Opening a window on future plankton assemblages

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Marine heatwaves offer a unique glimpse into how global warming will change plankton assemblages, inducing a cascading shift up the trophic chain and ultimately changing the entire pelagic ecosystem. Predicting these changes is the crucial first step towards preparing for them.

We have genomics data from a number of marine heatwaves around Australia representing the way plankton assemblages adapt to heatwave conditions. We will use these data to study the response of plankton assemblages to increasing temperature and associated changes in the physics and chemistry of the ocean. The study will allow us to better predict how Australia's marine ecosystems will change under predicted climate change scenarios.

Microbes are the foundation of the food web and the engines of biogeochemistry

By virtue of their combined abundance (10^5 - 10^6 per millilitre of surface seawater), activity and metabolic diversity, marine microbes are responsible for the vast majority of biogeochemical transformations in the ocean ecosystem [1]. They form the foundation of the marine food web and modulate the ocean's reservoirs and fluxes of carbon and climatically active gases, **ultimately determining the *net* metabolic state of the ocean** [2] and controlling global climate. However, marine waters are not homogenous. Gradients in physical, biogeochemical, and climatic parameters provide strong selection on microbial assemblages resulting in both temporal and geographic partitioning of critical microbial processes across the global ocean [3, 4]. That is, **the direction and magnitude of biogeochemical transformations are constrained by the types of organisms present in the local community**. Climate related changes that alter physical mechanisms of microbial assemblage in marine waters, including warming, stratification, and shoaling of mixed layers, may therefore have broad-scale effects on biogeochemical cycles and food web dynamics, especially where they act to change the scale or mode (i.e. the type of organisms primarily responsible) of primary productivity [5]. **Fundamental shifts in trophic status at the base of the pelagic food web are unlikely to be constrained by local intervention, so predicting microbial assemblage structure should become part of the integrated science assessment framework [6] for identifying climate change impacts and informing restoration efforts for populations, habitats and ecosystems [7].**

Temperature response

Temperature is regularly identified as the strongest correlate to changes in pelagic marine microbial assemblage structure. This is illustrated in the change of diversity and biogeochemistry of the pelagic microbiota along latitudinal gradients, like the one from the 2016 P15S GO-SHIP scientific voyage in Figure 1.

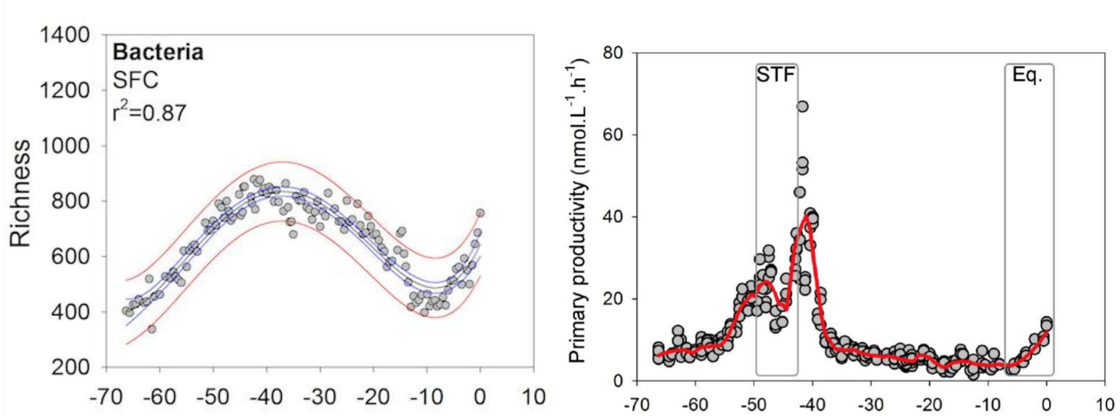

Figure 1. Diversity and primary productivity gradients following the latitudinal/temperature gradient. [8]

Species Temperature Index (STI) and Community Temperature Index (CTI)

STI is a measure of the mean realised thermal niche of an organism. CTI is a characteristic of the entire assemblage based on the realised thermal niche of each organism present in the system weighted by their abundance [9].

Assemblages of marine macro-organisms (fishes, invertebrates etc) tend to be 'thermally biased', or dominated by species that have higher or lower thermal preferences than their local environments [9] (Figure 2A) however the relationship has not previously been characterised for marine microbial assemblages. Given the ease of dispersal, rapid turnover times and deep "seed banks" of microbial assemblages it might be considered likely that these organisms would more closely track their local temperatures. This first analysis of the top 5,000 microbial species in Southern Ocean, Pacific Ocean and Australian coastal waters potentially indicates this may not be the case (Brown et al unpublished data). Indeed the shape of the microbial curve is substantially different to the bimodal distribution observed in higher organisms across the same temperature distribution (Figure 2 A,B) and the close relationship (tracking the black 1:1 line) breaks down at temperatures above ~20 °C (Figure 2B) and at a local level where the relationship is flatter (e.g. temporal data from IMOS National Reference Stations (NRS Figure 1C, D).

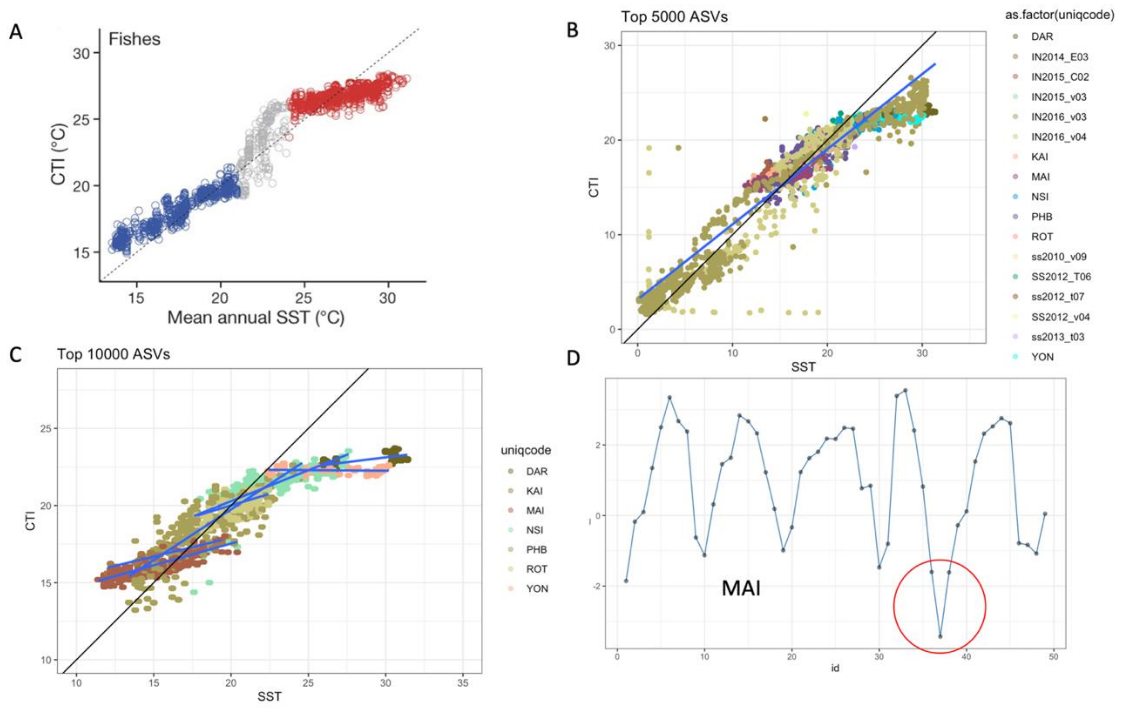

Figure 2. Unimodal vs. bimodal distribution of the Community Temperature Index in marine microbes vs. higher marine organisms. A) Shallow water marine fishes from a global survey. B) Microbes from Australian coastal waters, the Southern Ocean and the Pacific Ocean (Brown et al 2020, In review). C) Microbes at IMOS NRS stations. D) Temporal analysis of thermal bias at MAI, with samples taken during the 2015-2016 summer heatwave highlighted in the red circle.

Case Study: Can we use marine heatwave samples to predict the adaptation trajectory of the marine plankton assemblages to ocean warming?

Our globally unique molecular dataset **tracks the presence and abundance of 100,000s organisms** (coupled with physical and chemical oceanographic information) in currently ~6,000 samples spanning both temporal (seven IMOS NRSs) and spatial (-66 - 0° Latitude, surface to bathypelagic) scales. These samples represent baseline data about the seasonal dynamics of organisms across the breadth of their habitat range. This dataset also contains samples from a number of heatwave events, both from the NRSs and from scientific voyages (Figure 3).

Our initial findings show that heatwaves strongly change the microbiota. In heatwave samples from Maria Island (TAS) we found that the microbiota resembled that from Port Hacking (NSW) during the 2015-2016 summer heatwave (Figure 4). However, thermal bias analysis (Figure 2D) suggests these organisms are still far from acclimated to the heatwave conditions, which may potentially result in functional breakdown of the pelagic ecosystem.

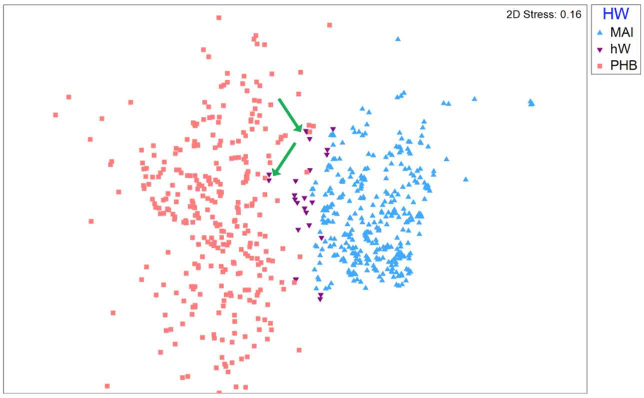

Figure 4 Plankton communities at Maria Island (MAI; TAS) and Port Hacking (PHB; NSW). Maria Island samples from the 2015-2016 marine heatwave are highlighted. Arrows indicate extreme cases with communities from March 2016 at Maria Island never seen there before but commonly found at Port Hacking, 500 nautical miles further up north. The figure shows data on the bacterioplankton.

A recent analysis of the impact of the East Australian Current on microbial assemblages along the NSW coast has shown it causes a shift in the microbial assemblage. This is associated with significant ecosystem changes including a decrease in chlorophyl A (ChlA) and total organic carbon content, decreasing average phytoplankton cell size (increasing *Prochlorococcus* abundance and a decreasing diatom:dinoflagellate ratio), a decrease in zooplankton biomass and a shift towards carnivorous species (from herbivorous), and a decrease in the average bacterial genome size (Brown et al 2020, In review).

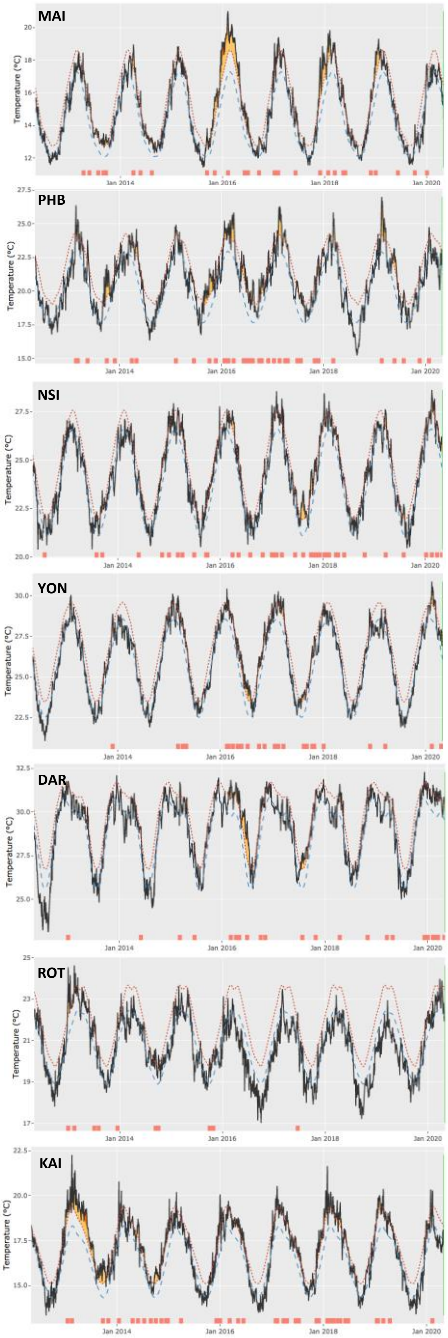

Figure 3 Heatwave events at the IMOS National Reference Stations May 2012 – May 2020. **Orange and red colours indicate strong and severe heatwaves, respectively.** (**http://www.marineheatwaves.org**)

We propose to systematically identify samples from our dataset that are associated with heatwave events, and identify shifts in species and the Species and Community Thermal Indices. We will identify what ecosystem functions these species shifts might represent and link these to established marine ecosystem indices including productivity and food chain composition measures. We will pay particular attention to the temporal aspects of the heatwave effect. Does a heatwave have the strongest effect if it happens during the hottest time of the year, exceeding the temperature maximum normally experienced by that community? How long does the impact last following the dissipation of the heatwave? Do longer heatwaves cause stronger impact and is the relationship linear? Do repeated heatwave events gradually compromise the resilience of the community? We will also compare the impact of the two different kinds of heatwaves (current based vs. local warming). These results will be used to predict the future of Australia’s marine pelagic ecosystems under future global warming scenarios.

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