Marine Pollution Bulletin 105 (2016) 324–336

Contents lists available at ScienceDirect

Marine Pollution Bulletin

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

Selective responses of benthic foraminifera to thermal pollution

Danna Titelboim [a], Ahuva Almogi-Labin [b], Barak Herut [c], Michal Kucera [d], Christiane Schmidt [d], Orit Hyams-Kaphzan [b], Ofer Ovadia [a], Sigal Abramovich [a,*]

[a] Ben-Gurion University of the Negev, Beer Sheva, Israel
[b] Geological Survey of Israel, Jerusalem, Israel
[c] Israel Oceanographic and Limnological Research, Haifa, Israel
[d] MARUM-Center for Marine Environmental Sciences, University of Bremen, Bremen, Germany

A R T I C L E I N F O

Article history:
Received 6 October 2015
Received in revised form 3 January 2016
Accepted 1 February 2016
Available online 16 February 2016

Keywords:
East Mediterranean
Thermohaline pollution
Climate change
Benthic foraminifera
Lessepsian invaders
Hard-bottom habitat

A B S T R A C T

Persistent thermohaline pollution at a site along the northern coast of Israel, due to power and desalination plants, is used as a natural laboratory to evaluate the effects of rising temperature and salinity levels on benthic foraminifera living in shallow hard-bottom habitats. Biomonitoring of the disturbed area and a control station shows that elevated temperature is a more significant stressor compared to salinity, thus causing a decrease in abundance and richness.

Critical temperature thresholds were observed at 30 and 35 °C, the latter representing the most thermally tolerant species in the studied area *Pararotalia calcariformata*, which is the only symbiont-bearing species observed within the core of the heated area.

Common species of the shallow hard-bottom habitats including several Lessepsian invaders are almost absent in the most exposed site indicating that excess warming will likely impede the survival of these species that currently benefit from the ongoing warming of the Eastern Mediterranean.

1. Introduction

Considering the expected changes in ocean seawater temperature and salinity in the next decades (IPCC, 2014), it is important to evaluate the effects that such changes can inflict on marine ecosystems. This is especially true for the coastal ecosystems of the easternmost Mediterranean, occupying the most extreme temperature and salinity levels within the entire Mediterranean Sea; these ecosystems will be inevitably influenced by these abiotic changes, exceeding the range they have been adapted to tolerate.

The surface temperature and salinity in the easternmost Levantine basin vary between 18 °C and 30 °C and between 38.5 and 39.7 psu, making this basin the warmest and the saltiest in the entire Mediterranean (Herut et al., 2000; Gertman and Hecht, 2002). The observed annual warming rate in the Mediterranean Sea was 0.027 °C, and it is forecasted to continue at a similar rate until the end of the century (Macias et al., 2013). This is a cause for concern as it has been estimated that between 60% and 80% of the domestic species are likely to disappear from the southern European Mediterranean region if the global mean temperature increases by 1.8 °C (IPCC, 2007). In addition to the increase in temperature, a gradual rise in salinity with a maximum of 0.014 psu per year was recorded in the upper water layer of the Israeli shelf during the autumn months over the past few years (Gertman and Hecht, 2002). This probably coincides with the rise in the salinity levels of the Aegean Sea and a decline in the water flow of the Nile River (Lascaratos et al., 1999) and could also be a significant stressor to the native species that already live in high-salinity habitats.

Benthic foraminifera, the most diverse group of microscopic organisms with calcareous shells currently existing, represents an ideal model system to study the effects of rising temperature and salinity on shallow marine ecosystems (Sen Gupta, 1999). Foraminiferal distribution is known to be controlled by different environmental conditions (i.e., changes in irradiation, nutrient abundance, oxygen concentration, anthropogenic contaminations, salinity, and temperature fluctuations; Alvarez et al., 2000; Saraswat et al., 2004; Yanko et al., 1994, 1998).

Water temperature is one of the main factors that control distribution patterns of marginal marine and inner shelf foraminifera. All physiological processes are influenced, to some degree, by temperature, and most species, especially the symbiont-bearing larger benthic foraminifera (LBF), display distinct thresholds for reproduction and survival (Langer and Hottinger, 2000; Murray, 2006) as well as bleach in response to heat stress (Hallock et al., 1992, 2006a,b; Talge and Hallock, 2003; Schmidt et al., 2011; Uthicke et al., 2012). It has also been observed that high temperature can cause dwarfism and deformed tests in certain species (Alve, 1995). These studies demonstrate the potential of benthic foraminifera as a model system to study response to thermal stress.

* Corresponding author at: Geological and Environmental Sciences, Ben-Gurion University of the Negev, Mailbox 653, Beer-Sheva 84105, Israel.
E-mail address: sigalabr@bgu.ac.il (S. Abramovich).

http://dx.doi.org/10.1016/j.marpolbul.2016.02.002
0025-326X/

The permanent heat anomaly in Hadera provides a unique opportunity to study the effect of persistently elevated temperature and salinity on benthic communities in situ. This heat anomaly is generated by the power plant "Orot Rabin" located on Israel's northern Mediterranean coast near Hadera (Fig. 1) and is active since 1981. Seawater is pumped year-round into the power plant to cool the turbines and then discharged back into the sea. In 2010, a desalination plant started working adjacent to the power plant discharging brines together with the power plant cooling water. This creates a disturbed area, with warmer and saltier seawater, extending about 1.5 km to the south and 1 km to the west (Fig. 2). The higher temperatures and salinities affect the natural seasonal pattern, and the resulting peak warmth and salinity produced seasonally may have serious consequences for marine organisms. The most extreme scenario occurs in summer with the ambient temperature increasing from 30 to 42 °C and the salinity levels from 39.7 to 41.6 psu within the plume (Glazer, 2010).

The study of Arieli (2010), Arieli et al. (2011) on the benthic foraminifera living in this area has shown a clear negative response to elevated temperature and different levels of sensitivity among the investigated species including a highly tolerant recent invader species of benthic foraminifera, *Pararotalia calcariformata* hosting endosymbionts that survive high seawater temperatures of up to 35 °C (Arieli et al., 2011; Schmidt et al., 2015).

This paper presents an ecological field investigation of the foraminiferal communities living within and outside the Hadera heat plume, and the response of benthic foraminifera to increased temperature and salinity levels in a thermally polluted area mimicking the expected climate changes is documented. The results of this study can help assess the possible fate of species in a warmer and more saline ocean.

Revisiting the Hadera heat plume half a decade after the study by Arieli et al. (2011) enabled us to evaluate the effect of persistent thermal stress on the foraminiferal populations as well as the ongoing invasion of Lessepsian species (i.e., recent migration through the Suez Canal (Langer and Hottinger, 2000; Galil and Zenetos, 2002; Hyams et al., 2002; Langer, 2008; Langer et al., 2012; Zenetos et al., 2012). Moreover, the critical temperature thresholds for the different species were detected by implementing a new experimental approach including the use of temperature loggers for continuous recording of temperature values at the studied stations. Furthermore, a new selected control station, north of the plume, better represented the natural local community structure of the Israeli coast. Finally, the introduction of brines into the disturbed area by a desalination plant in 2010 added a new potential stressor, simulating future local increase in the salinity levels; thus, we investigated whether the latter creates additional stress on the foraminiferal communities. This is of particular interest as it simulates further changes, as expected, in addition to the increase in temperature.

2. Experimental design and methods

2.1. Field work

Three sampling stations along the Mediterranean coast of Israel were chosen in order to simulate different stages of the future climate change: 1. Station H2, located about 300 m from the discharge point in Hadera (= station H2 of Arieli et al., 2011) at the core of the heat plume, representing excessive change; 2. Station H4, located about 2 km south of station H2 (=~500 m south of station H4 of Arieli et al., 2011) at the edge of the heat plume, representing only a minor change

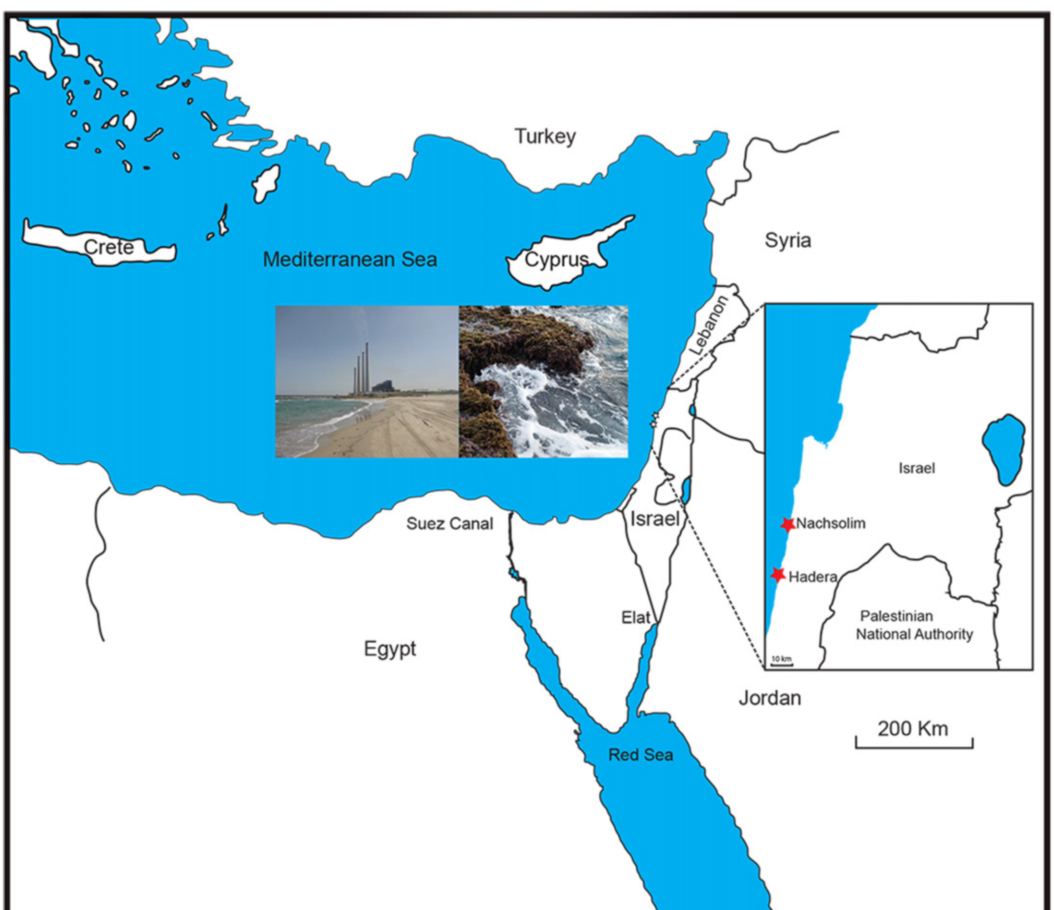

Fig. 1. Location map of the studied stations: Nachsholim (control), and the two stations of the Hadera heat plume, H2 and H4.