**The Global Ocean Acidification Observing Network, GOA-ON: working from local to global scales**

**NEWTON Janet**

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The Global Ocean Acidification Observing Network, GOA-ON, is a collaborative international network formed in 2012 that now has over 860 scientists from over 100 countries (Tilbrook et al., 2019). Our activities are framed around three high-level goals:

1. Improve our understanding of global ocean acidification (OA) conditions
2. Improve our understanding of ecosystem response to OA
3. Acquire and exchange data and knowledge necessary to optimize modelling for OA and its impacts

The newly gained knowledge is provided to communities and stakeholders from industry, national and local governments, and global organizations seeking to better understand OA, its effects, and to develop action plans, best practices, and mitigation and adaptation strategies to address OA impacts. GOA-ON plays a significant role for the UN by supporting the development and implementation of the methodology for the Sustainable Development Goal indicator 14.3.1 (average ocean acidity). GOA-ON provides guidance on how to measure ocean acidification and what to report towards the indicator.

As an active network, GOA-ON has partnered with several other key organizations to offer opportunities for capacity building and training to its members. Through our scientific mentorship program, ‘Pier2Peer’ we facilitate an exchange of expertise and provide a platform for international collaborations.

In the summer of 2021, GOA-ON’s program proposal “Ocean Acidification Research for Sustainability”, also known as OARS, was formally endorsed as a UN Ocean Decade program The OARS program will build on the existing work of GOA-ON, bringing in several key international partners to further develop the science of ocean acidification. Over the next ten years we, together with existing and new partners, hope to provide society with the observational and scientific evidence needed to sustainably identify, monitor, mitigate, and adapt to ocean acidification, from local to global scales.

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**An overview of CO2 seep studies worldwide**

**HALL-SPENCER Jason**

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This presentation covers some of the approaches that have been used to assess the effects of ocean acidification as well as other stressors using areas acidified by underwater volcanoes. A major advantage of such work is it shows which marine organisms can survive and what coastal habitats might look like in the coming years. These systems can also be used to assess effects on ecosystem services and how people might be affected by the consequences. As carbon dioxide levels increase this benefits some organisms but it causes an overall loss of marine biodiversity, both in temperate and in tropical systems. Key groups, like hard corals, sea urchins and coralline algae, are often lost and the diversity of fish and their reproduction are impacted. The talk highlight the diverse methods used to quantify the abundance and diversity of biota along these natural gradients in carbonate chemistry, the use of settlement substrata, reciprocal transplants, physiological studies as well as molecular and ‘omics approaches. ICONA provides a great opportunity to replicate studies worldwide.

**The contribution of the Vulcano Island CO2 seep (Italy) to ocean acidification research**

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Submarine volcanic hydrothermal fields have geochemical conditions that provide opportunities to characterise the effects of elevated levels of seawater CO2 on marine life in the field. Here, I present the geochemical and ecological aspects of a shallow marine CO2-rich seep, focusing on gas composition, water chemistry, marine organisms and biological communities from one of the best-studied marine CO2 seep site: the Vulcano Island (Sicily, Italy). In areas of intense bubbling, extremely high levels of pCO2 (>10,000 µatm) result in low seawater pH (<6) and undersaturation of aragonite and calcite in a marine zone mostly devoid of calcified organisms such as shelled molluscs and hard corals. Around 100-400 m away from the seep area the geochemistry of the seawater becomes analogous to future ocean acidification conditions with dissolved carbon dioxide levels falling from 900 to 420 µatm as seawater pH rises from 7.7-8.0. Calcified species such as coralline algae and sea urchins fare increasingly well as sessile communities shift from domination by a few resilient species to a diverse and complex community (including abundant calcified algae and sea urchins) as the seawater returns to ambient levels of CO2. Transplant experiments and observational studies advanced in our understanding of species and community sensitivity to high CO2 and low pH seawater, revealing how marine organisms react to ocean acidification conditions (e.g., using energetic and behavioural adjustments for calcification, reproduction, growth and survival). Research at volcanic marine seeps, such as those off Vulcano Island, highlight consistent ecosystem responses to rising levels of seawater CO2, with the simplification of food webs, losses in functional diversity and reduced provisioning of goods and services for humans.

**Simplification of marine ecosystems under ocean acidification: a case study of the Shikine Island CO2 seep**

**HARVEY Ben**

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Human activities are rapidly changing the structure of coastal marine ecosystems, but the ecological consequences of these changes remain uncertain. Natural analogues of futuristic conditions are increasingly being used to assess the likely effects of rising atmospheric CO2 emissions on marine ecosystems. Here, using a CO2 seep in Japan, we show how ocean acidification causes habitat and biodiversity loss, resulting in the simplification of marine ecosystems. This simplification involves structurally complex habitat-forming species (including corals and larger macrophytes) being replaced by more homogenous and simple turf algal habitats. Such ecological shifts are concerning because they result in habitats that have less ecological and human value. Moreover, once these ecological shifts occur, OA-driven stabilising feedback loops ‘lock-in’ these novel turf systems making them particularly difficult to reverse. By understanding the ecological processes responsible for driving community shifts, we can better assess how communities and ecosystems are likely to be altered by ocean acidification. Taken together, we demonstrate how the simplification of marine habitats by increased CO2 levels will cascade through the ecosystem and will have severe consequences for the provision of goods and services.

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**The adjustability and susceptibility of marine ecosystems
to ocean acidification**

**CONNELL Sean**

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Many modern taxa have persisted through natural climate variability and extremes, including large changes in past temperature and CO2 concentrations. It seems possible that adaptive responses not only occur at the level of individuals and species (phenotypic and genetic adaptation), but they also integrate with ecological interactions that that stabilize community and ecosystem processes (compensatory dynamics). I will talk about my discoveries of non-genetic compensatory adaptation at ecosystem levels. Adaptation is not a phenomenon that only occurs at molecular levels. These discoveries have introduced new factors that require more thoughtful analysis to fully understand the complex consequences of increasing CO2 levels. Such dynamics are seldom examined across generations and across levels of a food chains. I suggest that complex systems have the mechanistic capacity to resist change, but can collapse of when pushed beyond their adaptive capacity to accommodate abiotic change.

**CO2 seeps in PNG and the Bouraké semi-enclosed lagoon in New Caledonia. Two special natural laboratories to study coral reef responses to extreme conditions**

**RODOLFO-METALPA Riccardo**

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Since 2016, in the framework of the projects CARIOCA and SuperNatural, the Institute for Research and Development IRD- Entropie based in New Caledonia has used two volcanic CO2 seeps in PNG (Normanby and Ambitle) and one unique semi-enclosed bay in New Caledonia (Bouraké) to study the response of corals to ocean acidification and its combination with other climate change-like conditions.

Although the IRD team, in collaboration with several international partners, investigated during seven 10-day expeditions the PNG vents, and hundreds of days the Bouraké site, which is more accessible, we have only touched on the potential offered by those unique sites toward a better understanding of the acclimation and adaptation capabilities of corals. Much will be possible to discover, especially thanks to the enlarged consortium offered by the Icona project.

During this presentation, I will introduce the study sites, their many environmental parameters, which make them unique and suitable as natural laboratories, and a critical view of their limitations when they are used to project the future of coral reefs. Finally, I will briefly sum-up the main past and on-going research programmes together with some results.

**Natural field analogues for evaluation of coral reef community response to climate change: a case study at acidified and warmed Nikko Bay, Palau**

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Ocean is now facing a steady warming and acidification, and our needs to understand how marine ecosystems will respond to these changes is highly essential for future prediction and consideration for adaptative strategies under climate change. Under those circumstance, the finding of acidified natural field analogues has emerged lot of new knowledge and insights of the scenarios of future reef ecosystem. For example, CO2 vent at Papua New Guinea suggest a shift from highly diverse and complex structured to a less diverse and less structured reef which were dominated by massive Porites1. Meanwhile, CO2 vent at Iwotorishima Island in Okinawa suggest a shift from diverse hard corals to less calcified soft corals2. Those examples suggest that ocean acidification can cause different shifts at reef community structures, while both suggest loss of biodiversity.

Here in this presentation, we will present another completely different natural analogue which shows warmed and acidified condition but highly diverse coral community at Nikko bay in Palau3. This bay is highly sheltered and the seawater residence time was estimated to be longer than 2 months. Hence, seawater within the bay is highly affected by the physical and biological activity and showed lower alkalinity and higher *p*CO2 concentration compared to the out of the bay. However, the bay was found to be fully covered by diverse corals. Community structure differed among close sites and was mostly absent of *Acropora*. Transplantation and laboratory experiments using corals including *Porites cylidrica* and *Pocillopora acuta* within and out of the bay suggested that corals within the bay can be well acclimated and potentially adapted to the environment found within the bay3,4. These results suggest that different scenarios can be happen between place to place and comparison between different analogues may give us a clearer picture of how ecosystems will respond to the climate change.

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**Local adaptation to acidifying oceans:
Evidence from natural CO2 seeps**

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Laboratory experiments show that predicted future CO2 levels can affect a variety of physiological and behavioural traits and processes in reef fishes, but underlying mechanisms remain uncertain and with considerable variation among species. Natural CO2 seeps provide a unique opportunity to investigate the fundamental responses of reef fishes to long-term exposure to elevated CO2, which can inform us about how they may adjust in a future world. 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 CO2 seep and nearby control reefs 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. Our study provides a broader understanding as to the molecular alterations crucial for coping with naturally elevated CO2 conditions. We also demonstrated that there are common but also variable molecular mechanisms among species in coping with elevated CO2. To date, this study is the most comprehensive molecular analysis on coral reef fishes in the context of ocean acidification that describes the fundamental molecular alterations underlying how reef fishes may be adapting to future pH conditions.

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