we address this challenge using data from the GIFT mooring, located at Cape Spartel at the Atlantic entrance to the Strait of Gibraltar, a dynamically active site where Atlantic and Mediterranean water masses interact, producing strong thermohaline variability on tidal, seasonal, and interannual timescales.

The mooring has recorded seawater pH, temperature, and salinity since 2012, making it one of the longest continuous sub-surface records of the carbonate system in this strategically important region. However, intermittent sensor gaps reduce the effective temporal coverage, limiting the ability to identify multi-year acidification trends and biological-physical interactions.

We apply a data-driven reconstruction method that uses the co-variability between pH and related hydrographic variables to fill the gaps in a gapless hourly pH time series spanning 2012–2025.

The reconstructed record captures the complete seasonal cycle, tidal modulation, and interannual variability typical of the Strait of Gibraltar while preserving the statistical properties of the observations. Validation techniques show the reliability of this approach through different gap lengths and hydrographic conditions. The resulting continuous time series shows a significant long-term acidification trend, consistent with anthropogenic CO₂ absorption, and highlights episodic anomalies linked to Mediterranean Outflow Water dynamics.

This work emphasizes the importance of gap-filling methods to maximize the scientific value of existing mooring infrastructure for ocean acidification monitoring.

Long-Term pH Trends and Spatiotemporal Variability of the Carbonate System in Jakarta Bay

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Poster Session 2, Exhibition Area, Level 1, October 14, 2026, 18:00 - 19:30

Jakarta Bay, a densely populated and industrialized coastal area, faces significant environmental pressures from organic pollution and nutrient inflow. To assess ecosystem health, we investigated the spatiotemporal variability of the carbonate system (pH, pCO₂, total alkalinity, and dissolved inorganic carbon) during rainy and dry seasons in 2023, complemented by pH trend data (2011–2023) from DLH DKI Jakarta. Results show that during the southeast monsoon, pH reached its lowest values (mean 8.06 ± 0.43), coinciding with reduced alkalinity and elevated pCO₂ and DIC. Spatially, pH increased seaward while pCO₂, alkalinity, and DIC decreased. Long-term analysis revealed a slight but statistically insignificant upward trend in pH, reflecting strong variability driven by local biogeochemical and physical processes. Semi-enclosed hydrodynamics and continuous nutrient inputs from rivers further modulate carbonate balance. These findings underscore the complex interplay of anthropogenic and natural drivers shaping carbonate chemistry in Jakarta Bay, with implications for monitoring and management of vulnerable tropical coastal ecosystems.

New Caledonian Large Benthic Foraminiferal S/Ca signatures as sulfate seawater proxies: Results from controlled growth experiments

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Poster Session 2, Exhibition Area, Level 1, October 14, 2026, 18:00 - 19:30

Sulfate (SO₄²⁻) is the second most abundant anion in seawater. Nevertheless, its long-term accumulation and variability throughout Earth's history remain largely uncertain. Considering the preservation potential of benthic foraminifera in the fossil record, geochemical signatures of large tropical benthic foraminifera (LBF) are an important tool for paleoclimatic proxies. Considering their significant deposit of high-magnesium calcite within fragile tropical ecosystems threatened by climate change, an improved understanding of both their calcification processes and geochemical signatures in the face of climate change environmental variables, is of main interest, particularly as LBF have not been intensively studied. Cultures of *Marginopora* sp. from New Caledonian environments were performed with modern and decreased seawater pH values and modern and increased [SO₄²⁻]_{sw} to calibrate the impact of seawater sulfate concentration on both S/Ca concentrations and $\delta^{34}\text{S}$ composition of the S incorporated in the shells. We present S/Ca data and other Element/Calcium ratios derived from LA-Q-ICP-MS (NWR193UC & Thermo Fisher Scientific iCAP-Q) and solution SF-ICP-MS (Thermo Fisher Scientific Element-2) analyses, as well as sulfur isotope data acquired from Isotope Ratio Mass Spectrometry (IRMS, Elementar vario EL cube). As already described in previous studies looking at the geochemical signatures of small benthic foraminifera, S/Ca ratios within *Marginopora* sp. tests increased with increasing seawater S/Ca concentration. However, and contrarily to what was reported previously, the Mg/Ca content of *Marginopora* was observed to decrease with increasing S/Ca calcite content, highlighting potential differences in calcification disruption between low-Mg and high-Mg calcitic foraminifers when exposed to an increase in seawater sulfate concentrations.

A BBNJ Compliant Roadmap for Ocean Negative Carbon Emissions in a High-CO₂ World

Prof. Nianzhi Jiao

¹Xiamen University, China

Keynote 5: Nianzhi Jiao, Rongomātāne, October 15, 2026, 09:10 - 09:50

Global Ocean Negative Carbon Emissions (Global-ONCE) is a United Nations Ocean Decade Program, which is initiated from a newly recognized carbon sequestration mechanism, the microbial carbon pump (MCP) that transforms organic carbon from labile states to refractory states for long term storage of carbon in the ocean. Global ONCE integrates the four ocean carbon pumps -- Biological pump, Carbonate pump, MCP and Solubility pump (BCMS), providing a nature-based solution for negative carbon emission in the ocean, which is aligned with Biodiversity Beyond National Jurisdiction (BBNJ) that becomes effective this year. Application scenarios including wastewater-coupled ocean alkalinity enhancement, integrated sea-farming, and land–sea coordination are demonstrated to span observational, experimental, and management pillars that translate BCMS roadmap into practice for ecosystem-based climate governance.

From Bays to Boundaries: a Journey Across Scales in a High CO₂ Ocean

Prof. Helen Findlay¹

¹Plymouth Marine Laboratory, Plymouth, United Kingdom

Keynote 6: Helen Findlay, Rongomātāne, October 15, 2026, 09:50 - 10:30

Understanding what constitutes a “safe” ocean in a high CO₂ world requires moving seamlessly between biological detail, regional context, and planetary perspective. In this keynote, I reflect on my scientific journey across those scales, illustrating how early experimental and field based work on organismal and ecosystem responses to ocean acidification ultimately led to re examining ocean acidification within the planetary boundaries framework. Working in naturally variable systems, particularly in the Arctic and coastal seas, highlighted both the value and limitations of global thresholds, and raised a critical question: how do we make planetary boundaries meaningful for the places where decisions are made?

Here, I will explore how observation based approaches and coordinated networks, such as the Global Ocean Acidification Observing Network (GOA ON), provide a pathway to translate global concepts into regional indicators that capture exposure, vulnerability, and change. Finally, I will discuss how these indicators can inform action - supporting adaptation, guiding governance, and framing responsible responses to emerging interventions such as marine carbon dioxide removal. By tracing this journey from organisms to oceans, and from science to decision making, I aim to highlight how working across scales is essential for navigating the challenges of an increasingly high CO₂ ocean.

Beyond winners and losers: the role of the sponge microbiome in climate acclimation

James Bell¹, Dr Francesca Strano^{1,2}, Dr Valerio Micaroni¹, Dr Manon Broadribb¹, Dr Riccardo Rodolfo-Metalpa³

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5A: Multiple Stressors: Assessing high-CO₂ and multi-stressor effects on aquatic organisms using natural laboratories of climate change, Rongomātāne A, October 15, 2026, 11:00 - 13:00

Sponges are key components of benthic ecosystems worldwide, performing critical ecological functions. Although often predicted to be “winners” under climate change on coral reefs, emerging evidence from temperate systems highlights their vulnerability, particularly to thermal stress. Sponge responses to climate-associated stressors, and their capacity for acclimation, are increasingly linked to their microbial symbionts. Our previous *ex situ* experiments demonstrate that ocean acidification (OA) has limited negative effects on sponges. However, microbial associates can mitigate thermal stress in photosymbiont-containing species. Building on this, we hypothesised that photosymbiont-bearing sponges may benefit from OA via enhanced CO₂ availability and increased carbon fixation. However, *in situ* observations at a natural CO₂ seep in Papua New Guinea reveal no evidence of elevated productivity under OA conditions. Instead, seep-associated sponges appear to offset increased metabolic costs associated with climate stress through microbial-mediated mechanisms. Our most recent work shows that sponges can restructure their microbial communities under thermal stress, highlighting microbial flexibility as a key mechanism underpinning resilience. Collectively, our findings challenge assumptions of universal sponge “winners” and emphasise the central role of host–microbe interactions in determining species-specific sponge responses to future ocean conditions.

Uncovering cryptic reef biodiversity in coral rubble using eDNA at a natural CO₂ seep

Ms Britta Fiedler^{1,2}, Mr Luca Kubota^{2,3}, Mr Jeffrey Jolly^{2,4}, Mr Joseph Proietti^{1,2,4}, Prof Timothy Ravasi^{2,4}, Ms Magali Boussion^{2,5}, Dr Carlos Leiva^{2,6}, Dr Sylvain Agostini^{2,5}, Dr Riccardo Rodolfo-Metalpa^{2,5}, Prof James Davis Reimer^{1,2,7}, Dr Fabian Gösler^{1,2}

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5A: Multiple Stressors: Assessing high-CO₂ and multi-stressor effects on aquatic organisms using natural laboratories of climate change, Rongomātāne A, October 15, 2026, 11:00 - 13:00

Anthropogenic CO₂ emissions drive ocean acidification (OA), posing a threat to many marine ecosystems such as shallow water tropical and subtropical coral reefs, which support approximately one quarter of all marine biodiversity. Volcanic CO₂ seeps can serve as natural laboratories, offering insights into how marine communities may respond to future acidification. While the effects of OA on macrofauna are well-studied, the majority of reef diversity is hidden in the cryptobenthos, including coral rubble habitats, and is poorly understood. With intensifying stressors causing increased coral mortality, many reefs are changing to degraded, rubble-dominated states. Therefore, understanding the community dynamics and ecological role of rubble-associated fauna will become increasingly important. This study analyzed the diversity and community composition of coral rubble cryptofauna at a volcanic CO₂ seep in Ambitle, Papua New Guinea, using environmental DNA. In August 2025, we collected coral rubble underwater at three low-pH sites near the seep (pH 7.80–8.00) and two control sites (pH ~8.04). The rubble was incubated for two hours to allow for the release of motile fauna and accumulate DNA in the water, improving detection of cryptic taxa. After incubation, water samples from the buckets were collected and filtered through Sterivex cartridges (0.45 µm). DNA was extracted from the filters and metabarcoded using an 18S ribosomal DNA marker to target a broad spectrum of metazoans.

This work highlights how OA may restructure overlooked but ecologically important reef communities, contributing to a better understanding of how reef ecosystems may change in a high-CO₂ future.

Physiological and cellular mechanisms of multi-stressor resilience in reef fishes from a natural climate change analogue in New Caledonia

Miss Hayley Kennedy¹, Dr Angus Mitchell^{1,2}, Mr Mahé Dumas³, Dr Riccardo Rodolfo-Metalpa, Professor Ivan Nagelkerken¹

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5A: Multiple Stressors: Assessing high-CO₂ and multi-stressor effects on aquatic organisms using natural laboratories of climate change, Rongomātāne A, October 15, 2026, 11:00 - 13:00

Bouraké lagoon in New Caledonia is a natural climate analogue characterised by extreme and highly variable temperature, dissolved oxygen, and pH, often surpassing that of future projected climate conditions. Bouraké harbours a diverse coral and fish community, making it a valuable natural laboratory for investigating climate resilience in marine organisms. Here, we examined the physiological and cellular responses of fishes to determine whether life-time exposure to climate extremes is associated with enhanced tolerance to multiple climate-related stressors.

Reef fishes were collected from Bouraké and nearby reference reefs. Individuals were subjected to controlled laboratory ramping experiments involving increasing temperature, decreasing pH and decreasing dissolved oxygen, both separately and in combination. Physiological metrics were assessed, including body condition, hepatosomatic index and time to loss of equilibrium. Tissue analyses quantified biomarkers of stress, including oxidative stress responses, aerobic and anaerobic capacities and heat shock protein expression.

Fishes from Bouraké displayed altered tolerance to individual and combined stressor exposure relative to fishes from reference reefs. Bouraké individuals showed increased thermal tolerance and exhibited enhanced protective cellular capacity.

Our findings demonstrate that natural analogues of climate change can confer resilience to future ocean conditions. Bouraké therefore provides a rare, ecologically-relevant window into the capacities of fish to tolerate climate change. Understanding these mechanisms is essential for predicting which species and populations are most likely to persist in a changing climate.

Limited Adaptation of Crustose Coralline Algae in a Carbon Dioxide Vent

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5A: Multiple Stressors: Assessing high-CO₂ and multi-stressor effects on aquatic organisms using natural laboratories of climate change, Rongomātāne A, October 15, 2026, 11:00 - 13:00

Ocean acidification threatens the persistence of crustose coralline algae (CCA), which build skeletons from highly soluble high-Mg calcite. Populations persisting at natural CO₂ vents provide opportunities to investigate long-term tolerance mechanisms under realistic environmental conditions. Here we conducted a reciprocal transplant experiment at Shikine Island, Japan, between a natural CO₂ vent site and an adjacent reference site to test whether CCA populations exhibit enhanced physiological tolerance following chronic exposure to elevated pCO₂. Molecular identification revealed that *Spongites* sp. dominated both sites, allowing within-species comparisons across the pH gradient. After six months, both vent-origin and reference-origin populations exhibited 100% survival across all transplant treatments. However, net calcification rates were determined primarily by transplant location rather than population origin. Both populations converged with higher calcification at the reference site and significantly reduced calcification at the vent site. Short-term incubations showed coupled responses of calcification and photosynthesis, with both processes suppressed at the vent site regardless of origin. These results indicate that stress tolerance in *Spongites* sp. is a species-level trait. However, survival comes at a substantial cost, with reduced calcification rates at vent sites diminishing CCA's ecosystem functions. The lack of population-level differences suggests that observed tolerance most likely reflects constraints imposed by unfavorable pH conditions rather than adaptive physiological compensation. Relying on morphological identification alone obscured species-specific responses, underscoring the necessity of molecular taxonomic verification in CCA physiological studies. These findings demonstrate that some calcifying taxa may persist under near-term ocean acidification through tolerance, but with compromised ecological function.

Ocean acidification drives negative skeletal responses in sea urchins across experimental and natural systems

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5A: Multiple Stressors: Assessing high-CO₂ and multi-stressor effects on aquatic organisms using natural laboratories of climate change, Rongomātāne A, October 15, 2026, 11:00 - 13:00

Sea urchins play a key role in structuring benthic communities, but as calcifying organisms, they are vulnerable to ocean acidification. Recent studies have documented negative effects of elevated pCO₂ on multiple sea urchin species. However, most studies rely on short-term or simple experimental manipulations and rarely compare responses with those observed in natural ecosystems. Here, we assessed the growth, skeletal properties, and physiological performance of two sea urchin species (*Echinometra* sp. A and *Diadema setosum*) in a six-month incubation experiment under present-day conditions (pH 8.05) and three elevated pCO₂ treatments (pH 7.9, 7.75, and 7.45), and compared these responses with individuals inhabiting natural volcanic CO₂ seeps (Shikine Island, Japan), representing lifetime (post-settlement) exposure to acidic conditions. Responses were species-specific, indicating distinct strategies under short-term versus lifetime exposure to ocean acidification. Under naturally and experimentally elevated pCO₂, both species exhibited increased skeletal porosity, reduced growth, and lower coelomic fluid pH, alongside thicker skeletal plates compared to present-day conditions. Responses of wild *D. setosum* were consistent with the trend of experimental results but not the extent, whereas wild *Echinometra* sp. A exhibited reduced skeletal thickness, contrasting with the thickening observed under experimental conditions. These patterns suggest compromised calcification and increased dissolution, likely reflecting constraints on energy allocation under acidified conditions. These findings highlight important discrepancies between laboratory experiments and natural analogues, improving our understanding of how ocean acidification affects marine calcifiers in ecologically realistic settings.

Roca Redonda, Galápagos: Baseline evidence supporting the need for sustained monitoring of a tropical natural CO₂ laboratory

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5A: Multiple Stressors: Assessing high-CO₂ and multi-stressor effects on aquatic organisms using natural laboratories of climate change, Rongomātāne A, October 15, 2026, 11:00 - 13:00

Naturally acidified marine systems are rare field analogues for understanding ocean acidification under realistic environmental conditions, yet tropical long-term records remain scarce. Roca Redonda, a shallow volcanic CO₂ seep north of Isabela Island in the Galápagos Archipelago, is one of the few documented naturally acidified tropical marine sites worldwide. This contribution builds on the baseline dataset originally developed in master's thesis (Hurtado M., 2021), which provided the first oceanographic characterization of Roca Redonda, and reassesses its relevance as a priority site for sustained monitoring. The dataset was generated from two seasonal surveys conducted in 2019 at Roca Redonda and a nearby control site at Punta Albemarle, including measurements of temperature, salinity, density, currents, and pH. Results showed clear seasonal variability in physical structure, but low-pH conditions remained persistent at the seep site. Mean pH values reached 6.866 during the dry season and 6.922 during the warm/rainy season, whereas the control site remained within typical oceanic values (7.944–8.076). pH increased away from the seep centre, approaching background conditions at approximately 50 m. These findings indicate that Roca Redonda is not a transient anomaly, but a stable tropical high-CO₂ natural laboratory of strategic value for ocean acidification research. However, despite the original intention of developing interannual monitoring, this baseline has not been followed by sustained campaigns. The lack of time-series continuity now represents a major knowledge gap, limiting interpretation of variability, ecological response, and long-term change in one of the few naturally acidified tropical systems available for study.

The brain transcriptional program and behavioural responses of the Pajama cardinalfish under multiple environmental stressors

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5A: Multiple Stressors: Assessing high-CO₂ and multi-stressor effects on aquatic organisms using natural laboratories of climate change, Rongomātāne A, October 15, 2026, 11:00 - 13:00

Most information on marine organisms' responses to multiple stressors comes from single-species lab studies, missing reef ecological complexity. Nikko (Ngerikuul) Bay in Palau is a semi-enclosed system, where elevated temperature, chlorophyll-a and CO₂, together with low oxygen, have persisted for decades. These characteristics make it a unique site to study how reef fish species respond to changes in biogenic habitats and seawater conditions expected to occur in future oceans. Using in situ observations and a reciprocal transplant we assess whether changes in coral communities' composition driven by environmental variation in Nikko Bay influence the behaviour and gene expression of the pajama cardinalfish, *Sphaeramia nematoptera*, a coral specialist typically associated with branched *Porites cylindrica*. Field patterns showed a shift in coral communities, from branching species dominating at the control site to massive species and high cover of the opportunistic branching coral *Montipora stellata*, selected by the cardinalfish at the inner Nikko Bay site. Reciprocal transplants showed that control fish moved to altered environment and provided with a non-preferred coral (*M. stellata*) exhibited reduced activity and altered habitat use, along with a significant upregulation of brain transcriptomic profiles compared to fish maintained in their original habitat and environment. Conversely, no behavioural and transcriptomic changes were detected when fish were translocated into Nikko Bay and exposed to their preferred habitat (*P. cylindrica*). These results show that altered environmental conditions and shifts in coral composition can strongly influence ecological and molecular responses, offering insight into plastic responses in coral-associated fishes under changing ocean scenarios.

Localized biogeochemistry and seasonality govern carbonate chemistry in estuarine mangrove ecosystems

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5B: Beyond tipping points: Actionable oceans: putting ocean acidification science and information into the right hands, Rongomātāne B, October 15, 2026, 11:00 - 13:00

Sundarbans, the world's largest contiguous mangrove ecosystem and representing shallow coastal Bay of Bengal of the Northern Ocean, faces dynamic climate variations, including ocean acidification. To delineate ocean acidification from natural pH variations, it is crucial to perform long-term measurements of multiple carbonate chemistry parameters such as pH, total alkalinity (TA), and dissolved nutrients, among others. In the present study, surface water carbonate chemistry parameters, including TA, pH, and dissolved nutrients (o-phosphate and silicate), were analysed monthly between 2014 and 2022 in three pre-defined stations, namely Stn1, Stn2, and Stn3, part of Sundarbans Biological Observatory Time Series (SBOTS) located in Sagar Island, the largest island of the Indian Sundarbans. The observed deviation from the linear TA-Salinity curve in the studied sites of SBOTS showed the influence of freshwater in modulating TA. Generalized Additive Model (GAM) revealed substantial seasonal variability in the controls on TA. During monsoon, salinity was a dominant driver of carbonate chemistry, consistent with enhanced freshwater discharge. In contrast, during the post-monsoon season, primary productivity as indicated by the relationship with Chla, dissolved silicate, was found to exert a stronger influence on TA variability. Multilinear regression (MLR) analysis of calculated $p\text{CO}_2$ further supported these seasonal trends. Overall, the findings highlight the importance of season-specific assessments, highlighting the critical role of freshwater discharge in shaping estuarine carbonate dynamics. These insights are vital for predicting the vulnerability and response of mangrove estuaries under future climate change scenarios.

From science to practice: Collaborative carbonate system monitoring for scallop aquaculture decision making in northern Peru

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5B: Beyond tipping points: Actionable oceans: putting ocean acidification science and information into the right hands, Rongomātāne B, October 15, 2026, 11:00 - 13:00

Peruvian scallop farming (*Argopecten purpuratus*), one of the most important economic activities, concentrates 80% of the national production in Sechura Bay in northern Peru. Artisanal farming is subjected to environmental conditions and the occurrence of the ENSO, La Niña, and other extreme events, causing mass mortality events during summer with significant economic losses. Faced with this situation, a collaborative monitoring program of the carbonate system was designed with the participation of scallop farmers, Pedro Ruiz Gallo National University and the Peruvian Institute of the Sea as members of the Research Network of Marine-Coastal Stressors in Latin America and the Caribbean. In this study, time series data from three sites of interest within Sechura Bay from 2019 to 2023 were analyzed to characterize oceanographic variability and identified favorable conditions for scallop farming in Las Delicias, where the carbonate system parameters were calculated following REMARCO's standardized protocols for the collection and analysis of water samples for the 2023-2025 period. Our results presents conditions with pHT values <7.9 throughout the year and occasionally below 7.7 during winter, associated with seasonal upwelling. The water was saturated ($\Omega_{\text{calc}} > 1$) throughout the year, except for the winter months. This study presents the first characterization of the carbonate system in Sechura Bay and the report of indicator 14.3.1 of SDG 14 for the Las Delicias area, which meets favorable conditions for scallop farming throughout the year. These results help scallop farmers in decision-making and management of the cultivates during changing environmental conditions in summer.

Puget Sound Acidification and Impacts (PSAI): A data product for estimating acidification in Puget Sound and surrounding areas

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5B: Beyond tipping points: Actionable oceans: putting ocean acidification science and information into the right hands, Rongomātāne B, October 15, 2026, 11:00 - 13:00

Puget Sound estuary of the northwestern North American continent supports many economically and ecologically important species and has naturally acidified waters in many areas, which are experiencing more extreme acidification over time. There is an urgent need among communities that rely on Puget Sound for economic, recreational, and cultural purposes to address this acidification threat. This project aims to help local communities address acidification and its impacts in Puget Sound and surrounding marine waters by creating the Puget Sound Acidification and Impacts (PSAI) data product tool to estimate ocean acidification parameters. Scientists and managers from Tribes and State agencies are refining PSAI through an Advisory Team. The Team is co-designing our project by identifying where higher-resolution estimates are needed, determining what information PSAI should present, and contributing local ecosystem expertise. The objective is for PSAI to support local experts and community members seeking to improve management and research in Puget Sound by increasing the accessibility and interpretability of acidification information. We plan to develop and train empirical algorithms on misfits between model output and water chemistry data from Puget Sound and surrounding areas and apply these trained algorithms to model to create an improved model-data product hybrid, resulting in a publicly accessible PSAI tool. Here we present preliminary hybrid data product results. Ultimately, PSAI will deliver acidification information to experts and the public, supporting fisheries management and informed responses to acidification. PSAI may also help target areas for ocean acidification mitigation.

Implications of monitoring and modeling results of acidification in Japan coasts

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5B: Beyond tipping points: Actionable oceans: putting ocean acidification science and information into the right hands, Rongomātāne B, October 15, 2026, 11:00 - 13:00

In Japan coasts, there have been few reports to date of ocean acidification having a serious impact on marine life. However, it is not clear whether there are truly no effects, or whether effects are already present but are being overlooked. To clarify this, the Nippon Foundation Ocean Acidification Adaptation Project has conducted high-frequency, continuous monitoring of ocean acidification parameters at various coasts in Japan with distinct characteristics. We have also conducted future projections using a combined ocean physical-biogeochemical model. Monitoring results revealed that marine environments where aragonite saturation state (Ω_{ara}) drop to levels capable of causing severe acidification impacts on oyster larvae frequently occur along Japan coasts. Furthermore, since the rapid decline in Ω_{ara} is largely synchronized with the timing of heavy rainfall, a trend of coastal acidification has been confirmed: excessive inflow of freshwater and organic matter due to river flooding caused by heavy rain leads to decreased pH and Ω_{ara} in the coastal waters. Future projections suggest that, unless CO₂ emissions are significantly reduced, oyster farming will be severely impacted by the end of this century due to the prolongation of the oyster spawning season caused by a rise in water temperature and significant decline in Ω_{ara} . These project-based research results highlight the need for global efforts to reduce CO₂ emissions, as well as the importance of local adaptation measures, such as the regulation of organic matter inflow from rivers to coastal areas, and modifications to shellfish farming practices in response to additional local marine environmental changes.

OA on the ground: a virtual tour of NOAA's ocean acidification tools and real-world impact

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5B: Beyond tipping points: Actionable oceans: putting ocean acidification science and information into the right hands, Rongomātāne B, October 15, 2026, 11:00 - 13:00

Translating ocean and coastal acidification (OA) monitoring and research into tangible, on-the-ground action is paramount for communities facing OA impacts. The National Oceanic and Atmospheric Administration's Ocean Acidification Program (OAP) provides national and regional decision support tools for OA. Products and services include next-generation ocean chemistry forecasts and models integrating both ocean chemistry and socioeconomic information to create risk maps for communities. Data dashboards help audiences visualize complex information for places, species, and ecosystems they care about. In addition, outreach and education efforts can integrate data and knowledge systems to support awareness and action for students and informal education. This virtual tour of NOAA's suite of products presents real-world examples that people and communities use to inform decision-making.

Love Rimurimu: Turning Kelp Restoration into Community Action in Te Whanganui-a-Tara

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5B: Beyond tipping points: Actionable oceans: putting ocean acidification science and information into the right hands, Rongomātāne B, October 15, 2026, 11:00 - 13:00

Giant kelp (*Macrocystis pyrifera*) is a foundation species critical to coastal ecosystems and can locally mitigate coastal erosion and ocean acidification. *M. pyrifera* is declining globally due to marine climate change and anthropogenic pressures. Despite growing urgency and interest in kelp restoration as a tool for climate adaptation and ecosystem recovery, many approaches remain constrained within academic or government-led frameworks.

The Love Rimurimu project in Te Whanganui-a-Tara (Wellington Harbour) aims to translate restoration science into action by developing accessible, community-based restoration methodologies. Community volunteers are trained in breath-hold techniques, out-planting and monitoring methods, enabling consistent data collection and ongoing local restoration. Low-cost, accessible methods include adaptations of the green gravel technique and small-scale seeded line-based systems.

Across four years, 37 community volunteers and 16 students from Te Kura Kaupapa Māori o Ngā Mokopuna were trained, contributing to the deployment of over 2,200 green gravel and 7 m of seeded line. Green gravel showed a mean survival of 9.5% after four months, with surviving sporophytes reaching mean lengths of 47.9 cm and maximum lengths exceeding 2 m. Seeded lines demonstrated successful early growth, with a 58-fold increase in sporophyte length in 2 months, though rising spring water temperatures resulted in significant mortality.

Findings from the Love Rimurimu project highlight the challenges and benefits of expanding kelp restoration beyond specialised research settings. Developing accessible methodologies, training and empowering community volunteers supports data acquisition and enhances the scalability and longevity of restoration efforts by embedding them within the community.

Development of a biogeochemical modeling approach to investigate present and project future states of ocean acidification in Tokyo Bay, Japan

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5C: Ocean Solutions: Addressing Coastal Acidification and Enhancing Carbon Sinks through Coordinated Management of Wastewater, Nutrients, and Ecosystems, Rongomātāne C, October 15, 2026, 11:00 - 13:00

As worsening ocean acidification (OA) due to excessive anthropogenic CO₂ emissions is feared to adversely affect calcifying organisms, we have been developing a biogeochemical modeling approach to help evaluate the present state and make future projections of OA in Japan coasts (Bernardo et al., 2023). The Coastal and Regional Ocean Community model (CROCO) system is used to couple the Regional Ocean Modeling System (ROMS) with the Pelagic Interactions Scheme for Carbon and Ecosystem Studies version 2 (PISCES-v2) model to simulate physical and biogeochemical processes, and the approach is applied to the highly eutrophic Tokyo Bay. The model has a ~1 km spatial resolution, with initial and boundary conditions derived from a combination of global databases, regional model outputs, and annual monitoring by government agencies. Comparison of model results with available time-series and research cruise data shows that while the setup captures the general trends in observed physical parameters, it is unable to reproduce periods of highly elevated pH and aragonite saturation state (Ω_{arag}) at the surface, particularly in summer. Periods of relatively low pH and Ω_{arag} in near-bottom waters are also not well reproduced. Trends in dissolved oxygen (DO) are generally well-reproduced, except for the summer season in near-bottom waters. River nutrient and carbonate inputs in the model require modification, along with the proper consideration of near-bottom processes. Overall, this study highlights the potential usefulness of model setups capable of incorporating regional and local factors affecting OA as helpful tools in determining necessary mitigation and adaptation measures.

Carbon Capture and Ecosystem Effects of Okinawan Seaweed farms

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5C: Ocean Solutions: Addressing Coastal Acidification and Enhancing Carbon Sinks through Coordinated Management of Wastewater, Nutrients, and Ecosystems, Rongomātāne C, October 15, 2026, 11:00 - 13:00

Seaweed aquaculture has recently been proposed as a scalable, minimally-invasive marine carbon dioxide removal (mCDR) strategy. In addition, their high productivity and ability to co-locate with key marine calcifiers (e.g., shellfish aquaculture, coral reefs) highlights their potential to offer local refugia from ocean acidification (OA), deoxygenation, and eutrophication. To evaluate the carbon sequestration potential of these systems and associated co-benefits, we investigated long-standing mozuku (*Cladosiphon okamuranus*) seaweed farms in Okinawa, Japan. This study focuses on the carbon uptake potential during the growth phase, with the final product intended for consumption, as is representative of the majority of global seaweed farming. We developed a framework for assessing the net ecosystem metabolism and effects of the farm by combining physical (flow speed/direction, significant wave height) and chemical (TA, DIC, pH, oxygen, nutrients, etc.) measurements upstream and downstream of the farm with drifters, discrete sampling, and in-situ sensors. To complement this, we have created a carbon budget with sediment cores, dissolved organic carbon release rates, and percent recalcitrant dissolved organic carbon to constrain the carbon sequestration capacity of this farm. Ultimately, this study aims to highlight sustainable seaweed cultivation as a means of mitigating climate change and its associated effects.

Sediment–Seagrass Coupling Enhances Alkalinity-Driven CO₂ Uptake in Seagrass Mesocosms

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5C: Ocean Solutions: Addressing Coastal Acidification and Enhancing Carbon Sinks through Coordinated Management of Wastewater, Nutrients, and Ecosystems, Rongomātāne C, October 15, 2026, 11:00 - 13:00

Seagrass meadows are widely recognized as coastal blue carbon ecosystems, yet most assessments emphasize organic carbon burial while overlooking inorganic carbon processes that regulate seawater carbonate chemistry and influence carbon dioxide (CO₂) uptake. Here, we examine how sedimentary organic matter and calcium carbonate (CaCO₃) interact with seagrass metabolism to regulate carbonate chemistry and CO₂ exchange. In a controlled mesocosm experiment, sediments enriched with both organic carbon and CaCO₃ produced higher total alkalinity and lower water-column pCO₂ than unamended sediments. Porewater profiles showed declining pH and increasing dissolved inorganic carbon and alkalinity with depth, consistent with coupled organic matter remineralization and metabolically driven carbonate dissolution. When combined with seagrass photosynthesis, these sedimentary reactions enhanced seawater buffering capacity and sustained atmospheric CO₂ uptake. Our results reveal a mechanistic coupling between sediment biogeochemistry and plant metabolism that amplifies CO₂ removal in seagrass ecosystems and highlights an overlooked alkalinity-driven pathway supporting nature-based climate solutions.

Moving from monitoring to action in the north-east Atlantic

Prof. Helen Findlay¹

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5C: Ocean Solutions: Addressing Coastal Acidification and Enhancing Carbon Sinks through
Coordinated Management of Wastewater, Nutrients, and Ecosystems, Rongomātāne C, October 15,
2026, 11:00 - 13:00

Coastal acidification results from the complex interaction of coastal activities and land-ocean interactions in addition to the overarching global issues of ocean acidification (resulting from ocean uptake of carbon dioxide). Within the north-east Atlantic, monitoring of pH has shown that rates of acidification vary spatially and are influenced by a number of important factors. Over the past five years the north-east Atlantic hub of the Global Ocean Acidification Observing Network (GOA-ON), along with the Ocean Acidification Alliance and OSPAR have been investigating ways in which acidification monitoring and action can be incorporated into European policy frameworks. In this talk I briefly explore the changing chemistry within the coastal north-east Atlantic and discuss how different approaches and policy-levers can be applied to help address coastal acidification.

Wastewater treatment plants as hubs for marine carbon dioxide removal: Insights from a cleantech startup

Dr Simon Reid¹

¹Aspiring Materials, Christchurch, New Zealand

5C: Ocean Solutions: Addressing Coastal Acidification and Enhancing Carbon Sinks through Coordinated Management of Wastewater, Nutrients, and Ecosystems, Rongomātāne C, October 15, 2026, 11:00 - 13:00

Wastewater treatment is currently responsible for 1–3% of global emissions. Meanwhile, the discharge of low-pH, high-DIC wastewater effluent into surrounding waters is a contributor to coastal acidification. These issues are only set to become more prevalent with a rising global population and trend towards urbanization. Fortunately, the unique chemistry of wastewater treatment plants (WWTPs) and their abundance of biogenic CO₂ make them compatible with carbon dioxide removal (CDR) technologies, which could transform the industry from a net carbon source into a carbon sink. Two technologies highlighted here are biogas carbon mineralisation and wastewater alkalinity enhancement (WAE), having a combined potential to permanently sequester ~40 kg CO₂/capita/year. Implementation of these technologies at WWTPs could also deliver significant co-benefits, such as reduced hydrogen sulphide odour and corrosion, improved sludge dewatering, alkalinity buffering for nitrification, and improved utilisation of bioenergy. Both require a low-carbon source of alkalinity, and Aspiring Materials is pioneering a decarbonised process to manufacture alkalinity in the form of magnesium hydroxide. This presentation lays a foundation for incorporating magnesium hydroxide into existing WWTPs to enable CDR on a megatonne scale, while offering perspectives from a NZ-based startup in the cleantech industry.

Dynamics of the marine carbonate system under the influence of Sargassum in the Mexican Caribbean

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5D: Changes in biodiversity. Buffer or Booster? When Primary Producers Mitigate or Amplify Ocean Acidification, Mătiu, October 15, 2026, 11:00 - 13:00

Ocean acidification is increasing across the world's oceans; however, the rate of acidification varies by region. The Caribbean has been documented to experience higher rates of acidification than the global average. In addition, since 2015 the Caribbean has been receiving large amounts of Sargassum that accumulate on its shores, affecting the local ecosystems. Previous studies have shown that Sargassum debris leaches acidic compounds that may affect the water column, compounding the effects of OA. On the other hand, photosynthesis produced by the large amounts of Sargassum may counteract the effects of OA. In this study, we evaluated the spatial distribution of carbonate system variables during May-June 2025 in the presence of Sargassum blooms. Around 2.4 million metric tons of Sargassum were detected in the western Caribbean during the sampling dates. Surface Total alkalinity (TA), pH, and aragonite saturation state ranged from 2294.1-2409.4 $\mu\text{mol kg}^{-1}$, 7.58-7.98, 1.2-3.6, respectively. Surface pH minima were located north of Cozumel Island and in the central western side of the study area, where a cyclonic eddy was located. The maximum TA values were found in the northern region near Yucatan. The region most influenced by Sargassum had medium pH and aragonite values compared to the rest of the study area. At least in this study, the dynamic features had a greater influence on the carbonate system than the distribution of Sargassum blooms.

Do coccolithophores boost the impact of ocean acidification?

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5D: Changes in biodiversity. Buffer or Booster? When Primary Producers Mitigate or Amplify Ocean Acidification, Mātiu, October 15, 2026, 11:00 - 13:00

Coccolithophores are single cell phytoplankton that produce a calcite exoskeleton using bicarbonate ions, making them sensitive to ocean acidification (OA). Simultaneously calcification removes alkalinity while producing CO₂ and hydrogen ions, lowering seawater pH. The fate of this particulate inorganic carbon (PIC) may reduce surface ocean CO₂ uptake capacity: dissolution in the surface ocean recycles and retains alkalinity, while export below the mixed layer removes alkalinity. Coccolithophores dominate (73%) global PIC production, yet contribute only 13% to global PIC stocks, with 60% coccolithophore produced PIC exported from the surface ocean. The majority of the remaining coccolithophore PIC in the surface ocean must then dissolve, releasing alkalinity. This highlights coccolithophore's ability to mediate the exchange of alkalinity between dissolved and particulate inorganic carbon pools and across depths. As ocean pH decreases, coccolithophore calcification rates are expected to decline, altering PIC production and export, influencing the efficiency of the biological carbon pump. To quantify the impact of calcification on open ocean CO₂ (and subsequently OA), we developed a simple model integrating calcification, photosynthesis, export and variable pCO₂ scenarios. We tested this framework using culture, mesocosm and field measurements of coccolithophore calcite production and carbonate chemistry. Initial results indicate that coccolithophores can switch between sources and sinks of CO₂ but increasingly becoming OA "boosters" under rising atmospheric CO₂. However, this is species dependent, with the larger, more heavily calcified species having a greater impact on alkalinity (but also being more sensitive to OA) and more likely to boost the impact of ocean acidification.

Sediment-water fluxes of DIC and alkalinity in intertidal salt marshes: Blue C storage and acidification mitigation

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5D: Changes in biodiversity. Buffer or Booster? When Primary Producers Mitigate or Amplify Ocean Acidification, Mătiu, October 15, 2026, 11:00 - 13:00

Located at the interface between terrestrial and marine environments, estuarine intertidal sediments are sites of intense dissolved and particulate exchanges. Carbon budgets in these systems are particularly difficult to constrain due to tidal-driven alternation between aqueous and gaseous phases. In addition, some sites experience macroalgal accumulations (*Vaucheria* sp.), commercial harvesting of halophytes (*Salicornia* spp.), and winter ploughing to control the spread of the invasive species (*Spartina anglica*).

In this context, we present seasonal fluxes of dissolved inorganic carbon and alkalinity between surface sediments and the overlying water in Baie de Lanveur (Brittany, western France). A more comprehensive approach is applied to the Picardy estuaries (northern France), accounting for day–night emersion and immersion periods, as well as the presence or absence of macroalgae or anthropogenic disturbance (ploughing).

In Baie de Lanveur, dissolved exchanges vary markedly among stations, with higher exchanges in areas dominated by vascular plants (*Spartina* spp.) than in areas with macroalgae or bare mudflats. In the Picardy estuaries, vegetated intertidal zones (salt marshes) act as carbon sinks linked to primary production, particularly in spring and summer, resulting in net Blue Carbon storage while mudflats remain net carbon sources. However, ploughing strongly disrupts carbon storage in salt marsh sediments, with slow recovery, while macroalgae promote C burial.

Alkalinity fluxes, associated with anaerobic mineralization in these organic-rich sediments, are also significant and may partially offset dissolved inorganic carbon (DIC) releases during immersion periods, thereby limiting coastal acidification in these transitional waters.

Physics or Biology: which drives the variability of the carbonate system in a coastal area of the Southwest Atlantic Ocean?

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5D: Changes in biodiversity. Buffer or Booster? When Primary Producers Mitigate or Amplify Ocean Acidification, Mătiu, October 15, 2026, 11:00 - 13:00

In coastal areas, local processes such as biology (photosynthesis, respiration, calcification), currents, eutrophication, freshwater discharge and interaction with other physico-chemical parameters add to the absorption of atmospheric CO₂ to drive the variability in the seawater carbonate chemistry. This study characterized the carbonate chemistry of a marine near-shore coastal area in the Southwest Atlantic (Buenos Aires, Argentina) to identify its primary drivers, whether physico-chemical (water temperature, salinity and dissolved oxygen) or biological (phytoplankton abundance). Our results indicate that both physico-chemical and biological factors were driving changes in the carbonate system. Trends differed according to the distance from the shore. We observed that pH was strongly negatively correlated with water temperature, and positively with salinity and dissolved oxygen, as well as negatively correlated with phytoplankton abundance at 4 km from the shore. pCO₂ showed a strong positive correlation with water temperature and phytoplankton abundance at 1 and 4 km from the shore. The abundance of small phytoflagellates was the variable most strongly correlated with total alkalinity (TA), a relationship only observed at 1 km from the coast. Dissolved inorganic carbon (DIC) correlated negatively with water temperature for the whole area. In addition, the presence of potentially toxic phytoplankton species in the area was reported. Negative correlation of pH with temperature and phytoplankton suggests that this coastal area in Buenos Aires, Argentina, could be vulnerable to global changes, highlighting the importance of sustained monitoring programs in coastal areas worldwide.

Phytoplankton community response under coastal acidification scenarios within an estuarine mangrove ecosystem

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5D: Changes in biodiversity. Buffer or Booster? When Primary Producers Mitigate or Amplify Ocean Acidification, Mătiu, October 15, 2026, 11:00 - 13:00

Coastal ocean acidification is more variable and complex compared to open-ocean pH alterations, resulting in locally and regionally altered carbonate chemistry. The Sundarbans, world's largest contiguous mangrove, situated in the Ganga-Brahmaputra-Meghna (GBM) Delta of the subtropics, witnesses rapid diel and seasonal alterations of pH, which far exceeds the predicted global pH variabilities. A lab-scale mesocosm study with altered pH (increase and decrease by 0.5 units compared to ambient pH), showed observable changes in the composition of estuarine phytoplankton communities indicating loss of some diatom taxa, and shift towards large sized diatom taxa. There was an increase in abundance of dinoflagellates both under increased and decreased pH conditions reflecting the potential ecological consequences for growth of opportunistic phytoplankton taxa. The functional diversity indices such as FAD2 showed decreasing trends under high and low pH conditions while FDC was found to be higher in high pH. Chlorophyll-a and Carotenoids showed clear decreasing trends in high pH conditions reflecting consequences for phytoplankton driven estuarine mangrove productivity. Rapid change in phytoplankton community structure (for e.g. diatoms being replaced by dinoflagellates) would dramatically alter productivity of coastal oceans and impact the food chain, impact coastal nutrient and energy transfer to higher trophic levels. Given the intricate control of the microbial food web on coastal fisheries, such shifts would play a critical role in managing the ecological productivity and economic sustenance of coastal ecosystems.

AEOLUS: studying AEOLian macroalgal forests structure and functioning to support biodiversity under ocean acidification

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5D: Changes in biodiversity. Buffer or Booster? When Primary Producers Mitigate or Amplify Ocean Acidification, Mătiu, October 15, 2026, 11:00 - 13:00

Submarine CO₂ vents provide natural laboratories to investigate how marine primary producers respond to altered carbonate chemistry and associated environmental variability. In this study, we explored the metabolic performance of canopy-forming macroalgae along natural gradients of acidification in the Aeolian Islands (Mediterranean Sea), where venting activity creates persistent low-pH conditions. Preliminary results suggest a consistent enhancement of photosynthetic performance in algal individuals inhabiting vent-influenced sites compared to reference areas. This apparent stimulation of autotrophic processes, likely driven by increased CO₂ availability, was not paralleled by equally marked changes in respiratory activity, which remained comparatively stable across sites. These patterns point to a potential decoupling between photosynthesis and respiration under naturally acidified conditions, with possible implications for carbon balance and energy allocation in these habitat-forming species and the oxygen and pH conditions in which the associated fauna thrive. However, the variability observed across sites and sampling periods highlights the importance of local environmental context in modulating physiological responses. Ongoing analyses aim to disentangle the relative contribution of carbonate chemistry, light regime, and other environmental variables in shaping these metabolic responses, and to assess whether such patterns scale up to influence community-level functioning.

Exploring the potential of AI approaches to unravel the effects of complex climate change on marine phytoplankton

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6A: Multiple Stressors, Rongomātāne A, October 15, 2026, 16:00 - 18:00

Marine phytoplankton supply energy to most ocean ecosystems and play a key role in life support systems for Earth. Phytoplankton are encountering multi-faceted climate change through the concurrent alteration of ocean carbonate chemistry (acidification), temperature, underwater irradiance, and the supply of nutrients and trace metals. Our ability to tease apart the effects of complex environmental change is further confounded by the interactive effects between ocean properties – for example iron, light and temperature. Diverse approaches from observational to experimental have been employed to better understand and provide model projections of how climate change will alter phytoplankton processes in the coming decades. Due to the complexity resulting from the cumulative effects of multiple stressors, their interplay, and the many treatment levels that must be employed, these approaches have had limited success.

Other disciplines have been exploring the promise of Artificial Intelligence (AI) trained using observations from natural laboratories, to integrate the effect of multiple stressors on biota. For example, McClanahan (2025) (<https://doi.org/10.1007/s00338-025-02770-2>) recently synthesised the findings from 15 published regional studies that employed machine learning (ML) to explore the future for a range of coral reefs. He concludes that the ability of ML to integrate a wide range of complex observations that define coral reef responses provides more accurate projections than conventional theory-based approaches. Here, we use his approach as a point of departure to explore whether ML/AI offers a way through the current impasse in understanding how phytoplankton will respond to changing seascapes.

The joint effect of changes in temperature and CO₂ on growth and functional traits in a model diatom

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6A: Multiple Stressors, Rongomātāne A, October 15, 2026, 16:00 - 18:00

The link between environmental states and phytoplankton growth is described through nonlinear responses curves. Some of these, such as temperature response curves, are well understood and commonly used. Others, such as CO₂ response curves, are less commonly used in experiments. Here, we define the interaction between temperature and CO₂ over all combinations of 7 levels of each driver for a model diatom, using a trait-based approach. We describe how CO₂ response curves shift as temperatures move from suboptimal to optimal to supra-optimal, and apply this to discussing how shifts in CO₂ concentrations may affect responses to rapid warming during diatom blooms. We also outline the challenges and benefits of carrying out laboratory experiments capable of defining full response surfaces, key considerations when comparing between experiments, and implications for the design of smaller experiments that leverage information from experimentally defined response surfaces.

Pseudoreplication in experiments is, or is not, a sin: from debate to practical analysis with model averaging tools

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6A: Multiple Stressors, Rongomātāne A, October 15, 2026, 16:00 - 18:00

Pseudoreplication, introduced in a classic paper by S. A. Hurlbert (Ecological Monographs, 1984), describes a common flaw in ecological studies where treatments are not replicated, or replicates are analysed as independent when they are not. Ever since, there has been much discussion around pseudoreplication in field- and laboratory-based studies.

We revisit this discussion through the lens of multi-driver experiments, where factors are manipulated and replicated at different levels, usually due to logistical constraints such as the number of available fields in an agricultural experiment, or header tanks available for an ocean global change experiment. These designs are inherently hierarchical, yet their structure is often ignored in analysis, leading to charges of pseudoreplication.

Rather than simply echoing others' criticisms, we examine when pseudoreplication is, and is not, an issue, to form a more nuanced view based on model-averaging. Crucially, we move beyond conceptual discussion to practical tools by introducing a statistical tutorial and accompanying software that enable researchers to implement these approaches in multi-driver experiments.

A climate change risk assessment for the carbonate counter pump

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6A: Multiple Stressors, Rongomātāne A, October 15, 2026, 16:00 - 18:00

Pelagic calcifiers (coccolithophores, planktonic foraminifera, and pteropods) play a major role in the carbon cycle through the production of calcium carbonate (CaCO_3), the subsequent drawdown of alkalinity, and export of CaCO_3 to the deep ocean, in a process known as the carbonate counter pump. Our previous work has found that calcifiers globally produce an estimated 1700 Tg of inorganic carbon each year and export around 30% of this to the deep (>1 km) ocean, with pteropods dominating standing stocks and coccolithophores CaCO_3 production and export. Calcifiers are vulnerable to stressors such as ocean acidification, warming, deoxygenation, and nutrient and food stress. However, their responses to climate change vary due to major differences in their life cycle, morphology, and calcification mechanisms. Under future climate scenarios, CaCO_3 production and export attributed to each calcifier are expected to change due to susceptibility of each group to the different climate stressors and group-specific compounding effects. Reviews have evaluated only a single stressor or single organism response so far; none have created a risk assessment of calcifier responses (e.g growth, calcification, and dissolution) that accounts for their relative sensitivity to the different stressors and their relative importance in the carbonate pump. Using a meta-analysis and systematic review, we assess the responses of pelagic calcifiers to the effects of multi-stressors on CO_2 uptake by the ocean to create for the first time an assessment of climate change multi-stressors' impacts on alkalinity cycling and the carbonate counter pump.

The diatom shuffle: how a greenhouse ocean is selecting diatom species of the future

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6A: Multiple Stressors, Rongomātāne A, October 15, 2026, 16:00 - 18:00

Diatoms are responsible for nearly half of all marine primary production, making them essential for sustaining marine life. Diatoms incorporate silicon into their cell walls, forming glass-like shells, called frustules, which have contributed strongly to their evolutionary success, as it provides protection from grazing and sea-surface remineralisation. By virtue of being denser than seawater, their siliceous armour also underpins the central role of diatoms in marine silicon and carbon cycling. Rates of frustule synthesis are species specific and phenotypically plastic, and therefore strongly influenced by the environment, meaning that between and within species changes to silicification can alter survival rates, affecting community structure and nutrient cycling. As oceans acidify and warm, species-specific sensitivities to novel conditions will likely alter selection processes, yet little has been done to quantify expected changes, limiting our understanding of how future ocean conditions may impact diatoms and biogeochemistry. Using a double-gradient design, we investigated how ocean acidification and warming influence the physiology, community composition and silica production of diatoms from a natural coastal assemblage. We found strong floristic effects on phytoplankton abundance and diversity with high CO₂ and temperature, with stimulating effects of temperature on some species, but deleterious effects on others. Similarly, we detected differences in diatom silicification rates under different climate change scenarios within and across species, further supporting physiologically-driven community reshaping, which in turn, could alter diatom grazing susceptibility, and silicon-carbon export. Our data show how a greenhouse ocean, through its differential effects on individual species, may select diatoms of the future.

Compound Coastal Stress from Marine Heatwaves in a High-CO₂ Gulf of Thailand

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6A: Multiple Stressors, Rongomātāne A, October 15, 2026, 16:00 - 18:00

Marine heatwaves (MHWs) are emerging as critical amplifiers of compound ocean stress in a rapidly warming, high-CO₂ ocean, interacting with stratification, circulation, and biological productivity to reshape coastal ecosystem functioning. Yet, these coupled biogeochemical responses remain poorly constrained in shallow shelf seas, where strong physical variability intersects with high societal dependence. During May–June 2023 and 2024, intense MHWs developed across Southeast Asia following consecutive La Niña conditions, with persistent warming in the Gulf of Thailand (GoT). Here, we examine how these thermal extremes translate into biogeochemical and ecosystem responses using satellite observations, reanalysis products, and field-based evidence. We identify a regional decline in surface chlorophyll-a during MHW conditions, with strongest suppression in productive coastal waters. Reduced chlorophyll-a indicates weakened primary productivity, likely driven by enhanced stratification and reduced nutrient supply, contrasting with typical monsoon-driven replenishment. These changes coincided with widespread coral bleaching observed during field surveys in May 2023, providing direct ecosystem evidence of compounded thermal and biogeochemical stress in a shallow, fisheries-dependent oceans. Spatial heterogeneity, including weaker responses across parts of the Maritime Continent, highlights the role of circulation and mixing in modulating vulnerability to extreme events. We find that episodic MHWs can act as catalysts of multi-stressor impacts under ongoing high-CO₂ conditions, with implications for ecosystem resilience and coastal livelihoods. These results emphasize the need to integrate biological and biogeochemical indicators into climate risk assessments and align with Ocean Decade Challenge-5 priorities, emphasizing adaptation–mitigation strategies, improved predictive capacity, and relevant ocean-based solutions for climate-resilient coastal systems.

Cellular and Molecular Impacts of Ocean Acidification on Fish Brain Function at Single-Nuclei Resolution

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¹University of Hong Kong, Hong Kong, Hong Kong

6A: Multiple Stressors, Rongomātāne A, October 15, 2026, 16:00 - 18:00

Ocean acidification (OA) has emerged as a critical factor affecting marine life, yet the cellular and molecular mechanisms underlying its impact on fish neurobiology remain poorly understood. This study aims to investigate the indirect anthropogenic effects of OA on the neural architecture of the cleaner wrasse, *L. dimidiatus*, at an unprecedented single-cell resolution. Despite significant progress in understanding the molecular mechanisms underlying behavioural disruptions under elevated CO₂ conditions, there remains a gap in knowledge regarding the cell type and composition affected by elevated CO₂. Utilizing advanced single-nuclei RNA sequencing (snRNAseq) techniques, we will characterize the cell landscape of *L. dimidiatus* during interaction behaviours under OA scenarios. Our research focuses on two key questions: (1) does elevated CO₂ alter cell type identity and composition in the brain, and (2) are gene expression patterns at the single-cell level affected by acidification? The application of snRNAseq allows for high-resolution insights into cellular heterogeneity and transcriptional dynamics that are otherwise inaccessible. This approach promises to shed light on how OA impacts specific neural cell populations and their molecular pathways, ultimately enhancing our understanding of climate change effects on fish neurobiology and behaviour.

Projecting the multi-stressor at regional scale for conservation and restoration of marine ecosystems

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6B: Changes in biodiversity, Rongomātāne B, October 15, 2026, 16:00 - 18:00

An increased effort towards conservation and, where possible, restoration of marine ecosystem threatened by wide range of stressors is observed at local as well as international scale. Such effort risk however to be thwarted by global stressors like climate change and ocean acidification that can act against it.

Global Earth System Models (ESMs) from CMIP6 are often used either directly or indirectly (e.g. BIO-ORACLE) to assess the impact of global stressors on these actions, however their resolution and complexity is still sub-optimal. Regionally downscaled marine climate projections can therefore be used to overcome this limitation.

Here we present a 4 members ensemble of bias corrected projections for the North-Western European shelf under two different scenarios (SSP3-7.0 and SSP1-2.6), providing daily resolution projections of the marine environment at 7 km resolution.

We use this ensemble to study how global stressors could affect actions for conservation and restoration of cold-water corals under the two contrasting scenarios. We first focussed on the evolution of key biogeochemical indicators in areas of existing cold water coral reefs. In the higher emission scenario, corrosive conditions in respect for aragonitic structures are projected, coupled to a stronger warming and a general decrease in food availability. In the lower emission scenario, instead, the projected changes are more limited, with some indicators showing a stabilisation or even recovery.

Secondly, using a Lagrangian particle approach, we investigated how global changes will change the dispersal pathways of the larvae and the environmental conditions they will experience during their pelagic phase.

Ocean Acidification Effects on Reproduction and Early Life Stages of Marine Teleost Fishes: A Synthesis

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6B: Changes in biodiversity, Rongomātāne B, October 15, 2026, 16:00 - 18:00

Ocean acidification (OA) remains a major and underexplored threat to marine fishes, particularly regarding reproductive physiology and early life stages (ELS). Although research over the past 15 years has documented diverse OA effects, substantial knowledge gaps persist. Most studies focus on a limited set of species from North America and Europe, leaving broad uncertainty across phylogenetic groups, geographic regions, and multi-stressor conditions. In adults, especially females, elevated CO₂ can shift energy allocation, prioritising reproductive output at the expense of egg or clutch size. While adult and juvenile fish have developed acid-base balancing systems, embryos and larvae possess only rudimentary mechanisms, making them more vulnerable to OA. The synthesis stresses the importance of understanding these physiological and mechanistic responses to predict the future of fish stocks and ecosystem health as OA intensifies due to ongoing CO₂ emissions. Our results highlight that OA responses in fish are highly variable and often specific to life stage and species, with acute and sometimes stage-specific effects not fully documented. Lastly, our recommendations on targeted research and funding are necessary to address the remaining knowledge gaps, including broadening taxonomic and geographic sampling, exploring multi-stressor scenarios, and improving understanding of the downstream effects of OA on fish reproduction and development. Maintaining robust fish populations is vital for food security, employment, and ecosystem functioning, making continued investigation into OA's impacts a scientific and societal priority.

Early exposure shapes physiological resilience to chronic ocean acidification in embryonic sharks

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6B: Changes in biodiversity, Rongomātāne B, October 15, 2026, 16:00 - 18:00

Ocean acidification (OA) is a major threat to marine ecosystems, particularly in coastal environments that serve as critical nursery habitats for both teleost and elasmobranch species. Early life stages are especially vulnerable to OA-induced hypercapnia due to underdeveloped homeostatic organs and the high energetic cost of maintaining acid–base balance through ion-regulation mechanisms such as Na⁺/K⁺-ATPase activity in gill epithelial cells.

To investigate the biological effects of ocean acidification in catshark hatchlings, we exposed embryos of the oviparous shark *Scyliorhinus canicula* (L., 1758) at different stages of embryonic development to elevated pCO₂ conditions (519 µatm vs. ~991 µatm) until hatching. Our objectives were to test whether yolk consumption is altered to support increased Na⁺/K⁺-ATPase activity in gill epithelia, and whether developmental trade-offs occur due to energy reallocation toward chronic acid–base regulation.

Elevated pCO₂ induced developmental trade-offs; however, these effects were not directly linked to Na⁺/K⁺-ATPase activity. Instead, the developmental stage at which embryos first encountered acidified conditions emerged as the primary factor influencing hatchling mass and Na⁺/K⁺-ATPase activity. Notably, embryos exposed early in development did not upregulate Na⁺/K⁺-ATPase and maintained normal energy usage, suggesting reliance on alternative acid–base regulatory mechanisms that avoid high metabolic costs.

These findings provide the first evidence that early exposure to chronic acidification can trigger compensatory physiological responses in elasmobranch embryos. This contrasts with previous assumptions that early life stages are the most vulnerable and underscores the need for long-term, stage-specific studies to better predict shark resilience to future ocean acidification.

Multiple stressors, shifting biodiversity, and the reorganization of ecosystem functioning

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6B: Changes in biodiversity, Rongomātāne B, October 15, 2026, 16:00 - 18:00

Coastal benthic ecosystems are increasingly exposed to interacting stressors, including ocean warming, acidification, and extreme events, with major implications for biodiversity and ecosystem functioning.

Recent experimental, in situ, and synthesis approaches across biological scales show that responses to multiple stressors vary widely among functional groups. These interactions generate non-linear and context-dependent responses, limiting predictions based on single-species responses. Long-term observations, combined with mesocosm and in situ studies, further reveal that shifts in community composition and disturbance regimes can profoundly alter ecosystem structure and functioning across regions such as the Mediterranean, coral reefs in the tropics, and the Arctic.

These changes have important consequences for ecosystem functioning and services. In coastal vegetated systems such as seagrass meadows and kelp forests, environmental drivers can modify community composition and metabolic balance, with cascading effects on carbon storage (blue carbon) and carbon export. In coral reef systems, changes in community structure and carbonate production directly affect reef accretion, with implications for coastal protection under sea-level rise. These results highlight the need to integrate biodiversity, species interactions, and biogeochemical processes to better understand ecosystem responses to global change. They also emphasize that community structure can strongly modulate ecosystem services, with important implications for resilience and the evaluation of ocean-based climate mitigation strategies.

Ocean Acidification Biodiversity Task Force

Dr Kirsten Isensee¹, Lina Hansson², Prof Samuel Dupont³, Prof Stephen Widdicombe⁴

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6B: Changes in biodiversity, Rongomātāne B, October 15, 2026, 16:00 - 18:00

The world is living through a biodiversity crisis. The rapid pace at which the number of species has declined in recent decades has led to the assumption that a mass extinction is under way. Ocean acidification (OA) has been identified as one of the drivers of biodiversity loss with consequences for marine ecosystems and the communities that rely on them for food and livelihoods. A global strategy and framework, identifying and detailing research priorities, best practices and proxies to measure and understand the local and regionally relevant impacts of OA on marine biodiversity is currently missing. Such a framework is critically needed to prioritize fit-for-purpose research and guide actions to address and minimize the impact of OA on marine biodiversity. We will present a first attempt to fill this knowledge and management gap, based on the input of experts of the Global Ocean Acidification Observing Network and the field of marine biodiversity. The aim is to enable countries to combat OA and the associated biodiversity loss as mandated under the Global Biodiversity Framework (GBF) of the UN Convention on Biological Diversity.

Understanding mollusc host – microbe interactions in a changing ocean

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6B: Changes in biodiversity, Rongomātāne B, October 15, 2026, 16:00 - 18:00

Global climate change and ocean acidification are altering marine biodiversity by reshaping ecological interactions, disease dynamics, and the resilience of foundation species. Microbial communities are increasingly recognised as central mediators of these responses, linking environmental change to host health, ecosystem stability, and food safety. Here, we assess how ocean warming and acidification modify microbial assemblages across environmental and host-associated habitats, with implications for biodiversity outcomes and ecosystem resilience in coastal systems.

Using controlled mesocosm experiments alongside a two-year field time series from a climate change hotspot, we investigated microbial dynamics in seawater and two ecologically and economically important oyster species, the Sydney rock oyster (*Saccostrea glomerata*) and the Pacific oyster (*Crassostrea gigas*). Microbial communities were characterised using 16S rRNA gene sequencing, complemented by targeted qPCR quantification of pathogenic *Vibrio* species. Climate stressors drove coordinated shifts in both environmental and oyster-associated microbiomes, indicating strong coupling between external conditions and host-associated biodiversity. Warming consistently increased the abundance of putative pathogens, including taxa within the *Vibrio harveyi* clade, coinciding with elevated oyster mortality. Simulated atmospheric heatwaves further amplified *Vibrio parahaemolyticus*, a pattern independently validated through real-time monitoring of farmed oysters.

These results demonstrate that climate-driven changes in temperature and carbonate chemistry restructure microbial biodiversity and intensify pathogen emergence, undermining host resilience and ecosystem stability. By linking climate stressors to microbial community change and biological outcomes, this work highlights the critical role of microbiomes in shaping ecological responses to global change and informs strategies to enhance ecosystem resilience under future ocean conditions.

Trait-based quantification of biological responses to ocean acidification across global marine time series

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6B: Changes in biodiversity, Rongomātāne B, October 15, 2026, 16:00 - 18:00

Ocean acidification (OA), a CO₂-driven alteration of seawater carbonate chemistry, is known from two decades of largely laboratory studies to affect marine organism physiology and behaviour. Yet in situ biological consequences that can be confidently attributed to OA remain poorly documented due to limited integration of long-term biological and chemical observations. A key barrier is the lack of standardized approaches to quantify and compare biological responses across ecosystems under combined environmental drivers.

We developed a trait-based framework to quantify rates of biological change in relation to OA and other climate-relevant drivers. We compiled 15 global case studies from long-term marine time series spanning the Arctic, Atlantic, Pacific, and Southern Ocean, covering phytoplankton, zooplankton, and benthic organisms, including calcifiers. Biological observations were paired with carbonate chemistry and broader physico-chemical data, supplemented when necessary with reanalysis and remote sensing products. A semi-automated workflow removes the seasonal signal, applies piecewise trend segmentation, and estimates biological and physico-chemical rates of change. Multivariate ordination and mixed-effects models identify dominant environmental drivers and potential biological indicators of OA response.

Results highlight a scarcity of co-located long-term biological and carbonate system observations (>15 years), underscoring the need for better alignment of monitoring efforts. Nevertheless, OA contributes to biological change alongside temperature and nutrients, together explaining up to 80% of the response. Biological responses vary strongly in direction, magnitude, and nonlinearity, indicating contrasting sensitivity across biological groups and traits.

This work establishes a scalable framework to detect and compare biological responses to OA across ecosystems under global change.

Ocean observing technologies and strategies for Ocean Alkalinity Enhancement Research

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6C: Ocean solutions: Understanding ocean-based climate solutions: Ecological implications, monitoring needs, and financing pathways, Rongomātāne C, October 15, 2026, 16:00 - 18:00

Total Alkalinity has been identified as one of the key controls on atmospheric CO₂ on longer timescales, leveraging the ocean's large capacity to store carbon. Unsurprisingly, Ocean Alkalinity Enhancement (OAE) is proposed as one approach to carbon dioxide removal (CDR) to mitigate the effects of anthropogenic CO₂ on Earth's climate after substantial emissions reductions.

Research into safety, durability, and methodology for Monitoring, Reporting and Verification (MRV) can be done by deliberately introducing alkaline minerals in field trials or by using natural analogues, such as alkalinity-enriched riverine plumes.

The talk will report on major MRV developments during the OAE field trials ongoing in Halifax Harbour since 2023. The results will be contrasted with the preliminary findings from the 2026 RaGAS campaign in Hawkes Bay, NZ, in which the same observing methodology to observing the Esk river plume will be applied. The collected high-resolution autonomy-enabled data are needed in the context of MRV to construct an alkalinity baseline and interpret carbonate system signals for environmental assessment studies.

The sources and sinks of total alkalinity, related to riverine inflow, wastewater treatment plant outputs, organic alkalinity, benthic fluxes and deposition of organic matter and inorganic waste material (pyritic slate) will be discussed. The control of seasonality and water circulation dynamics on the dispersion of the alkaline plumes and their composition will be highlighted as well.

Linking Ocean Acidification to the Spatial Distribution of *Rochia niloticus* in Tiaro Bay, Guadalcanal, Solomon Islands

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6C: Ocean solutions: Understanding ocean-based climate solutions: Ecological implications, monitoring needs, and financing pathways, Rongomātāne C, October 15, 2026, 16:00 - 18:00

The sustainable management of trochus (*Rochia niloticus*) is essential for supporting coastal livelihoods and maintaining reef ecosystem health in the Solomon Islands. This study examines the spatial distribution of *R. niloticus* in relation to ocean acidification in Tiaro Bay, Guadalcanal. The study area was divided into five zones Northern Side, Northern Side Inner Bay, Inside Bay, Southern Side Inner Bay, and Southern Side to assess patterns in abundance and size structure. Preliminary results indicate that the Northern Side, Southern Side, and Southern Side Inner Bay recorded the highest overall abundance of trochus. In contrast, the Inside Bay contained a greater proportion of commercially sized individuals. These spatial variations suggest differences in habitat suitability, potentially influenced by ocean acidification. Historically, trochus populations in Tiaro Bay declined significantly. However, the introduction of Community-Based Resource Management (CBRM), supported by the Solomon Islands Government through the Ministry of Fisheries and Marine Resources and the Japan International Cooperation Agency (JICA), has contributed to a noticeable recovery in stocks. Despite this improvement, communities continue to report uneven distribution and abundance across reef areas, highlighting the need to better understand the impacts of ocean acidification. Monitoring ocean acidification is critical for strengthening CBRM by providing scientific evidence to complement local knowledge. In particular, pH monitoring enhances the ability of communities to detect environmental changes, evaluate management effectiveness, and support adaptive decision making. Integrating ocean acidification data into CBRM frameworks will promote the sustainable use of trochus resources and support long-term reef resilience in Tiaro Bay.

Biological thresholds for mCDR carbonate chemistry

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6C: Ocean solutions: Understanding ocean-based climate solutions: Ecological implications, monitoring needs, and financing pathways, Rongomātāne C, October 15, 2026, 16:00 - 18:00

Multiple approaches to marine carbon dioxide removal (mCDR) have been proposed and are being evaluated as climate change mitigation strategies. As part of their operation, mCDR interventions would alter ocean carbonate chemistry, which may affect marine organisms through multiple physiological pathways. We created a database of available information on marine species response to the carbonate chemistry conditions that can be generated by mCDR, such as high pH, low pCO₂ or high alkalinity. The database contains 310 studies, from which we estimated 276 biological thresholds, where thresholds are defined as carbonate chemistry conditions generating a biological response (negative or positive) or a high pH/alkalinity condition that generated no biological response. We reviewed studies designed to explicitly evaluate mCDR and studies designed for other purposes, such as those designed to explore basic physiological and biological responses as well as approaches to mitigate ocean acidification. We describe the distribution of pH and alkalinity threshold values from the studies stratified by taxa and other factors. The data reveal a high tolerance for high pH (>12) and high alkalinity for some species responses under some experimental conditions, but a negative response to experimental conditions only slightly above ambient (pH 8.3) for other species responses. A positive effect of pH above ambient levels was observed in six cases, just 3% of the total. In this work, we propose a pathway for management threshold development and provide recommendations for future studies to improve threshold estimates.

Ocean Alkalinity Enhancement as an Ocean-Based Climate Solution: Ecological Implications for Coastal Sediment Biogeochemistry

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6C: Ocean solutions: Understanding ocean-based climate solutions: Ecological implications, monitoring needs, and financing pathways, Rongomātāne C, October 15, 2026, 16:00 - 18:00

Ocean Alkalinity Enhancement (OAE) is a rapidly growing ocean carbon dioxide removal strategy, but its impacts on shallow coastal sediment processes remain unexplored. Using a controlled flow-through mesocosm system, we applied a gradient of NaOH-based alkalinity additions to quantify how elevated alkalinity and the immediate shifts in pH and carbonate speciation influences sediment biogeochemistry, focusing on metabolic exchanges of oxygen, carbon, and nitrogen. Across the gradient, we observed consistent shifts in water-column TA, DIC, and pH that altered sediment oxygen demand and dissolved inorganic nitrogen fluxes, indicating that sedimentary C and N-cycling pathways may be sensitive to unequilibrated OAE conditions in nearshore environments. This experiment also underscored several practical and methodological challenges relevant to mesocosm-based OAE research: (1) achieving stable, well-mixed alkalinity treatments under continuous flow; (2) managing rapid atmospheric CO₂ uptake following NaOH additions; and (3) separating true treatment effects from natural variability introduced by resident benthic communities. Addressing these challenges was central to improving experimental design and allowing for comparability across OAE mesocosm studies

mCDR Research and Initiatives in Southeast Asia

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6C: Ocean solutions: Understanding ocean-based climate solutions: Ecological implications, monitoring needs, and financing pathways, Rongomātāne C, October 15, 2026, 16:00 - 18:00

Marine carbon dioxide removal (mCDR) in Southeast Asia remains in its infancy, despite increasing global recognition of its role in achieving net-zero targets. The region's high coastal productivity and climate vulnerability position it as a potentially high-impact setting for mCDR, supported by extensive blue carbon ecosystems such as mangroves, seagrass meadows, and macroalgal systems.

Current efforts are primarily limited to nature-based approaches, including mangrove restoration, seagrass conservation, and seaweed aquaculture. While these initiatives provide important climate mitigation and socio-economic co-benefits, they remain fragmented and are not yet embedded within a cohesive mCDR framework. In contrast, engineered approaches—such as ocean alkalinity enhancement—are still at a nascent stage, with activities largely confined to early research and pilot-scale trials.

Key challenges include significant gaps in carbon accounting, monitoring, reporting and verification (MRV), and uncertainties surrounding long-term carbon sequestration. These limitations are further compounded by ongoing coastal degradation and the lack of coordinated regional governance, constraining scalability and investment readiness.

Southeast Asia is therefore at a decisive yet early-stage inflection point. Without accelerated scientific advancement, policy alignment, and regional coordination, the region risks remaining a passive carbon reservoir rather than becoming an active leader in ocean-based climate solutions. Strategic investment and integration of ecosystem-based and engineered approaches will be essential to unlock its full mCDR potential.

Progress in Ocean Acidification Observing Capacity in the Argentine Atlantic

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6D: Technological advances (General), Mătiu, October 15, 2026, 16:00 - 18:00

Over the last decade, the Argentine Atlantic has experienced substantial growth in its capacity to observe and understand ocean acidification and marine carbonate system variability. What was once characterized by sparse measurements and limited analytical infrastructure has evolved into a growing network of observations supported by expanded laboratory capabilities, oceanographic cruises, coastal time-series initiatives, citizen science programs, and international collaborations.

This presentation will provide an overview of the development of ocean acidification observing capacity in Argentina, across coastal and offshore environments. Examples from long-term monitoring efforts, regional capacity-building initiatives, and participation in international observing networks will illustrate how scientific, technical, and collaborative efforts have contributed to strengthening carbonate system observations in the South-West Atlantic.

The talk will also discuss remaining challenges, including sustaining long-term observations, expanding spatial coverage, and integrating carbonate system monitoring within broader climate and ecosystem observing frameworks. In a context of evolving scientific priorities and fluctuating funding opportunities, the Argentine experience illustrates both the vulnerability and resilience of long-term environmental observations, demonstrating how collaboration, capacity development, and community engagement can help sustain observing systems and support regional contributions to global ocean acidification research.

Electrochemical Acid Sequestration to Ease Ocean Acidification (EASE-OA)

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6D: Technological advances (General), Mătiu, October 15, 2026, 16:00 - 18:00

We review the successes, challenges, and key findings of the Electrochemical Acid Sequestration to Ease Ocean Acidification (EASE-OA) project, a collaborative effort among the University of Washington, the U.S. Department of Energy's Pacific Northwest National Laboratory (PNNL), NOAA's Pacific Marine Environmental Laboratory, and Ebb Carbon. From 2022 to 2025, the project conducted a field trial of Ebb Carbon's electrochemical ocean alkalinity enhancement (OAE) technology at PNNL's Sequim Bay Laboratory.

EASE-OA integrated (i) modeling to evaluate efficacy, environmental impacts, and detectability across deployment scenarios; (ii) mesocosm experiments assessing species-level responses among local fauna; and (iii) laboratory and field measurements to evaluate environmental safety and regulatory compliance.

Across these efforts, results indicate that impacts on local biota, carbonate chemistry, and carbon cycling are modest and largely undetectable beyond the immediate mixing zone, potentially even under scale-up scenarios several orders of magnitude larger than the field trial. No critical technical or environmental barriers were identified at the scales tested.

This project illustrates how coordinated efforts across industry, academia, and government can support rigorous, independently evaluated testing of emerging carbon dioxide removal technologies.

Sequential Treatment Application Robot Version 2: A robotic platform for high-replication, continuous ocean acidification experimentation and monitoring on marine organisms

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6D: Technological advances (General), Mătiu, October 15, 2026, 16:00 - 18:00

Ocean acidification (OA) experiments are often constrained by the challenges of maintaining multiple independent, continuous treatments, which limit throughput, replication, and the understanding of biological responses. Here, we developed an upgraded Sequential Treatment Application Robot (STARv2) system to autonomously manipulate and monitor pH at scale. The system consists of a robotic arm and a dosing end effector with an integrated optical pH sensor and a thermistor connected to an array of precise peristaltic pumps. The system is controlled via a Python-based interface, which allows for customizable treatment volumes and vessel locations. We validated this system using two robotic arms to sequentially deliver precise volumes from a high (pH 8.05) and a low (pH 7.40) reservoir to 56 independent vessels, thereby maintaining seven continuous pH treatments (7.63–8.05, ~0.07-unit intervals) across eight aquaria. This system maintained continuous operation (>98.5% uptime) for 51 days, with full water changes occurring every 1.6 hours. Automated and manual glass-bulb electrode pH measurements validated the system by demonstrating significant differences among all seven treatments. We then evaluated OA on the reef-building coral *Orbicella faveolata* and found no treatment effects on buoyant weight, photosynthetic efficiency, respiration, or photosynthesis, consistent with previous short-term studies on massive corals. STARv2 is a validated autonomous system that increases replication, enables continuous evaluation of biological responses in OA experimentation, and can be customized across different pH ranges, stressors, and tank designs. This enables enhanced resolution of biological thresholds in marine organisms in response to increasing CO₂ that are missed by traditional experimental designs.

Single-cell measurement of carbon allocation under environmental change

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6D: Technological advances (General), Mātiu, October 15, 2026, 16:00 - 18:00

Understanding how phytoplankton respond to climate change requires methods that can detect rapid changes in cellular carbon allocation. Current methods for quantifying cellular proteins and lipids are slow (hours to days), labour-intensive, and require large sample volumes. As a result, our ability to detect short-term physiological responses or heterogeneity among individual cells is limited. These measurement constraints are significant for experiments that assess the impacts of changing ocean conditions, and for efforts to monitor biological responses to marine carbon dioxide removal approaches, such as ocean alkalinity enhancement.

Here, we present a near real-time platform for quantifying carbon allocation in individual phytoplankton cells. This approach combines computational microscopy, shelf-stable fluorescent sensing layers, and AI-based cell detection to quantify intracellular protein, polar lipids, and neutral lipids. Hundreds to thousands of cells can be analysed within minutes using <0.1 mL of sample, allowing carbon reallocation to be measured at both single-cell and population scales. We have used this approach in laboratory experiments across temperate and subantarctic phytoplankton to quantify intracellular carbon allocation in response to short- and long-term changes in light, nutrient availability, sinking, and temperature.

By linking automated cell identification with intracellular sensing, this platform provides a rapid method to quantify carbon allocation in phytoplankton and detect reallocation between cellular carbon pools before changes in growth, abundance, or community composition are detected.

ESA-funded activities for enhancing satellite-based ocean carbon science

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Within a broader scope of scientific exploitation of satellite assets, the European Space Agency (ESA) is funding a critical mass of R&D activities aimed at enhancing the observation and understanding of the Ocean from space.

Namely, the ESA Ocean Science Cluster is a portfolio of several scientific opportunities and networking actions promoting synergistic ocean research. More than 40 projects are currently belonging to the Ocean Science Cluster, which is further regrouped into sub-topics, including a distinct focus on Ocean Carbon.

This presentation will provide an excursus of the results and outcomes of a sub-selection of the ocean-carbon related recent and ongoing projects, with special emphasis on Ocean Acidification, Ocean sink, Ocean carbon pools and fluxes, coastal carbon and ocean biodiversity.

Furthermore, an overview of the main elements and objectives of ESA upcoming projects regarding a Digital Twin (DT) for Ocean Carbon and marine carbon dioxide removal (mCDR) will be provided.

The projects' datasets are all freely and openly available to the community, providing a unique resource to further inspect open and coastal oceans in a high-CO₂ world.

The Pacific-Village NbS Framework: Indigenous-Grounded and Modern Science Supported Adaptation - A Case-Study of Saoluafata, Samoa

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6E: Knowledge systems: Rebuilding coastal ecosystems through transformative change: Coastal people and a changing world, Mākaro, October 15, 2026, 16:00 - 18:00

Saoluafata village in Upolu Island, Samoa, has been adapting to severe weather and tectonic submergence for centuries by drawing on Indigenous, place-based knowledge and traditional practices to protect both the environment and community. However, human activities have led to severe erosion, making Saoluafata one of the most vulnerable areas in Samoa to coastal erosion and flooding (MNRE, 2021). In response, a seawall was constructed, which resulted in the removal of the crucial bar-built estuarine features, including the sandbar, a meandering channel, shallow lagoon, floodplains, and accreting inlet/outlet. These natural features had previously sheltered the village from cyclones and storm surges, and facilitated sediment deposition that kept pace with rising sea levels. The seawall transformed the coastal geomorphology, damaging wetland systems and undermining Saoluafata's resilience to sea-level rise and climate change.

Restoring the coastal natural barrier and estuarine systems of Saoluafata, including the sand barrier and channel/estuarine wetlands, may be achieved through Nature-based Solutions (NbS). These solutions are increasingly recognised as beneficial, practical, and cost-effective alternatives to engineered solutions. They help communities adapt and build natural resilience to the impacts of climate change.

This presentation introduces the Pacific-Village NbS Framework, which is grounded in Indigenous knowledge and supported by science, and focuses on a potential longitudinal NbS case study in Saoluafata. This case study will provide insights into NbS and values-driven approaches to ecosystem-based resilience. It will also highlight the long-term advantages of reversing environmental damage by rebuilding coastal ecosystems to enhance climate resilience and adaptation.

The impacts of marine heatwaves and low salinity on blackfoot abalone (pāua) in Aotearoa/New Zealand

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6E: Knowledge systems: Rebuilding coastal ecosystems through transformative change: Coastal people and a changing world, Mākaro, October 15, 2026, 16:00 - 18:00

Climate-driven marine heatwaves are increasing in frequency, intensity, and duration, posing growing risks to coastal marine ecosystems. These large-scale thermal events often coincide with local stressors such as coastal flooding that can cause acute reductions in seawater salinity. Despite the increased likelihood of the co-occurrence of these events in our changing climate, the effects of extreme events on key marine invertebrates are poorly understood. Here, we investigated the responses of juvenile blackfoot abalone *Haliotis iris* (pāua) to the interaction of a simulated marine heatwave and short-term hyposalinity event. Responses were assessed through transcriptomic profiling, feeding rate, growth, and righting behaviour. Juvenile pāua under flood conditions had 6% righting success as compared with 100% righting success in control pāua. Following the return to ambient salinity, recovery varied among individuals, with those previously exposed to the marine heatwave showing more varied time-to-right and success of righting. Contrastingly, the marine heatwave alone had minimal behavioural effects but was associated with a slight increase in feeding, suggesting compensatory metabolic responses. To place these results in an ecological context, we compared experimental outcomes with local contexts at two North Island sites in Aotearoa New Zealand that experience contrasting issues associated with freshwater runoff. We also assessed behavioural and transcriptomic responses of pāua to locally relevant temperature fluctuations under coastal marine heatwaves on both the east and west coasts. Together, these results provide insights into how interacting climate-driven and local stressors may affect pāua populations and inform future management of this culturally and economically important species.

Kaimoana and Climate: Mātauranga Māori as a Pathway to Coastal Ecosystem Restoration

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6E: Knowledge systems: Rebuilding coastal ecosystems through transformative change: Coastal people and a changing world, Mākaro, October 15, 2026, 16:00 - 18:00

Rising atmospheric CO₂ and ocean acidification pose existential threats to coastal ecosystems that Indigenous and local communities have depended on for food security for generations. The degradation of traditional coastal food sources, including shellfish, kaimoana, and intertidal species, represents not only an ecological crisis but a profound disruption to cultural identity, relational knowledge, and community wellbeing.

This paper examines the intersection of ocean acidification, food insecurity, and Indigenous-led ecosystem restoration, arguing that transformative change requires more than technological intervention; it demands a fundamental reorientation toward coastal peoples as knowledge holders and governance actors.

Drawing on kaupapa Māori research methodologies and Indigenous governance frameworks, this paper explores restoration initiatives that centre community voice, intergenerational ecological knowledge, and relational approaches to environmental stewardship. It considers how traditional food-gathering practices, seasonal harvesting protocols, and place-based knowledge systems offer critical pathways for rebuilding coastal resilience in a high CO₂ world.

The paper further argues that food security cannot be decoupled from structural equity, that restoring coastal food sources requires addressing the colonial and institutional frameworks that have historically marginalised coastal communities from decision-making over the environments they depend on.

This paper contributes to growing calls for transformative ocean governance that honours the agency of coastal peoples and integrates Indigenous knowledge alongside Western science in shaping just and effective responses to the climate crisis.

A giant kelp forest on the edge

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6E: Knowledge systems: Rebuilding coastal ecosystems through transformative change: Coastal people and a changing world, Mākaro, October 15, 2026, 16:00 - 18:00

Kelp forests are vital to coastal communities but are declining in some regions under the combined pressures of marine heatwaves (MHWs) and trophic disruption, often shifting to persistent, denuded ‘urchin barrens’.

I surveyed the Mana Bridge, Aotearoa New Zealand—a culturally significant, underexplored shallow reef supporting what is likely the largest *Macrocystis pyrifera* forest in the North Island, near its northern range edge. Using diver surveys of macroalgae and mobile benthic invertebrates, remote sensing, and long-term temperature records, we mapped kelp forest extent and exposure to key drivers of decline to inform kaitiakitanga (stewardship).

The Bridge is characterised by strong tidal currents, a homogeneous gravel–cobble substrate, and a mosaic of nine habitat types, including giant kelp forests, maërl, and anemone beds. Sea urchins (*Evechinus chloroticus*; kina) occurred in dense, patchy aggregations, with small barrens observed. Predatory seastars were common, whereas red rock lobsters (*Jasus edwardsii*; kōura) were absent, likely due to low substrate complexity.

Satellite observations (2015–2024) revealed highly variable kelp surface canopy detection, with a potential maximum extent of 45.6 ha. Temperature records showed significant warming (~ 0.20 °C decade⁻¹) and 7–9 MHWs in 2025 (108–149 days), including prolonged summer events exceeding 19 °C—conditions linked to kelp decline.

These findings indicate the Mana Bridge kelp forest is experiencing thermal and grazing pressure; whether kina aggregation may serve as an early warning sign of incipient barrens remains unresolved. Rebuilding resilience will require transformative approaches integrating science, targeted iwi-led, place-based, kaitiakitanga, highlighting pathways for kelp forest recovery in a warming ocean.

One of nature's great events rises from the ashes of an extinguished tropical cyclone.

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6E: Knowledge systems: Rebuilding coastal ecosystems through transformative change: Coastal people and a changing world, Mākaro, October 15, 2026, 16:00 - 18:00

Slow-moving tropical cyclones upwell cold, nutrient-rich water into the euphotic zone, triggering phytoplankton blooms in otherwise oligotrophic waters (Lin, 2003). The magnitude of these blooms correlates strongly with a “hover parameter” that captures the integrated residence time of a storm over a given location, with extreme events ($H \geq 10$) predicted to recur on millennial timescales (Russell & Horvat 2023). Here we report on Tropical Cyclone Maila, which remained quasi-stationary over the Solomon Sea for eight days in April 2026, becoming the strongest tropical cyclone recorded there, and producing one of the largest phytoplankton blooms in the satellite record over approximately 500,000 km² of the typically low-biomass Solomon Sea. Maila’s hover index above 40 exceeds that of TC Oma ($H = 39$) in 2019, the previous most extreme such event ever observed. Yet what made Maila productive was also its own demise: the Ekman pumping that brought cold, nutrient rich waters to the surface of the Solomon Sea also cooled surface waters below levels required to sustain it. The death of Maila, and the clearing of the cyclone-related cloud cover, gave phytoplankton a high insolation, high-nutrient environment to thrive. That two such events have occurred within seven years, in areas where similar large, slow-moving TCs were estimated to have millennial return times, underscores both the possible non-stationarity of tropical cyclone statistics (Kossin 2018), and exposes an unreported and under-appreciated coupling between storm behavior, ocean dynamics, and the response of the marine ecosystem.

Ocean deoxygenation and marine heatwaves: scaling interacting stressors from organisms to ecosystems

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7A: Multiple Stressors, Rongomātāne A, October 16, 2026, 11:30 - 13:00

Ocean deoxygenation (OD) and marine heatwaves (MHWs) are major stressors reshaping marine ecosystems, yet their combined ecological impacts remain poorly resolved. While warming directly elevates metabolic oxygen demand and can increase physiological oxygen sensitivity thresholds, such as p_{crit} , ecosystem scale responses also depend on how MHWs alter the physical and biogeochemical drivers of oxygen supply and consumption. MHWs can modify circulation, increase microbial respiration, and/or suppress export production, each of which affects bottom water oxygen budgets. The balance of these processes is particularly important for productive upwelling shelf systems where dissolved oxygen concentrations often sit near thresholds for hypoxia. Using 16–23 years of moored observations from inner and mid continental shelf stations in the Northern California Current, we partition changes in bottom water oxygen into advective and respiratory components and show that MHWs tend to increase rather than decrease hypoxia risk. We then apply new parameters for temperature and oxygen sensitivity for Dungeness crab (*Metacarcinus magister*), the region's most economically important fishery species, to project impairment risks under coupled OD–MHW scenarios. We further leverage long term observations to quantify the time of emergence for independent and joint shifts in hypoxia and warming stress that the fishery will face. Our results reveal that the vulnerability of coastal food webs to global change depends critically on the interplay between organismal physiology and ecosystem scale oxygen dynamics.

Effects of abiotic factors on the behavior and luminescence of the sea pen *Pennatula phosphorea*

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7A: Multiple Stressors, Rongomātāne A, October 16, 2026, 11:30 - 13:00

Sea pen meadows are important components of soft-sediment benthic ecosystems, contributing to habitat structure, benthic–pelagic coupling, and biodiversity. However, they are increasingly exposed to anthropogenic stressors such as ocean warming, acidification, and changes in hydrodynamic conditions. Understanding how these stressors affect the functional traits of habitat-forming species is essential for predicting ecosystem responses to global change.

Here, we investigate the effects of warming, acidification, and current velocity on the common sea pen *Pennatula phosphorea*, using behaviour and bioluminescence as sensitive functional indicators. Colonies were exposed to elevated temperature, reduced pH, and varying flow conditions, both individually and in combination. We monitored survival, burrowing activity, and feeding behaviour (via polyp dynamics). In parallel, we assessed bioluminescence by analysing light emission patterns and associated biochemical components, including luciferase activity and coelenterazine content.

Temperature significantly increased mortality, identifying warming as a primary driver of stress. Reduced pH induced sublethal effects, including consistent alterations in burrowing and feeding behaviour. In contrast, no detectable effects of current velocity were observed on the measured traits. Under combined stress conditions, temperature and pH effects were amplified. Bioluminescence was also strongly affected, with altered emission patterns and reduced coelenterazine availability, indicating metabolic disruption.

Our results highlight bioluminescence as a sensitive proxy of physiological condition under environmental stress and emphasize the importance of prioritizing key stressors when predicting ecosystem vulnerability.

A framework for exploring the impacts of ocean acidification on food security

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7A: Multiple Stressors, Rongomātāne A, October 16, 2026, 11:30 - 13:00

Ocean acidification (OA) has been identified as a threat to human health and wellbeing, including through alterations in food quality and quantity. Regional and local scale vulnerability assessments have found food security to be the socioeconomic system most at risk from OA. Yet, the recognition that OA is a threat to food security and to 'blue foods from the sea' is primarily found in OA-specific epistemic communities and is rarely discussed in broader global conversations on food security. Here, we reorient the existing predominantly physical science knowledge of OA impacts toward a food security framing through a synthesis of existing literature. We do this by examining the known and proposed impacts of OA against the six dimensions of food security, as described by the High-Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security. Our analysis finds that OA poses risks to all six dimensions, with availability, stability and sustainability most acutely threatened through projected declines in shellfish availability, and access, utilization and agency disproportionately affecting small-scale fisheries and coastal communities reliant on blue foods. Viewing OA impacts through a food security lens provides an alternative means for understanding the compounding vulnerabilities faced by these communities that analyses of OA impacts alone have missed. This presentation aims to produce a more nuanced and actionable understanding of the OA-food security nexus that can in turn be used to inform global policy and adaptation approaches that better consider the intersection of these two issues.

Repeated acute stressors under chronic warming: seasonal resilience of the green sea urchin across behavioural, reproductive and molecular responses

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7A: Multiple Stressors, Rongomātāne A, October 16, 2026, 11:30 - 13:00

Cold-temperate coastal ecosystems are increasingly exposed to overlapping stressors, including chronic warming and episodic extreme events such as marine heatwaves and flooding. Yet their combined effects on the physiology, reproduction and behaviour of ecologically and commercially important species remain poorly understood. The green sea urchin *Strongylocentrotus droebachiensis* supports important fisheries in the St. Lawrence Estuary and Gulf, where harvesters from the Wolastoqiyik Wampanoag First Nation have reported delays in gonad development, raising concerns about whether warmer waters and extreme events may disrupt this species' reproduction and resilience.

To investigate these responses, adult urchins were exposed for six months under laboratory conditions to natural daily fluctuations in temperature and salinity, or to chronic warming (+1.5°C), both superimposing monthly 5-d stress events simulating marine heatwaves (+4°C) and flooding (−5 salinity), in isolation or combined. After each event, we characterised gonad quality, gonad maturation stage via histology, and behavioural responses (adhesion strength, activity, algal consumption). At the last event, we sampled gonad tissues for lipidomic profiling and oesophageal tissues for metabolomic analyses to provide molecular insights into the cumulative effects of chronic and repeated acute stressors.

Preliminary results indicate no mortality across treatments, suggesting adults tolerate short-term fluctuations within the tested range. However, low-salinity events reduced activity, adhesion and feeding, suggesting that flooding represent a stronger short-term stressor than warming. Together, these findings will help clarify how chronic and episodic stressors interact to shape seasonal resilience in coastal invertebrates, with direct implications for the sustainable management of urchin fisheries under climate change.

Towards understanding the role of coastal habitats as ocean acidification refugia within a seascape context

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7B: Changes in biodiversity. Buffer or Booster? When Primary Producers Mitigate or Amplify Ocean Acidification, Rongomātāne B, October 16, 2026, 11:30 - 13:00

Global change, including ocean acidification, is expected to exacerbate environmental variability in coastal systems, resulting in more extreme and prolonged acidification events in the future, which exceed the physiological limits of tolerance for some species.

Our research focuses on vegetated coastal habitats within coastal and estuarine seascapes, which play a critical role in supporting coastal biodiversity. We will present the results of short-term, autonomous monitoring conducted within coastal seagrass and macroalgal habitats along the warm temperate south coast of South Africa, together with the experimental assessment of the response of common coastal species, including sea urchins and early-stage fish, to acute low pH exposure. Data obtained from HOBO pH and temperature loggers revealed significantly more variable (range = ~0.6) and higher average pH conditions within densely vegetated macroalgal reefs (average = ~8.4) and seagrass meadows (average = ~8.3) compared to adjacent unvegetated habitats (average = ~8.03 – 8.17), suggesting that these vegetated habitats may function as potential acidification refugia.

Experiments demonstrated a high sensitivity of early-stage sea urchins to projected future coastal acidification scenarios (pH 7.6), evidenced by reduced growth rates and pronounced developmental regression. This is despite the occurrence of adults in habitats with highly variable pH conditions. In contrast, early-stage fish showed tolerance to acute low pH conditions, with no adverse physiological response observed down to pH 7.2. Future research efforts will focus on further disentangling the role of these habitats as refugia, through extended monitoring efforts and further experimental research on a wider range of species and habitat types across coastal seascapes. A wholistic understanding on the role of coastal vegetation as ocean acidification refugia can facilitate improved local management and mitigation of its effects on local species.

Field based observations to understand ecological interactions with carbonate chemistry between seagrass and coral habitats

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7B: Changes in biodiversity. Buffer or Booster? When Primary Producers Mitigate or Amplify Ocean Acidification, Rongomātāne B, October 16, 2026, 11:30 - 13:00

Coral reefs are among the ecosystems vulnerable to ocean acidification. Notably, aragonite saturation is now approaching the threshold for a regime shift, wherein juvenile coral and calcifying macroalgae decline and non-calcifying macroalgae proliferate. Despite these concerns, substantial uncertainties remain regarding the buffering capacity. Here we present field observations in carbonate chemistry from around Green Island on the Great Barrier Reef. Green Island has dense, productive seagrass meadows uncommon for the area making it an ideal study location. The first approach, investigates three different habitats (seagrass, coral, sand) effect on carbonate chemistry at the sea surface over a diurnal cycle. The second approach, spatially examines carbonate chemistry across the seascape between high and low tide. The third utilises pH loggers to investigate pH fluctuations in seagrass meadows compared to coral reefs. The results show pH and aragonite saturation of the water column were significantly higher above seagrass than sand or coral; though total alkalinity (TA) was significantly lower above the seagrass than sand or coral. The water column above coral was below the aragonite saturation threshold at every time point, except one. In the spatial assessment we observed the water column above the seagrass meadow had the largest standard deviations of TA at midday on a low tide compared to other habitats. Aragonite saturation was below the threshold above all habitats from midnight to midday. These results show the complex nature of carbonate chemistry dynamics in coastal ecosystems.

Florida Gulf Coast Spatio-Temporal Assessment of Acidification Events in Relation to Harmful Algal Blooms

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7B: Changes in biodiversity. Buffer or Booster? When Primary Producers Mitigate or Amplify Ocean Acidification, Rongomātāne B, October 16, 2026, 11:30 - 13:00

Coastal and ocean acidification, driven by elevated atmospheric CO₂, eutrophication, riverine discharge, and other threats, is impacting the Florida Gulf coast. Coastal waters of southwest Florida experience high biomass harmful algal blooms (HABs) of the dinoflagellate *Karenia brevis* near annually; and have the potential to impact and be impacted by seasonal to interannual alterations of carbonate chemistry. Monthly sampling was conducted along two coastal transects, from Tampa Bay to Charlotte Harbor, between July 2020 and May 2025 collecting measurements of carbonate chemistry prior to, during, and following *K. brevis* blooms. Conductivity, temperature, and depth profiles as well as discrete water samples for *K. brevis* cell abundance, nutrients, and carbonate chemistry were evaluated to identify seasonal patterns and linkages among carbonate system variables, nutrients, and *K. brevis* blooms. This study aims to connect observations of high biomass blooms of *K. brevis* and alterations of carbonate chemistry in Southwest Florida. Blooms of *K. brevis* were observed during the study period, and highest pCO₂ and lowest pH_T corresponded during or post-blooms. Our study demonstrates the need for integrated monitoring to improve understanding of interactions among the carbonate system, HABs, water quality, and acidification over local to regional spatial scales and event to decadal time scales.

Can integrated multi-trophic aquaculture help reduce the effects of ocean acidification on economically important filter feeders

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7B: Changes in biodiversity. Buffer or Booster? When Primary Producers Mitigate or Amplify Ocean Acidification, Rongomātāne B, October 16, 2026, 11:30 - 13:00

In aquarium and farm mesocosm experiments the increased costs of maintaining homeostasis under simulated ocean acidification (OA) is shown to divert energy away from growth and reproduction affecting the production of filter feeders important to aquaculture. It has been postulated that within Integrated multi-trophic aquaculture (IMTA) increased energetic demand may be met by greater food availability. However, assuming that IMTA increases food availability, results show that filter feeders are unable to utilise this energy due to reductions in absorption efficiency and clearance rate. Suggesting that lower scope for growth and production in the future may occur independently of nutrient availability. In some IMTA systems the fixation of inorganic carbon by macroalgae may, in part, reduce the effects of elevated pCO₂ on bivalves. Within field mesocosms supplied with elevated pCO₂ water (1000uatm) the introduction of macroalgae (*Saccharina japonica*) increased pH on average despite diurnal fluctuations. This was associated with increased clearance rate, absorption efficiency, and growth in oysters. Results also shown the importance of seagrass to local carbonate chemistry that effects bivalve production. Perhaps stretching the concept of IMTA to the management of local habitats and their services. The energetic interactions between species within IMTA systems will change due to climate change. It is unlikely that the elevated costs of maintaining homeostasis can be met by increasing energy availability in the seston. However, fixation of inorganic carbon by macroalgae and seagrass within some IMTA systems at the farm scale may, in part, mitigate the effects of OA on cultured bivalves.

Seasonal variability of air-sea CO₂ fluxes in the Northern Patagonian Shelf

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7C: Modulating role of time (General), Rongomātāne C, October 16, 2026, 11:30 - 13:00

The Argentine Continental Shelf (Southwestern Atlantic) is an important sink of atmospheric CO₂, exhibiting marked spatio-temporal variability. However, limited observational data constrain understanding of the processes driving this variability. Since 2018, continuous measurements of sea surface and atmospheric CO₂ fugacity have resumed in oceanographically and fisheries-relevant areas, including the San Jorge Gulf, using a General Oceanics 8050 pCO₂ system aboard the R/V Víctor Angelescu. We evaluated the seasonal variability of air-sea CO₂ fluxes (FCO₂) in the San Jorge Gulf and adjacent continental shelf (43°S-48°S, 68°W-61°W), a region important for fisheries and biodiversity, based on six cruises conducted between 2024 and 2025, including one in spring, one in summer, and four in winter. Results revealed a clear seasonal progression, with mean FCO₂ values of -12.5 ± 11.7 mmol m⁻² d⁻¹ in spring, -9.3 ± 12.1 mmol m⁻² d⁻¹ in summer, and 7.3 ± 11.7 mmol m⁻² d⁻¹ in winter, all significantly different from zero ($p < 0.001$). This seasonal pattern reflects a complex interplay between thermal and non-thermal effects, partially compensating across seasons with higher spatial variability in spring and summer, likely explained by biological uptake and temperature-driven solubility. Overall, the region acted as a net annual CO₂ sink (-4.8 ± 10.7 mmol m⁻² d⁻¹), despite winter CO₂ outgassing. These findings emphasise resolving fine-scale spatio-temporal variability in continental shelf systems, where short-lived and submesoscale processes strongly control air-sea CO₂ exchange. Sustained high-resolution observations are therefore essential to better constrain regional carbon budgets.

Interannual and Seasonal Variability of CO₂ Parameters in the Tropical Atlantic Ocean

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7C: Modulating role of time (General), Rongomātāne C, October 16, 2026, 11:30 - 13:00

This study examined the carbon cycling dynamics in the tropical Atlantic Ocean from 1985 to 2023, focusing on factors influencing the surface partial pressure of CO₂ (pCO₂), freshwater input, total alkalinity (ALK), total dissolved carbon (TCO₂), and pH levels. The time series data revealed significant trends, with average pCO₂ concentrations rising from approximately 350 μatm in the early 1990s to over 400 μatm by 2023. The TCO₂ levels increased from about 2000 μmol/kg to 2200 μmol/kg, while ALK rose from approximately 2300 μmol/kg to 2500 μmol/kg. This increase highlights the ocean's role as a carbon sink, particularly in areas with high biological productivity and upwelling where TCO₂ also rose. This study employed Empirical Orthogonal Functions (EOFs) to identify variability modes and understand spatial patterns of pCO₂. Freshwater dynamics significantly affect TCO₂ concentrations, particularly in coastal regions, where pH can shift from 8.2 to 7.9, exacerbating acidification. Rising sea surface temperatures have been linked to elevated pCO₂ values. These findings support the need for ongoing monitoring and effective management strategies to mitigate the impacts of climate change and ensure the sustainability of marine resources. This study documented the long-term trends in tropical Atlantic CO₂ parameters linked to the North Atlantic Oscillation (NAO) and Atlantic Multidecadal Oscillation (AMO).

CO₂ Outgassing Mechanisms in the Oxygen Minimum Zone of the Mexican Tropical Pacific

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7C: Modulating role of time (General), Rongomātāne C, October 16, 2026, 11:30 - 13:00

The Mexican Tropical Pacific (MTP) is a critical region within the Eastern Tropical North Pacific Oxygen Minimum Zone (OMZ), yet its carbonate system dynamics remain insufficiently characterized. This study investigates the impact of wind-driven circulation and mesoscale processes on dissolved oxygen (DO) and carbonate system variables—including dissolved inorganic carbon (DIC), total alkalinity (TA), pH and air-sea CO₂ fluxes (FCO₂)—using data from an oceanographic cruise conducted in March 2020 in the Gulf of Tehuantepec (GT) and the Tehuantepec Bowl (TB). Principal Component Analysis identified wind-driven circulation as the primary driver of biogeochemical variability in the region. In the central GT, "Tehuano" wind events and cyclonic eddies promoted the upwelling of hypoxic (DO < 20 μmol kg⁻¹) and carbon-rich (DIC > 2200 μmol kg⁻¹) waters to depths as shallow as 50 m. In contrast, downwelling conditions prevailed in the TB. A strong stoichiometric coupling between DIC and DO was observed (slope = -1.39), reflecting the intense remineralization processes within the OMZ. During the study period, the MTP acted as a net CO₂ source to the atmosphere, with FCO₂ values ranging from -1.92 to 24.11 mmol C m⁻² d⁻¹. The highest emissions were directly linked to eddy-induced upwelling, highlighting the role of regional physical forcing in modulation CO₂ outgassing. These results are essential for understanding the carbon cycle in under-explored regions like the Tehuantepec Bowl.

CDOM-Driven Light Attenuation Modulates Productivity and Hypoxia in an Estuarine System

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7C: Modulating role of time (General), Rongomātāne C, October 16, 2026, 11:30 - 13:00

Chromophoric dissolved organic matter (CDOM) plays a key role in regulating underwater light availability, yet its influence on hypoxia in estuarine systems remains poorly constrained. Here, we investigate how CDOM-mediated light attenuation modulates oxygen dynamics in Chesapeake Bay using a nitrogen-based biogeochemical model with an explicit representation of CDOM linked to riverine refractory dissolved organic carbon (rDOC).

Chesapeake Bay's strong salinity stratification and deep channel structure provide a natural testbed for examining spatially heterogeneous responses. Sensitivity experiments removing CDOM-associated light absorption reveal contrasting regional effects. In the upper Bay, increased light availability enhances surface primary production, leading to ~10% higher detrital production and elevated respiration, ultimately intensifying hypoxia. In contrast, in the middle and lower Bay, enhanced light penetration shifts productivity deeper due to surface nutrient depletion, increasing oxygen production at depth while also enhancing remineralization. The net effect is a reduction in time-integrated hypoxic volume by 8.8–27%, depending on freshwater forcing.

Hydrologic variability further modulates these responses: CDOM effects are strongest during dry years, while in wet years increased stratification and nutrient inputs dampen sensitivity. Importantly, multiple hypoxia metrics commonly used in fisheries and water quality management show consistent responses across experiments.

These results demonstrate that CDOM can either exacerbate or alleviate hypoxia depending on hydrographic context, highlighting its role as a key but often underrepresented control in estuarine oxygen dynamics. Incorporating CDOM explicitly in water quality models may improve projections of hypoxia under changing land use and climate conditions.

Two decades of sea-air CO₂ exchanges in the northern Antarctic Peninsula (1999-2019): Spatiotemporal variability and pCO₂ drivers

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7C: Modulating role of time (General), Rongomātāne C, October 16, 2026, 11:30 - 13:00

Surrounding the Southern Ocean, the northern Antarctic Peninsula (NAP) is known as a hotspot suffering climate change pressure. Nonetheless, an overview of the spatial and temporal variability of sea-air CO₂ fluxes (FCO₂) along the NAP is still poorly understood. Therefore, we investigated the variability of FCO₂ during the austral summer (1999 to 2019), along the NAP. Changes in dissolved inorganic carbon were identified as the main driver of interannual variability in sea surface CO₂ partial pressure (pCO₂). This indicates that CO₂ uptake/release is controlled by processes other than changes in temperature, such as photosynthesis, upwelling and air-sea CO₂ exchanges. We identified two cycles of FCO₂ variability with periodicities of 4 years until 2010, and an intensification to 2 years mainly from 2011 onwards. In general, summer sea-air CO₂ exchanges along the NAP have been near equilibrium over the past two decades, with an average FCO₂ of 0.4 ± 1.1 mmol/m²/day. Furthermore, we observed a change from a CO₂ outgassing behaviour of 0.31 ± 0.70 mmol/m²/day in the first decade investigated (1999-2009) to a CO₂ ingassing of -1.24 ± 0.92 mmol/m²/day from 2010 to 2019). This change occurred mainly due to the progressive increase in the atmospheric pCO₂, as we did not identify significant trends in the sea surface pCO₂ during summer. Therefore, these findings shed light on the sensitivity of sea-air CO₂ exchanges along the NAP and highlights the need to increase the studies about ocean acidification and CO₂ storage in this climate-sensitive region.

Improving Accessibility for Coastal Carbonate Chemistry Measurements: Expansion of Use Cases for the pCO₂ to Go, a Carbon Dioxide Sensor

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7D: Technological advances: Charting the Future: Emerging Technologies for Ocean Acidification Monitoring, Mātiu, October 16, 2026, 11:30 - 13:00

The pCO₂ to Go is a low-cost, handheld measurement toolkit developed to enable real-time accessible assessment of seawater CO₂ partial pressure (pCO₂) of coastal waters across a range of applications. It was initially conceived to provide shellfish hatcheries with a practical tool to monitor their seawater carbonate chemistry and guide buffering their tanks to enhance calcification. More recently, the pCO₂ to Go toolkit is being explored in nearshore environments where traditional instruments are limited by operational constraints, cost, or insufficient temporal and spatial resolution. Emerging applications include the rapid characterization of fine-scale spatial variability, such as assessing differences in overlying seawater across transition zones between seagrass meadows and adjacent sand flats. The pCO₂ to Go also enables the capture of short-lived, time-sensitive events, including episodic events like sargassum inundation over coral reefs or storm-responses. In parallel, project partners are expanding the accessibility of the tool through user-friendly resources, including step-by-step written and visual guides with multiple language options. Low-cost, portable tools such as the pCO₂ to Go are critical for broadening participation in coastal carbonate chemistry observations, enabling researchers and practitioners around the globe with the ability to understand and adapt to changing ocean conditions, develop stronger understandings of their coastal environments, and expand research across all ocean basins.

Advancing Autonomous Total Alkalinity Measurements for Ocean Acidification Monitoring and Ocean Alkalinity Enhancement Applications

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7D: Technological advances: Charting the Future: Emerging Technologies for Ocean Acidification Monitoring, Mātiu, October 16, 2026, 11:30 - 13:00

Total alkalinity (TA) is a central but under-observed parameter of the marine carbonate system, limiting our ability to resolve ocean acidification (OA) processes and evaluate emerging ocean alkalinity enhancement (OAE) strategies. Here, we present recent advances in autonomous TA sensing, focusing on the performance of a microfluidic, reagent-based system deployed on a moored platform in a dynamic coral reef environment in Kāneʻohe Bay, Hawaiʻi. Field deployments spanning multi-week periods demonstrate that autonomous TA measurements can achieve precision of $\sim\pm 6\text{--}7\ \mu\text{mol kg}^{-1}$, sufficient to resolve diel to tidal variability exceeding $100\text{--}200\ \mu\text{mol kg}^{-1}$ and capable of quantifying the excess alkalinity generated from OAE experiments. High-frequency field observations reveal pronounced daily variability driven by benthic biogeochemical processes—signals not fully captured by discrete sampling, the large uncertainties associated with pH+pCO₂–derived carbonate system estimates, or salinity-based empirical relationships that break down in highly productive reef systems. Integration of autonomous TA with co-located pCO₂ observations improves constraints on carbonate system calculations and reduces uncertainty in derived parameters such as carbonate ion concentration and aragonite saturation state (Ω_{arag}). Uncertainty propagation from combined TA and pCO₂ measurements yields relative uncertainties of $\sim 3\%$ for carbonate ion concentration and $\sim\pm 6\%$ for Ω_{arag} —above the $\sim 1\%$ target for climate-quality observations, but within the range typically considered acceptable for weather-quality and OAE applications. These results highlight the value of TA as a complementary constraint within OA observing systems and its critical role in distinguishing natural variability from engineered perturbations in OAE monitoring, reporting, and verification (MRV) frameworks.

From tropical shores to extreme winter storms: USV adaptive sampling for ocean carbonate chemistry

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7D: Technological advances: Charting the Future: Emerging Technologies for Ocean Acidification Monitoring, Mātiu, October 16, 2026, 11:30 - 13:00

Uncrewed surface vehicles (USVs) are expanding observing opportunities to regions with persistent data gaps and opening up novel application areas in event-driven adaptive sampling. Here we present two recent examples of adaptive USV surveys of ocean carbonate chemistry in nearshore Hawaiian waters and in extreme ocean conditions during austral winter in the Southern Ocean. In 2023, a mission of three USVs surveyed the eight main islands in the Hawaiian archipelago to establish a baseline of coastal carbonate chemistry. The mission was adapted in August when one USV diverted the original sampling plan to monitor for potential coastal runoff and associated biogeochemical impacts off Lahaina, Maui after the devastating wildfires. In the Southern Ocean, another USV mission is underway to fill observing and knowledge gaps in CO₂ uptake. Over the next five years, sampling design will be informed by model- and AI-tools aimed to direct the USVs to regions with the highest uncertainties in surface ocean pCO₂, such as during austral winter storms. A pilot mission in 2019 that circumnavigated Antarctica recorded surface aragonite saturation state values as low as 1.2 in the Indian Ocean sector during austral winter, highlighting the critical need for observational constraints to validate model predictions, which currently project that 20% of surface waters will be undersaturated with respect to aragonite by 2060. These missions demonstrate that autonomous ocean observing infrastructure delivering both sustained and responsive observations is key in a rapidly changing ocean experiencing extreme events, climatic shifts, and unanticipated changes/phenomena.

Development of high-frequency dissolved inorganic carbon and pH sensors to study in-situ effects of ocean acidification on fisheries

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7D: Technological advances: Charting the Future: Emerging Technologies for Ocean Acidification Monitoring, Mātiu, October 16, 2026, 11:30 - 13:00

There is an increasing need to study in-situ effects of ocean acidification (OA) on commercially important fishery species, particularly bivalves. However, there is a data gap between subsurface carbonate chemistry monitoring and concurrent measurements of fishery biology, particularly for bottom water where OA sensitive bivalve species live. To address this gap, we have developed dissolved inorganic carbon (DIC) and pH sensors that can be deployed on fishery surveys and fishing vessels.

The Channelized Optical System II (CHANOS II) is an in-situ sensor that utilizes spectrophotometric techniques to simultaneously measure high-frequency DIC and pH, enabling the carbonate system to be resolved with a desirable pair of CO₂ parameters. Previous versions of CHANOS have achieved near climate-quality measurements of DIC and pH in surface waters. CHANOS II has recently been redesigned to be suitable for subsurface measurements on diverse platforms. In 2024 – 2025 CHANOS II was deployed during several fishery surveys on a towed survey vehicle in shelf bottom waters to measure carbonate chemistry along with benthic biology of fishery species. These deployments demonstrated the sensor's ability to capture changes in carbonate chemistry across dynamic gradients in subsurface shelf waters.

The 2nd sensor is a newly developed low-cost, spectrophotometric pH sensor, ECLIPSE-pH, capable of automated underway measurements on fishing vessels. Recent deployments on a fishing vessel demonstrate its capacity to collect high-quality, continuous surface water pH data. Both CHANOS II and ECLIPSE sensors are promising technologies that may help to bridge the data gaps of OA monitoring for fisheries.

Sustained pH Observations from Underwater Glider Networks in the US

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7D: Technological advances: Charting the Future: Emerging Technologies for Ocean Acidification Monitoring, Mătiu, October 16, 2026, 11:30 - 13:00

Sustained, high spatial resolution subsurface pH observations are critical for assessing current and future ocean acidification impacts in the coastal ocean. However, widespread adoption of glider mounted pH sensors has remained elusive due in part to limited sensor availability and the heterogeneity of US glider operations. To address this gap, we developed the GliderFET pH sensor, based on the Deep-Sea-DuraFET technology deployed on hundreds of BGC Argo floats worldwide. The modular design enables straightforward integration onto a variety of autonomous underwater vehicles, and have been integrated onto the Spray, Spray2, and Seaglider. GliderFET sensors are now operating across three sustained glider networks along the US coast: the California Underwater Glider Network, the Trinidad Head glider line, and the Gulf Stream network. Gliders simultaneously measure ancillary parameters, including dissolved oxygen, temperature, salinity, chlorophyll, and currents. This provides critical biogeochemical context for interpreting pH variability driven by processes such as respiration and primary production. Additional carbonate system parameters including pCO₂, aragonite saturation state, and dissolved inorganic carbon can also be derived from the pH observations. Since April 2025, the networks have collectively acquired over 3,700 pH profiles to depths of 1,000 m. Real-time quality control, based on BGC-Argo protocols, are currently in development to enable delivery of accurate, actionable data streams in near-real time.

Shell shock: Investigating four decades of ocean acidification and warming on Atlantic sea scallop shells

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7E: Multiple Stressors: Ocean acidification multiple stressor effects on North American species, Mākaro, October 16, 2026, 11:30 - 13:00

The Atlantic sea scallop (*Placopecten magellanicus*) fishery is one of the most valuable in the U.S. and the largest wild scallop fishery in the world. However, managers and industry stakeholders are concerned that changing ocean conditions, including ocean acidification (OA) and warming, will cause declines in scallop populations and harvest. Scallops produce calcium carbonate shells that protect their soft tissues. OA hinders calcification by reducing seawater pH and carbonate ion availability and can cause shell dissolution at low calcium carbonate saturation states. Because shells serve as a critical line of defense, OA effects on shell production can reduce bivalve growth and survival. These effects may be exacerbated by additional physiological stress from OA, warming, and other stressors (e.g., predation). We measured shell thickness of 3,900 archived specimens collected during annual surveys across Georges Bank and the Mid-Atlantic since 1980 to investigate whether these stressors have already affected scallop shells. We evaluated spatiotemporal changes in shell thickness and examined potential environmental drivers using existing habitat datasets and output from a high-resolution regional ocean model. Our results indicate that scallop shell thickness has declined over the past four decades, although the rate of decline varied geographically and depended on local environmental conditions. Because thinner shells are likely more fragile, these findings suggest scallops may be increasingly susceptible to shell-crushing predators or damage-induced mortality. A better understanding of how spatial variation in habitat type and changing ocean conditions interact to influence scallop shells can inform rotational management and help the fishery adapt.

Embracing the Complexity of Life: investigating intraspecific variation across multiple levels of biological organisation within a multistressor context

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7E: Multiple Stressors: Ocean acidification multiple stressor effects on North American species, Mākaro, October 16, 2026, 11:30 - 13:00

Environmental stressors are highly variable locally, posing region-specific physiological challenges to distinct populations across a species' range. Long-term acclimatisation and local adaptation may enable some populations to face future challenging conditions, whilst others may be disadvantaged in the future world. Furthermore, the combined exposure to multiple stressors can trigger the emergence of unexpected synergisms and antagonisms. The response to environmental stressors can also vary across the biological hierarchy (e.g., molecules vs. whole-body). Therefore, when predicting species' fate under multiple stressors, we critically need to embrace the complexity of life forms by investigating the architecture of physiological networks, transcending reductionist approaches. Here, we assess the level of intraspecific variation among populations from different regions, in terms of their system-level response to isolated and combined stressors. As a study model, we integrate the multiomics (i.e., metabolomics, lipidomics, proteomics, and enzyme activities) and multilayer (i.e., multiomics, metabolic traits, and survival) responses of Northern shrimp *Pandalus borealis* from four locations in the Northwest Atlantic and experimentally exposed to ocean acidification in isolation or combined with ocean warming. We harness Systems Biology principles to better capture the emergent properties of multilayer networks in the different oceanic scenarios. We do so across and within populations to gather a more comprehensive understanding of the species- and population-level fate of shrimp in the future ocean. We demonstrate the value of Systems Biology approaches to support adaptive management strategies through synthesising complex physiological datasets into measurable biomarker networks as tools for diagnosing population performance under a changing ocean.

Can increased feeding mitigate the adverse effects of climate change in juveniles of *Atrina maura*?

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7E: Multiple Stressors: Ocean acidification multiple stressor effects on North American species, Mākaro, October 16, 2026, 11:30 - 13:00

Climate change is reshaping marine ecosystems through ocean warming and acidification (OA), imposing increasing energetic constraints on marine calcifying organisms. Elevated temperature raises metabolic demand, while OA reduces CaCO₃ saturation, impairing biomineralization, an energetically costly process in bivalve mollusks. Under these conditions, organisms must reallocate energy among essential functions such as growth, reproduction, and maintenance.

Because responses to multiple stressors depend on species, ontogeny, and energy availability, enhanced feeding may buffer climate-driven energetic stress. This study tests that hypothesis by integrating bioenergetic and transcriptomic approaches in two bivalve species, *Atrina maura* and *Panopea globosa*, which exhibit contrasting functional strategies (infaunal burrowing vs epifaunal subtidal) likely shaping energy allocation and stress sensitivity.

Optimal growth temperatures were determined using scope for growth analysis, while daily food rations were independently established to define experimental baselines. The interactive effects of elevated temperature, reduced pH, and increased feeding were then evaluated at the organismal level. In parallel, cellular energy status and the expression of stress-related genes were assessed under hyperthermic conditions, linking physiological performance with molecular responses.

By explicitly coupling energy balance with gene expression, this study identifies the mechanisms regulating metabolic performance and biomineralization under combined climate stressors. This integrative framework advances a mechanistic understanding of resilience in bivalves and provides a basis for predicting species-specific responses under future ocean scenarios, with direct implications for sustainable aquaculture and conservation.

Carbonate chemistry as a multiple stressor: experiments on parameters affecting Dungeness crab larvae

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7E: Multiple Stressors: Ocean acidification multiple stressor effects on North American species, Mākaro, October 16, 2026, 11:30 - 13:00

The addition of CO₂ to seawater creates changes to multiple components of the inorganic carbonate system (pH, pCO₂, HCO₃⁻, CO₃²⁻, Ω), which can each affect different physiological processes in marine species. We conducted a series of experiments independently manipulating carbonate system parameters to determine the drivers of lower survival in Dungeness crab (*Metacarcinus magister*) zoea exposed to conditions expected with ocean acidification (OA). We used HCl and NaOH to manipulate alkalinity and conducted the experiments in CO₂-chambers that control pCO₂, which allowed for the generation of treatment conditions with high contrast in individual carbonate chemistry parameters. The zoea were exposed to manipulated seawater for 45 days during which we observed mortality and the larval-stage z1 to z2 molting rate. In addition, we used SEM to analyze the exoskeletons of zoea with different exposure histories. Although there was a statistically significant effect of seawater chemistry for some parameters (the best model was for calcite saturation state), the seawater chemistry had only weak effects on survival and molting during the experiment. This is in contrast with previous experiments, which showed a negative effect of OA conditions on survival and molting rate when compared exclusively to ambient seawater. There was an inherent high variability in the SEM scans from different zoea, regardless of exposure treatment. Further experiments are needed to clarify the parameters driving zoeal survival response to OA.

Comparative stress indicators of juvenile Dungeness crabs (*M. magister*) exposed to simulated upwelling profiles

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7E: Multiple Stressors: Ocean acidification multiple stressor effects on North American species,
Mākaro, October 16, 2026, 11:30 - 13:00

Marine researchers are challenged with identifying cost-effective and reliable metrics to assess biological vulnerability to ocean change. Dungeness crabs (*Metacarcinus magister*), the most commercially valuable species along the US West Coast, are increasingly exposed to intense summer upwelling conditions characterized by concurrent acidification and hypoxia. Crabs exhibit a wide range of behavioral and physiological responses to these stressors, yet the comparative magnitude of these responses is poorly understood and rarely correlated with demonstrable changes in mortality and growth. In this presentation, we will present results from a two-week laboratory exposure of juvenile crabs to flow-through, multistressor treatments spanning a gradient of dissolved oxygen, pH, and temperature profiles representative of upwelling conditions in the California Current System. Preliminary respirometry trials have established temperature-dependent critical oxygen thresholds for juvenile crabs, providing a baseline for metabolic vulnerability. A suite of physiological (hemolymph pH, lactate, respiration rate, and exoskeletal dissolution) and behavioral (reflex impairment, feeding activity, and antennular flicking) indicators will be compared for their relative predictive power for growth and mortality outcomes. These indicators will be ranked by accuracy and cost-effectiveness, providing actionable guidance for researchers and fishery managers seeking evidence-based tools to assess Dungeness crab vulnerability to ocean climate stressors.

Quantifying the impact of ocean acidification on the aerobic habitat of marine organisms

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8A: Multiple Stressors, Rongomātāne A, October 16, 2026, 14:00 - 15:30

The ocean's accumulation of anthropogenic CO₂ and heat is driving a decline in both the pH and O₂ of seawater. Both factors can alter the energy balance of aquatic organisms but their relative magnitudes have not been compared. Here we compile a database of published laboratory measurements of metabolic rates across a range of pH and incorporate these sensitivities into an existing physiological framework, the Metabolic Index, to evaluate the relative impact of ocean acidification, warming and deoxygenation on marine species. We supplement the database with new laboratory studies to confirm the pH-dependence of key metabolic traits. We find that while the metabolism of individual species can be moderately sensitive to pH, there is no systematic effect across biota, likely due to the multiple competing influences of ambient pH on an organism's energy demand. The strong correlation between O₂ and pH in seawater allows a quantitative comparison of the energetic costs of climate change. We attribute the relative role of pH, temperature, and oxygen on aerobic habitat availability for a range of marine species and compare that to historical and future biogeochemical climate trends.

The UN-endorsed Global Estuaries Monitoring (GEM) Programme: A Collaborative Effort to Assess and Mitigate Anthropogenic Pollution in Urban Estuaries Worldwide

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8A: Multiple Stressors, Rongomātāne A, October 16, 2026, 14:00 - 15:30

Estuaries, which hold many essential ecosystems (e.g., wetland, mudflat, mangrove, seagrass beds) and serve as critical interfaces between land and ocean, are increasingly impacted by the release of anthropogenic chemicals. However, the extent of environmental contamination and associated ecological risks, particularly in developing and underdeveloped regions, remains poorly understood. The Global Estuaries Monitoring (GEM) Programme (www.globalestuaries.org) is an Ocean Decade Action endorsed under the United Nations Decade of Ocean Science for Sustainable Development (2021–2030). GEM unites scientists and stakeholders worldwide to build a global monitoring network, collect samples for qualifying contaminants of emerging concern (CECs), prioritize pollutants, and develop actionable solutions to reduce pollution and promote healthier estuarine ecosystems.

Since its inception, GEM has garnered strong support from over 120 collaborators and currently includes 187 estuaries across 51 countries spanning six continents. In its first phase, GEM focuses on pharmaceutical contamination, having developed harmonized sampling and analytical protocols capable of detecting 65 commonly used pharmaceuticals in a single sample. About 2500 water samples have been collected, and the chemical analysis will be completed within the first quarter of 2026. In its second phase, GEM will collect estuarine sediment samples and deploy novel passive samplers to participating partners for monitoring priority CECs, pathogens and antibiotic resistance genes. Following data collection, stakeholders will convene to share findings, identify best practices, and formulate evidence-based recommendations for pollution mitigation. These strategies will be communicated to the United Nations and national environmental authorities, supporting informed decision-making and policy development.

Multiple climate change stressors on coral reefs: potential for interactions between acidification, hypoxia and heat, and implications for reef resilience

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8A: Multiple Stressors, Rongomātāne A, October 16, 2026, 14:00 - 15:30

Coral reefs face intensifying threats from co-occurring climate stressors, yet the combined effects of ocean acidification, deoxygenation, and heat stress remain poorly understood. Deoxygenation, in particular, is an underrecognized driver of reef degradation but how it interacts with other climate stressors remains poorly understood. We present findings from two complementary experimental approaches examining how hypoxia interacts with acidification and heat across multiple coral species.

In extended-exposure experiments (12–17 days) with *Porites furcata*, *Porites astreoides*, and *Siderastrea siderea*, we disentangled individual and combined stressor effects across eight phenotypic traits. Hypoxia consistently suppressed dark respiration by 37–49% and altered photophysiology, while heat stress drove the most pronounced declines across traits. Although acidification alone had minimal independent effects, particularly in *S. siderea*, hypoxia and heat produced the highest number of synergistic interactions. The combined effects of hypoxia and acidification were largely additive, however acidification can nevertheless exert a profound influence on oxyregulation in corals. Using hypoxia response curves under rigorous pH control, we show that acidification significantly altered hypoxia sensitivity: three species exhibited increased sensitivity, while the fourth showed enhanced tolerance. Consequently, acidification pushes critical hypoxia thresholds (P_{crit}) into oxygen regimes already prevalent on reefs today, potentially driving shifts in community composition and accelerating risks to reef resilience as these stressors intensify. Together, these findings underscore the need for more multi-stressor experiments across a range of species to improve predictions of reef resilience under future ocean conditions, where compound stress events are expected to become more frequent and severe.

Membrane remodeling mediates differential acclimation and resilience to marine heatwaves in temperate sponges

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8A: Multiple Stressors, Rongomātāne A, October 16, 2026, 14:00 - 15:30

The increasing frequency and intensity of marine heatwaves (MHWs) pose a growing threat to sessile marine organisms. Sponges are ecologically important in marine ecosystems worldwide, yet their ability to acclimate to MHWs remains poorly understood. Here, we used a lipidomic approach to investigate how three abundant temperate marine sponge species (*Tethya bergquistae*, *Crella incrustans*, and *Suberites australiensis*) responded to simulated MHW conditions in an ex situ laboratory experiment over 33 days. As key components of cell membranes, phospholipid-derived fatty acids (PLFAs) mediate stress responses through desaturation and elongation. We quantified PLFAs both in situ and following a 33-day exposure to a MHW. We then linked PLFA composition and abundance to physiological parameters (survival and respiration). The most resilient species, *T. bergquistae* and *C. incrustans*, exhibited higher proportions of saturated fatty acids under MHW conditions compared to the control treatments. In contrast, the species with the lowest survival, *S. australiensis*, showed greater fatty acid unsaturation compared to the controls, likely resulting in increased membrane permeability and susceptibility to peroxidation. These results suggest that *S. australiensis* may be less likely to persist under MHW conditions, whereas *T. bergquistae* and *C. incrustans* demonstrate cellular acclimation mechanisms that may support resilience. To date, there has been no investigation on how MHWs influence membrane characteristics in temperate marine sponges. This represents a critical knowledge gap given their reported vulnerability to recent MHWs. Closing this gap is essential to understanding the mechanisms that contribute to resilience in the face of future extreme climatic events.

Effects of ocean acidification on shellfish growth and vulnerability to thermal stress, hypoxia, and predators

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8B: Changes in biodiversity, Rongomātāne B, October 16, 2026, 14:00 - 15:30

Although negative effects of ocean acidification (OA) have been documented for a wide variety of taxa, we have a relatively poor understanding of how OA may increase vulnerability to additional stressors like extreme temperatures, hypoxia, and natural enemies. We exposed Pacific oysters (*Magallana* = *Crassostrea gigas*), blue mussels (*Mytilus spp.*), and Dungeness crabs (*Metacarcinus magister*) to four levels of OA (pH values of roughly 7.9, 7.7, 7.5, and 7.3) and found that the bivalves but not the crabs were negatively impacted by acidification. Negative relationships between OA and performance were non-linear for some biological response variables (e.g., growth in mussels) but not others (e.g., growth in oysters). Traits that exhibited threshold effects did not all exhibit similar pH thresholds. For example, oyster shell aesthetics was more robust to mild acidification than was shell strength. OA exposure did not affect critical upper thermal tolerance in oysters or mussels. Surprisingly, OA increased hypoxia tolerance in Dungeness crabs. OA made mussels more vulnerable to predatory sea stars, although this relationship was complex and varied with predator size. Overall, we found that OA impacts are often non-linear, suggesting that conclusions drawn from experiments using only a small number of OA treatments should be interpreted with caution. Furthermore, OA may affect food web dynamics by altering bivalve vulnerability to crushing or prying predators. Finally, we found no evidence that OA will worsen the impacts of simultaneous extreme heat or low oxygen for these bivalves and crabs, respectively.

Energy reallocation and biomineralization responses of coastal marine calcifiers under future ocean acidification scenarios

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8B: Changes in biodiversity, Rongomātāne B, October 16, 2026, 14:00 - 15:30

Ocean acidification (OA) is fundamentally altering seawater carbonate chemistry and is increasingly challenging the ability of marine calcifiers to maintain calcification and physiological homeostasis. But whether calcifying organisms can maintain calcification under low pH environments, and whether such responses differ among taxonomic groups. To address this, we conducted a 4-week controlled laboratory experiment exposing two reef-building corals (*Pocillopora acuta*, *Porites lutea*) and two calcifying macroalgae (*Halimeda opuntia*, *H. macroloba*) to ambient pH 8.00 and reduced pH conditions (pH 7.80 and 7.60) representing future OA scenarios. We quantified photophysiology (Fv/Fm), net primary production, calcification rates, and skeletal microstructural characteristics to assess the coupling between energy dynamics and biomineralization. Reduced pH significantly decreased Fv/Fm in both corals and *H. macroloba* without changes in chlorophyll content, indicating functional impairment of photosystem II. In contrast, NPP increased under acidified conditions in *P. acuta*, *H. opuntia*, and *H. macroloba*, but not in *P. lutea*, suggesting species-specific metabolic strategies and CO₂-enhanced carbon fixation. Despite these shifts, calcification rates remained largely unchanged (except in *H. macroloba*), indicating short-term maintenance of CaCO₃ accretion. However, skeletal microstructure was significantly altered, with reduced crystallite size and increased density, reflecting modified growth kinetics. These results reveal a decoupling between calcification rate and skeletal integrity, highlighting species-specific vulnerability and the importance of integrating physiological and structural metrics under OA.

Impact of climate change on primary production in the Coral Sea

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8B: Changes in biodiversity, Rongomātāne B, October 16, 2026, 14:00 - 15:30

Phytoplankton are the basis of the marine food web, turning CO₂ into organic matter available for consumption by upper trophic levels. They also act as key regulators of marine biogeochemical cycles by contributing to the sequestration of carbon through the biological pump. Most of the tropical South Pacific Ocean is an ocean “desert”, with very low phytoplankton biomass resulting from low concentrations of the inorganic nutrients (such as nitrate, phosphate or iron) that are required for photosynthesis. These nutrients can be supplied through various mechanisms, which may generate oases of life within this desert. These mechanisms are sensitive to climate change, particularly the heat content and stratification of the ocean. Identifying the sources of nutrients and predicting their future evolution, while challenging, is of critical importance to sustainably manage marine resources. Here, we use an ocean-biogeochemistry high resolution regional model to evaluate the impact of climate change on the productivity of the lower trophic levels (phytoplankton and zooplankton) around the archipelago of New Caledonia. Specifically, we investigate the hypothesis that seamounts enhance biological productivity by supplying nutrients to the euphotic zone. Previous studies have shown that seamounts in this region interact with tides to generate particularly intense internal waves, but the impact on nutrient fluxes has not been examined. We quantify the effect of seamounts and tides on primary production and plankton biomass through sensitivity experiments in present-day and future climate. This allows us to identify the location of productivity hotspots and predict their evolution in future climate scenarios.

Long-term exposure of Spotted rose snapper (*Lutjanus guttatus*) to low-pH in an aquaculture setting

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8B: Changes in biodiversity, Rongomātāne B, October 16, 2026, 14:00 - 15:30

Costa Rica's Pacific coast holds many fishing communities in the Gulf of Nicoya, one of the most exploited estuaries in this region of Central America. Small-scale aquaculture of the "Spotted rose snapper" (*Lutjanus guttatus*) contributes to reduce the fishing pressure on natural populations and improves the socio-economic growth of coastal communities. However, there is a lack of knowledge regarding the potential impact of near-future ocean acidification on these aquaculture projects. This research is the first study evaluating the impact of low-pH conditions relevant in the context of ocean acidification on a species with local commercial value. A long-term (8-months) experiment was conducted at the facilities of the Parque Marino del Pacífico, to test the biological response of the fish *L. guttatus* under three different scenarios: two falling within the natural range of pH variability and low-pH ocean acidification scenario. Carbonate chemistry and other physicochemical parameters were measured on a regular basis, along with mortality and growth. Nutritional content analyses and a sensory evaluation test were carried out at the end of the experiment. Low-pH conditions did not affect growth rates or consumer perceptions of meat quality, suggesting that local aquaculture of "Spotted rose snapper" could remain resilient under ocean acidification scenarios. However, significant differences in nutritional content (protein and fat) were observed between treatments, raising potential concerns for human nutrition and challenging the long-term sustainability of aquaculture projects in the Gulf of Nicoya as contributors to local food security.

Ocean Acidification Depresses Skeletal Mineralisation in a Temperate Neonatal Shark

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8B: Changes in biodiversity, Rongomātāne B, October 16, 2026, 14:00 - 15:30

Ocean acidification (OA) is known to alter mineralisation processes of both the endoskeleton and otoliths of teleost fish, potentially as a by-product of chronic acid-base regulation. However, the effects of OA on the mineralisation processes of sharks remains virtually unresearched, despite their functional importance in global ecosystems. Although elasmobranch skeletons are primarily cartilaginous, they are also partially mineralised, with mineral deposition first occurring during embryogenesis. Mineralisation processes during early ontogeny could be disrupted by OA as haematic [HCO_3^-] is chronically elevated by the bicarbonate buffering system, leading to enhanced carbonate deposition on the endoskeleton.

Through chronic exposure to ambient ($\sim 500 \mu\text{atm pCO}_2$) and future OA ($\sim 1000 \mu\text{atm pCO}_2$) conditions during embryogenesis, this study investigates the effect of elevated pCO_2 on endoskeletal mineralisation in neonatal small-spotted catshark (*Scyliorhinus canicula*). Endoskeletal mineralisation was assessed by combining traditional two-dimensional clearing and double staining histochemical techniques with density-calibrated three-dimensional micro computed tomography, allowing for a holistic assessment of the effect of OA on endoskeletal development.

Elevated pCO_2 significantly reduced mineralisation of the vertebral column and second dorsal fin, challenging our hypothesis that the endoskeleton acts as a carbonate sink for excess HCO_3^- accumulated during homeostasis. Depressed mineralisation is likely to have serious ecological ramifications for *S. canicula* under future climate change conditions, inhibiting both locomotion and feeding during vulnerable stages of early ontogeny. However, further research is warranted to understand the mechanisms behind skeletal mineralisation in elasmobranchs exposed to OA.

Changes in energy metabolism in newly hatched small spotted catsharks reared under ocean acidification conditions

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8C: Modulating role of time, Rongomātāne C, October 16, 2026, 14:00 - 15:30

Under ocean acidification (OA), oviparous sharks may experience an energetic burden during embryonic development due to elevated costs associated with acid-base balance. Throughout embryonic development, nutrients (e.g. fatty acids) from the limited yolk supply are metabolised for growth whilst also partially stored in an internal yolk sac (IYS) and liver to sustain the hatchling until feeding independently. However, there is little information on the potential effects of OA exposure on nutrients utilisation and energy metabolism in developing sharks. Small-spotted catshark (*Scyliorhinus canicula*) embryos from varying developmental stages were exposed to ambient (~500 μatm) and high pCO_2 (~1000 μatm) conditions to investigate changes in nutrient utilisation. After hatching, metabolic and developmental fatty acids (FAs) in the liver and IYS, and biomarkers of cellular energy metabolism in muscle tissues, were measured to determine metabolic responses. Sharks reared under high pCO_2 conditions hatched with 29% less total FA mass in the IYS, with a pronounced reduction in saturated and monounsaturated FAs implying greater energy uptake in these individuals. In the liver, high pCO_2 caused a reduction in C18:1, 22:5 ω 3 and 20:4 ω 6 FAs linked to elevated metabolism and immune function. Notably, energetic requirements were modulated by the developmental stage first exposed to high pCO_2 – e.g., the proportion of lipids to proteins in muscle tissue was reduced only in hatchlings exposed from later in their development. This research highlights that the timing of OA exposure plays an important role in shaping shark resilience and patterns of energy allocation under future climate conditions.

Legacy effects of marine heatwaves: Impacts of recurring bleaching events on microbiome and genomic signatures of *Acropora hyacinthus*

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8C: Modulating role of time, Rongomātāne C, October 16, 2026, 14:00 - 15:30

The unprecedented decline of coral reefs is mainly caused by climate change. Marine heatwaves (MHW) can disrupt the mutualistic symbiosis between corals and Symbiodiniaceae, leading to bleaching and mortality. The increasing frequency and intensity of MHWs reduce the recovery time between bleaching events, threatening the persistence of coral reefs.

Here, we investigated the effects of prior exposure to heat stress on coral thermotolerance and identified molecular processes involved. Coral reefs of Mo'orea (French Polynesia) experienced a severe bleaching event in 2019, followed by a less severe event in 2024, providing a unique natural laboratory to examine coral holobiont responses after recurring MHWs. *Acropora hyacinthus* colonies that survived the 2019 event ('pre-exposed') and those born afterwards ('not pre-exposed') were sampled before, during, and after the 2024 bleaching event across two thermally distinct sites. Host genetics (ddRAD) and community composition of bacteria (16S rRNA) and Symbiodiniaceae (ITS2) were assessed.

Before the 2024 bleaching event, microbial communities varied across sites and pre-exposure status, while no genomic differentiation was detected among host populations.

Symbiodiniaceae shifted from a community with high *Cladocopium* prevalence to one dominated by *Symbiodinium*. The variability in bacterial associations increased during the bleaching event, indicating dysbiosis, while a distinct community was established after the stress ended.

Our work demonstrates that microbiome restructuring is important for coral acclimation and shows how differences in thermal regimes and prior exposure to heat stress can shape thermotolerant coral-microbial associations.

Understanding the role of crustose coralline algae in buffering the carbonate system in shallow reef environments

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8C: Modulating role of time, Rongomātāne C, October 16, 2026, 14:00 - 15:30

Calcifying organisms in coral reefs face major climate-driven threats, including ocean acidification, which reduces calcification and the resilience of reef builders. Crustose coralline algae (CCA), a key group in reef ecosystems, are vulnerable to acidification because their skeletons are made of highly soluble high magnesium calcite (HMC). However, this high solubility may also give CCA a role in reef resilience. As CCA dissolve before corals, they buffer the seawater above reef structures and slow the dissolution of coral aragonite. We demonstrate this effect by measuring hourly changes in carbonate chemistry during low tide at One Tree Island in the southern Great Barrier Reef, at both whole-community and individual-taxa levels. Within a “normalised” single day, water chemistry exhibited high variability, including pH (7.47–8.61), total alkalinity (1970–2451 $\mu\text{mol kg}^{-1}$), dissolved oxygen (45–459 $\mu\text{mol kg}^{-1}$), and strontium-to-calcium ratios (8.52–8.61 mmol mol^{-1}). These large diurnal swings expose reef organisms to highly dynamic, sometimes extreme, biogeochemical conditions shaped by photosynthesis, respiration, calcification, and dissolution. Importantly, during nighttime low pH periods, respiration-driven dissolution of CCA HMC kept overlying seawater supersaturated with respect to aragonite, reducing coral dissolution. Consequently, HMC-producing communities may help partially buffer reefs against future acidification.

Influence of submarine groundwater discharge on carbonate chemistry dynamics of a coastal coral reef system in East Portland, Jamaica

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8D: Knowledge systems (General), Mătiu, October 16, 2026, 14:00 - 15:30

Submarine groundwater discharge (SGD) plays a significant role in shaping nearshore coral reef environments and can have significant impacts on ambient biogeochemical cycling. We report the results of a high-resolution (bihourly) diel investigation of the carbonate chemistry system on a fringing coral reef located on the karstic northeastern coast of Jamaica. SGD has been identified in this region using aerial, high-resolution thermal infrared imagery and radiometric tracing ($^{222}\text{Rn} > 500 \text{ Bq/m}^3$ at our reef site). Total dissolved inorganic carbon (DIC) and total alkalinity (TA) generally followed diel metabolic patterns with drawdowns associated with net photosynthesis/calcification during the daytime and accumulation associated with net respiration/dissolution at night. Salinity followed a 24-hour oscillation from a minimum of 35.60 to a maximum of 37.54, suggesting the presence of a nighttime pulse of briny, high-TA/low-DIC groundwater. Relatedly, a six-hour offset between metabolic and physical changes was observed within the system. While the maximum rate of DIC accumulation occurred before 23:00 (Night 1), salinity did not increase to its maximum until 3:00; a steady decrease in salinity was observed throughout the remainder of the observation period (3:00 – 21:00). Our results provide evidence of the physical and chemical impacts that local SGD and offshore waters have on fringing reef environments over short yet metabolically significant timescales. This study underscores the need for further high-resolution monitoring of carbonate chemistry dynamics here and within other coral reef systems in ways that incorporate spatiotemporal changes in SGD and its interactions with local environmental stressors.

Indigenous Knowledge as Living Practice for a Changing Ocean: Experiences from Alaska

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8D: Knowledge systems (General), Mātiu, October 16, 2026, 14:00 - 15:30

For the most part, though, Indigenous knowledge has been treated as a source of information to be considered and applied in the context of dominant-society systems and paradigms. While this approach has resulted in some gains for Indigenous societies, Indigenous ways of being, as part of, and in relationship with the surrounding world, remain on the margins of dominant-society research and stewardship. As a result, the ways that Indigenous societies have thrived for hundreds and thousands of years are largely ignored in favor of dominant-society systems that have in a short time produced the current triple planetary crisis. These ways include not just the technical knowledge to support sustainable harvests or to increase productivity, but also the values of reciprocity, humility, and gratitude that lead to living within the limits of what the Earth is able to provide. This presentation will explore these ideas, drawing on several examples from Alaska, including hunting of marine mammals, gathering of intertidal organisms, and fishing for marine and anadromous species. These examples also illustrate responses to societal and environmental change and the prospects for restoring customary Indigenous ways amid climate change and increasing industrialization and commercialization of Alaska's waters. The presentation will conclude with ideas for better acknowledging, respecting, and practicing Indigenous ways that have proven their effectiveness as a foundation for responding to a high-carbon world.

Mātauranga Hapū Navigating High-Carbon Dioxide (CO₂) in Te Takutai Moana

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8D: Knowledge systems (General), Mātiu, October 16, 2026, 14:00 - 15:30

Rapid increases in atmospheric CO₂ are driving profound changes in our Takutai Moana systems. Addressing these complex and interconnected challenges requires approaches that move beyond single-discipline science and draw on Indigenous knowledge systems.

My research explores Mātauranga Hapū, enhancing understanding of the changes in our Moana, supporting more effective, equitable, and context-specific responses.

I highlight a transformative approach to rebuilding Te Takutai Moana ecosystems, emphasising the role of Hapū in shaping adaptive pathways, recognising that ecological recovery is inseparable from social, cultural, and economic resilience.

My Hapū knowledge system reflects and embodies a deep interconnectedness with our Takutai Moana, expressed through our identifiable whakataukī 'Ko ngā pāpaka o Rangataua'.

An inseparable relationship between people and place, grounded in whakapapa. We are saying 'we are as abundant, resilient and tenacious as the crabs in Rangataua Bay'.

Pāpaka were once abundant in our Tāhuna, illustrating the vitality of my Hapū and the depth of observational knowledge. Juveniles and larvae are most vulnerable to lower global pH levels, which interact with local stressors to create even stronger acidification. Of major concern is the relational interconnectedness of Te Takutai Moana and our Mokopuna.

The decline in Pāpaka population provides a powerful lens for understanding ecosystem shifts. Pāpaka, a species of ecological importance and a living indicator of environmental change and relational wellbeing

By synthesising Mātauranga Hapū, my research fosters dialogue across disciplines and knowledge systems, identifying shared priorities and advancing collaborative frameworks for working with Te Takutai Moana in a high-carbon dioxide world.

Turning Ocean Acidification Monitoring into Action: Lessons from the Pacific Islands Ocean Acidification Centre

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8D: Knowledge systems (General), Mātiu, October 16, 2026, 14:00 - 15:30

Ocean acidification has direct impacts on Pacific marine ecosystems and the communities that depend on them for food security, livelihoods, culture and connection to the ocean. Yet many Pacific Island Countries and Territories face barriers to sustained monitoring, including limited equipment, technical capacity, data support and long-term resourcing.

The Pacific Islands Ocean Acidification Centre (PIOAC), hosted by the Pacific Community, addresses these gaps through regional technical support, training, coordination and international partnerships. This presentation will highlight PIOAC's support model, drawing on examples from Fiji and Solomon Islands to show how partners are moving from receiving equipment to sustaining monitoring programmes and generating usable data.

PIOAC's work shows that actionable ocean acidification science requires more than equipment. It depends on sustained regional backstopping, local capacity-building, institutional partnerships, student and early-career engagement, and clear pathways linking monitoring to adaptation, policy and community resilience.