MORGAN MEYERS

Acidic Oceans: How Will Copepods Cope?

With every drop of water you drink, every breath you take, you're connected to the sea.

Sylvia Earle

In early November 2017, at the Wellington site of the National Institute for Water and Atmospheric research (NIWA), nine giant 4000-litre test tubes (called mesocosms) were filled with water pumped in from nearby Evan's Bay and submerged in an outdoor, square, concrete pond. Our CARIM[1] research team, led by Dr Cliff Law, used these mesocosms (literally, "medium-sized worlds") as tools to create ocean 'worlds' from the future to gain a better understanding of what kinds of changes for marine ecosystems may be on the horizon.

Almost ten billion tons of carbon dioxide (CO_2) accumulates in the atmosphere each year, mostly from activities that burn fossil fuels like driving or using coal to generate electricity.[2] Not only does this excessive CO_2 trap heat inside our atmosphere, but more than a quarter of these annual anthropogenic CO_2 emissions dissolve into the oceans[3] and make the water more acidic through a process we call ocean acidification (OA). Because life in the oceans has evolved over billions of years to form complex, overlapping webs of interactions, even the slightest environmental change, such as a decrease in pH or increase in temperature, can affect organisms and processes in ways that are difficult to see and understand.

Early OA research quickly established the serious threat that more acidic oceans directly impose on calcifying organisms such as corals and bivalves because their calcium carbonate structures dissolve more easily and are more difficult to build as seawater pH decreases.[4] Research continued to establish baseline effects of OA on individual organisms, before looking at multiple species responses and effects of double stressors (e.g., low pH + high temperature) (Figure 1).[5] Current OA research is leaning into community-level responses to two or three environmental drivers simultaneously, with the ultimate goal of understanding effects of OA within the context of multiple stressors and entire ecosystems.[6] This goal, however, is not easily achieved; it is one that requires great effort, time, resources and collaboration. As a student team member of the CARIM project, a portion of my PhD research is dedicated to better understanding how future ocean conditions, especially OA, may affect interactions among the tiny plankton drifting in our seas.

The word “plankton” is an umbrella term we use to describe any aquatic organism that drifts along with the ocean currents. Some members of plankton stay plankton their whole lives, like jellyfish, krill and diatoms. Other members of plankton are only plankton for a short while during their larval stages of life. Animals like fish and barnacles start out as plankton, but eventually grow large enough to swim against currents or become attached to substrate. Phytoplankton are a unique group of plankton. They are photosynthetic, like land plants, which means they capture the sun’s energy and transform it into a type of energy that all life forms can use. Also, phytoplankton amazingly produce half the oxygen in our atmosphere, even though their total biomass makes up less than two percent of all photosynthetic biomass on Earth.[7]

Zooplankton are the animal-like plankton (the krill, fish, jellyfish, etc. – any non-photosynthetic plankton), and are often grouped into three size classes (from smallest to largest): microzooplankton (20-200µm, smaller than a grain of salt), mesozooplankton (200µm-20mm size, between sesame seed and coffee bean size), and macrozooplankton (2-20cm, larger than a thumbnail). Copepods are an extremely abundant type of crustacean mesozooplankton (similar to krill) and have the important job of recycling nutrients like carbon and nitrogen within their ecosystems. Copepods often graze heavily on phytoplankton before larger animals, such as fish, come along and eat the copepods. Microzooplankton often serve as a link between phytoplankton and copepods, being predators of phytoplankton and prey for copepods (Figure 2).

These first trophic connections make phytoplankton’s unique and essential energy molecules available to animals higher up the food chain and ultimately support some of the largest animals on Earth, not to mention the over two and a half billion people who rely on seafood as a main source of protein.[8] OA could potentially modify these early trophic pathways in ways that would affect entire ocean communities and could dramatically escalate the global impact of ocean acidification.

These overlapping baseline trophic links create a dynamic foundation for the quality and quantity of energy transfer in the oceans, and create a challenging experimental system for learning about what plankton trophic interactions might look like in a future ocean environment. To take on this challenge, our research team used the large-scale mesocosm experiment at NIWA to carry out a series of plankton-feeding experiments that took place in warmer, more acidic conditions. Three of the nine mesocosms were kept at present-day temperature and pH conditions (~16° C, pH 8.05), another three were mesocosms set in year 2100 (~18° C, pH 7.72), and the final three were mesocosms set in year 2150 (~20° C, pH 7.55). Once the mesocosms were up and running, work was non-stop for three weeks; scientific sampling, system maintenance and troubleshooting were daily occurrences to make sure we gained as much information as we could in the limited time we had.

Our plankton-grazing team tested out a few different methods by trial and error before finding the best option, which ultimately was a series of plastic jars slipped into nylon fishnet stockings suspended from the top of each mesocosm (Figure 3). By comparing the food (phytoplankton and microzooplankton) inside the jars before and after a 24-hour feeding period, we could estimate the grazing rates and behaviour of copepods and then compare the estimates across the three treatment conditions (ambient, 2100, and 2150) to see if there were differences. Data from this research are still being processed and analysed at the time of writing, and plans for similar experiments to take place during another CARIM mesocosm experiment are in the works for September 2018. We still have much to learn.

The ultimate goal for these experiments (and others like them) is to help move us closer to a comprehensive understanding of what is likely to be a complicated, shifting future for many marine organisms and for us who depend on them for our own well-being.

ARTIST RESPONSE: MORGAN MEYERS

The final watercolour piece is a result of combining art and science in terms of both concept and physical execution. The concept of the piece was inspired by scientific illustration, as it naturally blurs the lines between art and science; a work of scientific illustration can be appreciated for both its accurate, practical use in the field as well as its pleasing aesthetic. I chose a copepod as the subject, not only to represent one of the key organisms in my research, but also to bring awareness to and appreciation of the often-ignored, humble beauty of microscopic life.

For the execution of the piece, I was curious about the physical combination of science and art. I manipulated watercolour paints with various solutions relevant to my scientific research: filtered seawater, carbonated water, sea salt, and an acid (vinegar). In addition to expressing the ocean acidification research theme within the painting, the chemical presence of these non-traditional elements is likely to compromise the quality of the paper and artwork over time. This effect, while undesirable from an artwork-preservation standpoint, further communicates the detrimental effects that ocean acidification will have on marine life in the coming years.

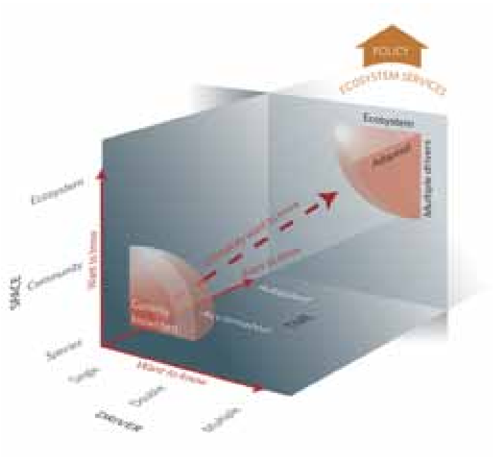

Figure 1. Present state of knowledge and knowledge needs: most information on the impacts of ocean change currently available is on acclimated single species/strains under the influence of a single driver (lower left corner). Red arrows indicate the direction where we need to expand our understanding. Assessment of impacts on ecosystem services, leading up to science-based policy advice, requires information on adapted responses to multiple drivers at the ecosystem level (upper right corner). Original figure design by Rita Erven.[9]

Figure 2. Diagram depicting a simplified example of a marine plankton food web. Copepods consume microzooplankton and phytoplankton. Microzooplankton consume other microzooplankton and phytoplankton.

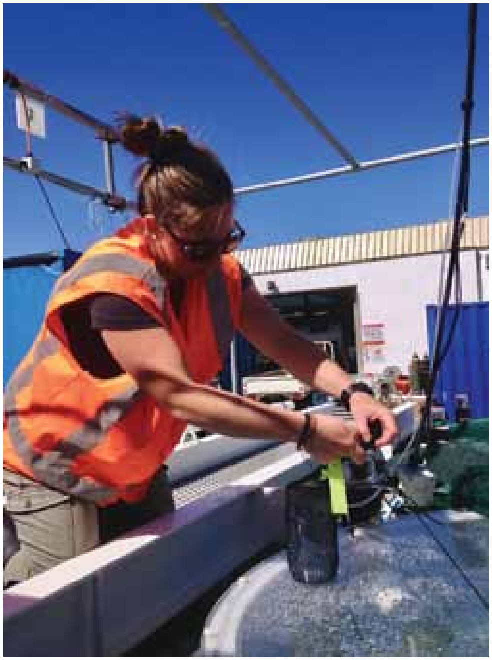

Figure 3. Suspending zooplankton grazing incubation jars from one of the nine mesocosms.
Photograph: Nadjejda Espinel Velasco.

Figure 4. Morgan Meyers, watercolor painting of copepod, 2018.

Morgan Meyers is a PhD candidate in the Botany and Marine Science departments at the University of Otago. Her research is focused on how climate change will impact various marine plankton processes and zooplankton distribution patterns in the waters off the Otago coast. The trials mentioned in this article were conducted as part of the third CARIM mesocosm experiment at NIWA Wellington with the support of Moira Decima (NIWA), Qingshan Luan (NIWA; Chinese Academy of Fisheries Science), Cliff Law (NIWA), Mark Gall (NIWA), Neill Barr (NIWA), Linn Hoffmann (University of Otago, Department of Botany), and Steve Wing (University of Otago, Department of Marine Science).

1. NIWA Science, *CARIM (Coastal Acidification: Rate, Impacts & Management)*, 2 March 2016, https://www.niwa.co.nz/coasts-and-oceans/research-projects/carim-coastal-acidification-rate-impacts-management. CARIM is a NIWA-led research project funded by the Ministry of Business Innovation and Employment.
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3. Ibid.
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9. Figure and caption from Riebesell and Gattuso, "Lessons Learned from Ocean Acidification Research."

MARTIN KEAN

Artist's Response: How will Copepods Cope?

Figure 1. Martin Kean, *Acidic Oceans: How will Copepods Cope?*, 2018, interactive screen-based artwork.

Utilising game development tools within Unreal Engine, plus the Kinect for Xbox Windows adapter kit, an interactive game space was prototyped, that mimicked a hypothetical situation where an underwater game player increased acidity in the water by 'generating' harmful CO_2.

When exhibition visitors moved their hands in front of the artwork, carbon dioxide 'clouded' the surrounding water, 'reducing' copepod and phytoplankton numbers and generally making the game environment look unliveable. Only when visitors did not engage with the work did pH levels 'normalise;' the water within the game environment cleared, and healthy copepods, phytoplankton and fish could be seen swimming within the projection.

The interactive character of the artwork conveyed a positive message, for "pro-environmental behaviour", illustrating that human behaviour can help mediate or slow down the harmful effects of OA.[1] Gamification for environmental change is one way to encourage audiences in being actors for pro-environmental behaviour.

From the 2018 Art+Oceans project collaboration with Morgan Meyers, PhD candidate at the University of Otago's Department of Botany and Marine Science.

Martin Kean is a senior lecturer in design at the Otago Polytechnic

1. CP Stern, "Toward a Coherent Theory of Environmentally Significant Behavior," *Journal of Social Issues*, 56 (2000), 407-24.