Estuarine, Coastal and Shelf Science 180 (2016) 242–257

Contents lists available at ScienceDirect

Estuarine, Coastal and Shelf Science

journal homepage: www.elsevier.com/locate/ecss

Zooplankton responses to increasing sea surface temperatures in the southeastern Australia global marine hotspot

Paige Kelly [a, b, c, *], Lesley Clementson [b], Claire Davies [b], Stuart Corney [a, c], Kerrie Swadling [a, c]

[a] Institute for Marine and Antarctic Studies, University of Tasmania, Private Bag 129, Sandy Bay, Tasmania 7005, Australia
[b] CSIRO Oceans and Atmosphere, GPO Box 1538, Hobart, Tasmania 7001, Australia
[c] Antarctic Climate & Ecosystems CRC, University of Tasmania, Private Bag 80, Hobart, Tasmania 7001, Australia

ARTICLE INFO

Article history:
Received 1 December 2015
Received in revised form
4 May 2016
Accepted 31 July 2016
Available online 3 August 2016

Keywords:
Climatic change
East Australian Current
Zooplankton
Coastal zones
Coastal fisheries
Regime shift
Southeastern Australia
Maria Island

ABSTRACT

Southeastern Australia is a 'hotspot' for oceanographic change. Here, rapidly increasing sea surface temperatures, rising at more than double the global trend, are largely associated with a southerly extension of the East Australian Current (EAC) and its eddy field. Maria Island, situated at the southern end of the EAC extension at 42°S, 148°E, has been used as a site to study temperature-driven biological trends in this region of accelerated change. Zooplankton have short life cycles (usually < 1 year) and are highly sensitive to environmental change, making them an ideal indicator of the biological effects of an increased southward flow of the EAC. Data from in-situ net drops and the Continuous Plankton Recorder (CPR), collected since 2009, together with historical zooplankton abundance data, have been analysed in this study. Like the North Atlantic, zooplankton communities of southeastern Australia are responding to increased temperatures through relocation, long-term increases in warm-water species and a shift towards a zooplankton community dominated by small copepods. The biological trends present evidence of extended EAC influence at Maria Island into autumn and winter months, which has allowed for the rapid establishment of warm-water species during these seasons, and has increased the similarity between Maria Island and the more northerly Port Hacking zooplankton community. Generalised Linear Models (GLM) suggest the high salinity and low nutrient properties of EAC-water to be the primary drivers of increasing abundances of warm-water species off southeastern Australia. Changes in both the species composition and size distribution of the Maria Island zooplankton community will have effects for pelagic fisheries. This study provides an indication of how zooplankton communities influenced by intensifying Western Boundary currents may respond to rapid environmental change.

1. Introduction

Studies of zooplankton, the ocean's core secondary producers, can improve existing knowledge of how marine ecosystems are coping under a changing climate. Zooplankton are particularly sensitive to short-term environmental changes in salinity and temperature, as both their population dynamics and physiological processes are influenced by salinity and temperature Hays et al. (2005); Richardson (2008). Due to this sensitivity, zooplankton communities can be used to assess whole-of-ecosystem health, and variation to distribution patterns can provide valuable information about the physical and chemical changes occurring off Australia's coast (Hays et al., 2005).

The Tasman Sea, situated between Southeast Australia and New Zealand, has been identified as 'hotspot' for rapid oceanographic change (Hobday and Pecl, 2013; Ridgway, 2007). Monitoring of the Sea Surface Temperature (SST) of the waters off Maria Island (42.6°S, 148.08°E) since 1944 shows a warming of +2.28 °C per century (Ridgway, 2007), a pace far exceeding the average rate of global surface-ocean warming of 1 °C per century (Rhein et al., 2013). During the Austral 2015/2016 summer, record high SSTs, exceeding 21 °C, were observed off eastern Tasmania (Bureau of Meteorology (2016)). Accelerated warming in this area has largely been attributed to the intensification and southerly extension of the

* Corresponding author. Institute for Marine and Antarctic Studies, University of Tasmania, Private Bag 129, Sandy Bay, Tasmania 7005, Australia.
E-mail addresses: kellyps@utas.edu.au (P. Kelly), Lesley.Clementson@csiro.au (L. Clementson), Claire.Davies@csiro.au (C. Davies), Stuart.Corney@utas.edu.au (S. Corney), K.Swadling@utas.edu.au (K. Swadling).

http://dx.doi.org/10.1016/j.ecss.2016.07.019

major poleward flowing Western Boundary current bordering Australia's east coast: the East Australian Current (EAC). The current originates from the South Pacific Ocean Gyre and extends southward along the Australian east coast between 18°S and ~33°S, where it reaches the separation point (Ridgway and Dunn, 2003). Here, the current diverges, with one component, now detached from the coast, flowing eastward to the Tasman Sea (Andrews et al., 1980), and the other component persisting southward as far as the Tasmanian east coast (Reid, 1986; Ridgway and Godfrey, 1994). EAC flow is highly variable and displays multiple signals including seasonal (strongest in summer and weakest in winter), El Niño/La Niña/Southern Oscillation (ENSO) (strongest during La Niña episodes), and interannual and decadal trends (Holbrook et al., 2011; Kelly et al., 2015; Ridgway, 2007). Globally, southeastern Australia is an area experiencing one of the strongest shifts and/or intensification of the dominant surface current (Popova et al., 2016). The waters of this region are also influenced, though to a lesser extent, by the current bordering Australia's west coast: the Leeuwin Current (LC). Like the EAC, the LC redistributes heat from the tropics to the southern, temperate latitudes and flow is increased during La Niña periods (Feng et al., 2009), however, as opposed to the EAC, seasonal LC flow is weakest during summer and strengthens during winter (Cresswell, 2000).

The southeastern Australia hotspot is of high biological and commercial significance. This region supports the largest of Australia's commercial fisheries (Koehn et al., 2011), and, here, EAC-driven changes in zooplankton distribution have led to rapid alterations in the distribution of pelagic fish species. During the La Niña summer of 1988/1989, increased intrusions of EAC-extension water off southeastern Tasmania resulted in the reduction of the cold-water preferring euphausiid *Nyctiphanes australis*, the major food source for the commercially fished species Jack Mackerel (*Trachurus declivis*), from the surface waters and contributed to the collapse of the purse seine fishery (Harris et al., 1991). Recently, Robinson et al. (2015) concluded that there is 'high confidence' in the occurrence of temperature-driven shifts in the distributions of some fish species off southeastern Australia. Little is known, however, of the potential changes in zooplankton distribution patterns in this region. Until recently, knowledge of how the EAC and LC drive zooplankton distribution patterns was limited, as, Australia lacked a continuous long-term zooplankton dataset (Hobday et al., 2006). In the Northern Hemisphere, multiple long-term zooplankton sampling regimes are currently active, including the North Atlantic CPR programme (Warner and Hays, 1994), the California Cooperative Oceanic Fisheries Investigation programme, the Hawaiian Ocean Time-Series and Bermuda Atlantic Time-Series study (both components of the Joint Global Ocean Flux Study) (Karl et al., 2001), the Long Term Ecological Research Station MC in the Gulf of Naples, and the North-Sea Dove Marine Laboratory time series (Pitois et al., 2009). Such long-term datasets have proven vital for identifying zooplankton range shifts (Beaugrand, 2004; Beaugrand et al., 2002; Richardson et al., 2006) and observing trophic cascades (Beaugrand, 2003). These time-series have also highlighted differing responses by zooplankton communities to the large-scale warming occurring across the majority of the world's upper ocean (Levitus et al., 2012). In the Southern California Current System, a long-term increase in temperature (Lorenzo et al., 2005) has coincided with a decline in overall zooplankton biomass (Kang and Ohman, 2014). The same study found an increase in all major zooplankton groups in the Northeastern Asian Marginal Sea, also a region of warming (Chang et al., 2002). Biomass and species assemblages of some coastal zooplankton communities have also remained consistent under prolonged warming, i.e. the Gulf of Naples (Mazzocchi et al., 2011).

The accelerated warming trend observed in Western Boundary currents (Wu et al., 2012), coupled with the research benefits illustrated by coastal zooplankton time series in the Northern Hemisphere, highlights the need for increased zooplankton monitoring across Southern Hemisphere coastal systems. In 2009, the Integrated Marine Observing System (IMOS) initiated two streams of plankton monitoring surveys to address the need for a long-term monitoring program targeting coastal Australia zooplankton. One stream is The National Reference Station (NRS) Network, part of the Australian National Mooring Network (ANMN), where zooplankton sampling is part of a monthly biogeochemical sampling program, and the other is the Continuous Plankton Recorder (CPR) surveys, which are conducted on a regular basis along repeat transects off the Australian coasts. The NRS zooplankton samples have been valuable in identifying EAC-associated long-term changes in east coast Australia ecosystems, including a rise in warm-water zooplankton species, and a decline in cold-water zooplankton species from 1971 to 2009 (Johnson et al., 2011). Recent change in zooplankton distribution patterns requires greater investigation, with underexplored aspects including the EAC's influence on both latitudinal shifts in distribution patterns and seasonal patterns in community composition.

This study provides the first comprehensive account of zooplankton responses to increasing temperature in the southeastern Australia hotspot. Recent and historical zooplankton abundance records have been incorporated to identify short-term and long-term trends in the Maria Island zooplankton community composition. The relationship between community composition at the Maria Island and two other east coast IMOS NRS located further north, Port Hacking (34°S, 151°E) and North Stradbroke Island (27°S, 154°E), was also examined. Major hypotheses that this study addresses are; (a) from 2009 to 2014, at Maria Island, abundances of warm-water species have continued to increase, exceeding abundances of cold-water species; (b) warm-water species reflect a prolonged seasonal influence of the EAC at Maria Island by extending their presence into winter months; (c) heightened EAC influence during summer and autumn months changes the Maria Island zooplankton community, resulting in increased similarity between the Maria Island zooplankton community composition and that of the closest site north, Port Hacking; and (d) periods of increased similarity between the Maria Island and Port Hacking zooplankton assemblages are largely due to warm-water species. In-situ physical and chemical data have been incorporated via statistical modelling methods to validate high abundances of warm-water species occurring under conditions indicative of increased EAC influence (increasing temperature and salinity, and decreasing nitrate). Satellite-derived SST were also analysed to confirm whether trends observed in the zooplankton communities are consistent with EAC activity. This study aims to improve understanding of the distribution of the present-day Maria Island zooplankton community and its relationship with the EAC and its associated eddy field, as well as examining changes in regional zooplankton assemblages along the entire Australian East Coast, through a combination of both NRS and CPR data. The findings from this study are interpreted in context of consequences for pelagic fish species, and global changes occurring in zooplankton communities alongside increasing SST. Outcomes from this study will aid in understanding how other Southern Hemisphere and Western Boundary current zooplankton communities are responding to rapid environmental change.

2. Materials and methods

2.1. Study locations

The Maria Island (MI), Port Hacking (PH) and North Stradbroke