

4.1 | The response of the copepod community to long-term warming along the east coast of Australia

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Summary

Warmer-water copepod species down Australia's east coast (at Maria Island, Port Hacking and Yongala) are now more common compared with the community 50-100 years ago. Warm-water copepods are generally smaller and lighter and are thus a poor food source for fish, seabirds and marine mammals.

Key Data Streams



Ships of Opportunity



National Reference
Stations

Rationale

Copepods, the most abundant zooplankton, are sensitive indicators of climate change, as temperature regulates their physiology and influences their interactions with other species (Richardson, 2008). Ultimately, warmer temperatures alter species' ranges, timing of blooms, diversity, composition, and size structure. Examples of poleward movement of species (Beaugrand et al., 2002), earlier timing (Edwards & Richardson, 2004), higher diversity (Richardson, 2008), change toward a community that prefers warmer waters (Poloczanska et al., 2013) and smaller species (Campbell, 2018) have been described in many areas in the northern hemisphere with long-term datasets, but there are few examples from Australian waters. Now we have over ten years of zooplankton data from the Integrated Marine Observing System (IMOS) National Reference Stations, we can start to explore how climate change might be impacting Australian zooplankton communities.

Surface waters off the east coast of Australia have warmed by up to 2°C over the past 70 years, with greater warming in the south (e.g., Maria Island) than further north (e.g., Port Hacking) (Figure 1). This is a consequence of global warming and its influence on the intensification of the poleward-flowing East Australian Current (EAC) (Cai et al., 2005), which is distributing more warm-water to southern Australia (Ridgway, 2007). This increasing strength of the EAC has contributed to ocean warming off southeast Australia ~3–4 times the global average (Ridgway, 2007).

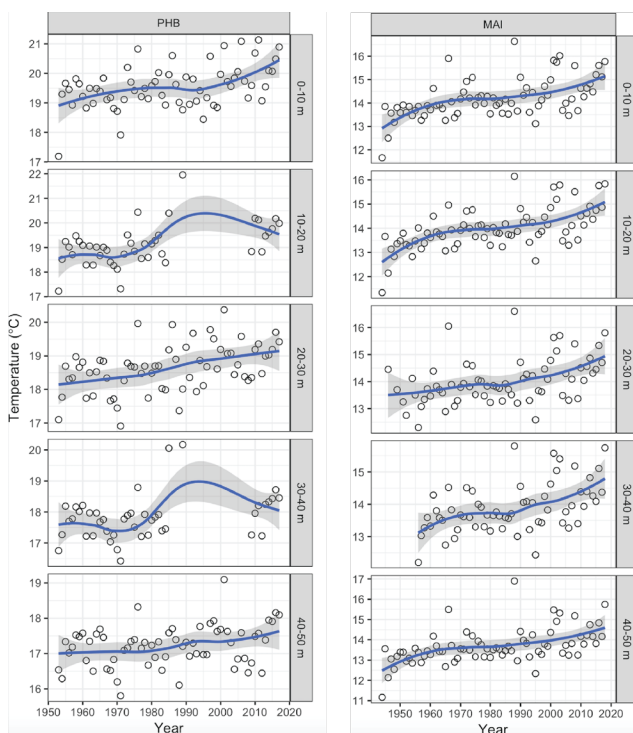


Figure 1. Mean annual temperatures (°C) from Maria Island (MAI) and Port Hacking (PHB) National Reference Stations in three depth strata (0–10 m, 20–30 m, 40–50 m) in the top 50 m, showing long-term warming since 1940s/50s. Data are not shown from Yongala because no long-term data exists from there.

Here we compare the IMOS copepod data from three National Reference Stations in eastern Australia – Maria Island (42.6°S), Port Hacking (34.1°S) and Yongala (19.3°S). We chose these regions because there was historical zooplankton data in each region to assess whether there is a signature of warming in the copepod community.

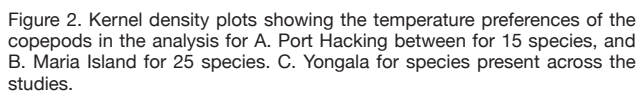
Methods

To investigate whether warming has impacted the copepod community, we compared the preferred temperature of copepods from historical samples to that from recent samples using the Community Temperature Index (CTI) (Stuart-Smith et al., 2015). The CTI is the overall temperature preference of species in a sample, weighted by their abundance, so that more abundant species have greater influence. It has been used to assess the temperature preference of communities of microbes, butterflies, fish and benthic invertebrates (Stuart-Smith et al., 2015 and references therein). We chose the CTI because it is sensitive to large-scale changes in temperature and is relatively robust to variations in sampling methods, as it is most responsive to relative and not absolute changes in abundance.

We performed three separate analyses – one for Maria Island, one for Port Hacking, and one for Yongala. All analyses compare current IMOS data with historical data from the Australian Zooplankton Database (Davies et al., 2014). For Port Hacking, IMOS samples from 2009–2018 were compared with two historical datasets. The first was 29 samples collected monthly from January 1931 to March 1932 by Dakin & Colefax (1940). The second was more recent; 71 samples were collected monthly from 2001–2008 (by the NSW Environment Agency). The 2001–2008 data were counted in the same way and by the same people as the 2009–2018 IMOS (104 samples). Only the most abundant 15 species were reported historically from 1931–1932, so these same species were extracted from the more recent data for comparison using the CTI.

For Maria Island, the historical dataset was collected monthly from August 1971 to May 1973 over a grid off the east coast of Tasmania by Nyan Taw (1975). We retained samples in our analysis that were within 150 km of Maria Island and <200 m depth to ensure similar conditions to the current IMOS National Reference Station. We then compared these data with IMOS data collected from January 2009 to the present. As the 1971–1973 data included only 25 copepod species, we selected the same species from the 2009–2018 period.

For Yongala, we use copepod data the 1928–1929 GBR expedition (Farran, 1949), Peter Liston's PhD thesis (Liston, 1990), sampling in the early 2000s (Mckinnon et al. 2005), and IMOS data since 2009.



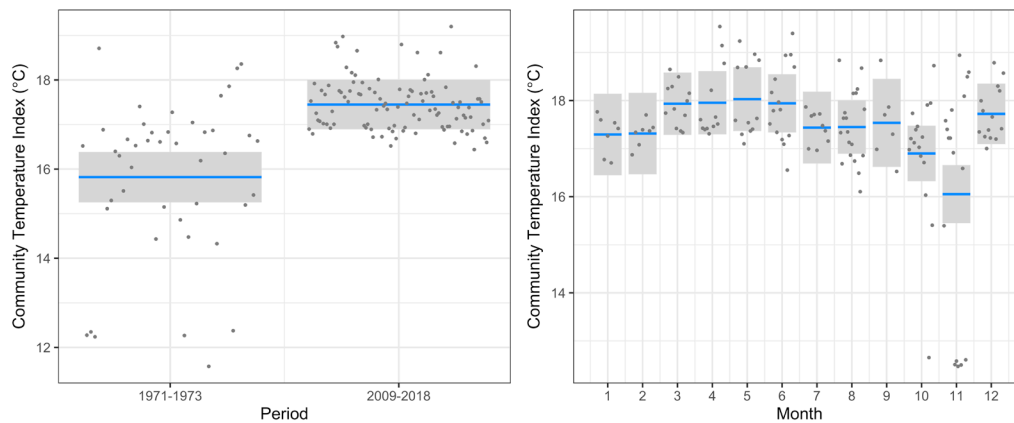


Figure 4. The linear model at Maria Island of the Community Temperature Index (response) and the Period and Seasonal cycle (predictors).

Results and interpretation

Copepod species at Port Hacking and Maria Island have a range of thermal preferences, with some preferring colder waters and some warmer waters (Figure 2). As expected, species from Port Hacking (Figure 2a) generally have warmer temperature preferences than those from Maria Island (Figure 2b).

At Port Hacking, the linear model clearly showed a significant increase in the CTI of 1.5°C from 1931-1932 to 2001-2008, and then a further increase of 0.9°C to 2009-2018 ($r^2=35.9\%$, Figure 3). This increase in CTI is similar in magnitude to the warming since the 1930s, and implies that warm-water copepod species have increased in abundance whilst cold-water copepods have decreased. The increase in CTI is accompanied by some samples having extremely warm-water affinities with CTIs around 26°C, about 6°C warmer than the warmest communities observed in 1931-1932. There was a clear seasonal cycle in CTI at Port Hacking, with highest values in July-September, and lowest values in November-January.

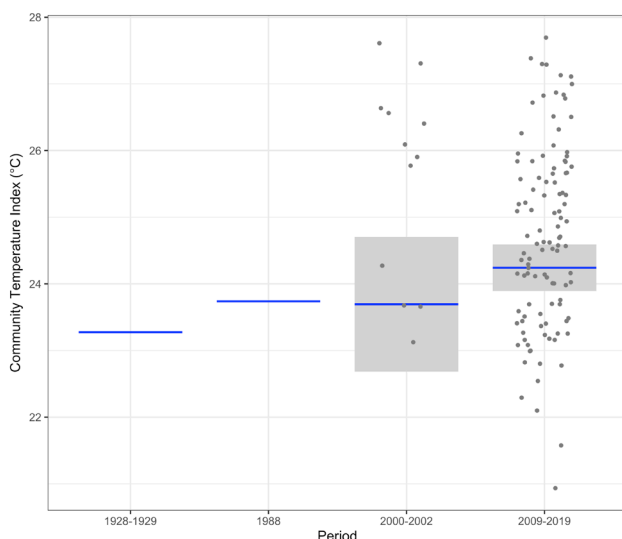


Figure 5 The linear model at Yongala of the Community Temperature Index (response) and the Period (predictor).

At Maria Island, the linear model clearly showed a significant increase in the CTI of 1.6°C from 1971-1973 to 2009-2018 ($r^2=47.7\%$, Figure 4). This increase in CTI is similar in magnitude to the warming over the same period, and implies that warm-water copepod species have increased in abundance whilst cold-water copepods have decreased. There was a clear seasonal cycle in CTI, with highest values in March-June, and lowest values in October and November. The very low values of CTI (~12.5°C) seen in October and November in the 1970s (spring) is a consequence of high abundances of a single species – *Neocalanus tonsus*, a large cold-water copepod indicative of intrusions of Southern Ocean water. Despite nearly 10 years of monthly IMOS sampling since 2009, we have not seen *Neocalanus tonsus* in similar large numbers at Maria Island, potentially because of the increased flow of the EAC and reduced incursions of Southern Ocean water in the region.

At Yongala, the linear model clearly showed a significant increase in the CTI of nearly 1°C from 1928-1929 to 2009-2019 (Figure 4). This is similar to the 0.75°C warming observed in the region, based on Hadley ISST data from the UK Met Office. Data from two surveys – one in 1988 and the other 2000-2002 show intermediate values of CTI.

Implications for people and ecosystems

This is the strongest evidence to date that global warming is affecting zooplankton composition in response to warming in Australian waters. The increased abundance of warm-water taxa is consistent with what is happening in other systems including the North Atlantic (Beaugrand et al., 2002; Bonnet et al., 2005; Lindley & Daykin, 2005) and North Pacific (Poloczanska et al., 2013). Such a change from cold- to warm-water zooplankton species off southeast Australia is likely to have repercussions for higher trophic levels. Warm-water copepod communities generally have smaller individuals and lower biomass (Richardson & Schoeman, 2004) and are thus inferior food for fish, seabirds and marine mammals

(Beaugrand et al., 2003). Ongoing IMOS observations of zooplankton ensure we are well placed to identify future changes in the zooplankton community around Australia.

Acknowledgements

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Data Sources

IMOS National Reference Stations.

<http://imos.org.au/facilities/nationalmooringnetwork/nrs/>

IMOS Ships of Opportunity.

<http://imos.org.au/facilities/shipsopportunity/>

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