Quaternary Science Reviews 191 (2018) 256–274

Contents lists available at ScienceDirect

Quaternary Science Reviews

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

Distribution and ecology of planktic foraminifera in the North Pacific: Implications for paleo-reconstructions

Ben J. Taylor [a,*], James W.B. Rae [a], William R. Gray [a], Kate F. Darling [b,c], Andrea Burke [a], Rainer Gersonde [d], Andrea Abelmann [d], Edith Maier [d], Oliver Esper [d], Patrizia Ziveri [e,f]

[a] School of Earth and Environmental Sciences, University of St Andrews, UK
[b] School of Geography and Sustainable Development, University of St Andrews, UK
[c] School of Geosciences, University of Edinburgh, UK
[d] Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research, Bremerhaven, Germany
[e] Institute of Environmental Science and Technology (ICTA), Universitat Autònoma Barcelona (UAB), Bellaterra 08193, Spain
[f] Catalan Institution for Research and Advanced Studies (ICREA), Pg. Lluís Companys 23, Barcelona 08010, Spain

ARTICLE INFO

Article history:
Received 27 December 2017
Received in revised form
27 April 2018
Accepted 4 May 2018

ABSTRACT

Planktic foraminifera census data have been used to reconstruct past temperatures through transfer functions, as well as changes in ocean ecosystems, chemistry and circulation. Here we present new multinet, plankton net and core-top census data from 20 sites in the Subpolar North Pacific. We combine these with previous data to provide an up to date compilation of North Pacific planktic foraminifera assemblage data. Our compilation is used to define 6 faunal zones: the subpolar zone; transitional zone; upwelling zone; subtropical zone; east equatorial zone; west equatorial zone; based on the distribution of 10 major species of planktic foraminifera. Two species of planktic foraminifera *Neogloboquadrina pachyderma* and *Globigerina bulloides* provide the basis for many subpolar paleo-reconstructions. Through the analysis of new multinet and CTD data we find that *G. bulloides* and *N. pachyderma* are predominantly found within 0–50 m of the water column and coincide with high food availability. *N. pachyderma* also shows a strong temperature control and can thrive in food poor waters where temperatures are low. Both species bloom seasonally, particularly during the spring bloom of March to June, with *G. bulloides* exhibiting greater seasonal variation. We suggest that percentage abundance of *N. pachyderma* in paleo-assemblages can be used to assess relative changes in past temperature, with *G. bulloides* abundance more likely to reflect changes in food availability. By comparing our core-top and multinet data, we also find a dissolution bias of *G. bulloides* over *N. pachyderma* in the North Pacific, which may enrich assemblages in the latter species.

1. Introduction

Planktic foraminifera provide a key tool in studies of past changes in climate. Foraminiferal species assemblages may track a variety of oceanographic conditions, including temperature, salinity and nutrients, while the geochemistry of foraminiferal calcite can be used to reconstruct quantitative changes in ocean temperature and chemistry through time. However, downcore studies using foraminifera can only be justified if modern calibrations are well established, giving context to paleo-records. The upper water column may vary vertically, seasonally and spatially across the global ocean and it is therefore of prime importance that modern assemblages are fully understood in order to disentangle downcore signals.

Planktic foraminifera are known to exhibit variable depth distribution and seasonal abundance, thus identifying constraints on these variables has become vital to the interpretation of paleo-data (Schiebel and Hemleben, 2017). Early work using plankton tows and isotopic data suggested that planktic foraminifera are most abundant at chlorophyll maxima and that species were vertically stratified in accordance with their temperature preferences (Fairbanks and Wiebe, 1980; Fairbanks et al., 1982; Hemleben et al., 1989). The vertical distribution of planktic foraminifera in the North Pacific and globally has been linked to phytoplankton productivity

* Corresponding author.
E-mail address: bjt@st-andrew.ac.uk (B.J. Taylor).

https://doi.org/10.1016/j.quascirev.2018.05.006
0277-3791/

and food availability which are in turn related to variations in the pycnocline and thermocline. In the North-West Pacific, recent literature highlights the role of nutrients and seasonal changes in the thermocline as key drivers of foraminiferal abundance (Mohiuddin et al., 2002, 2004, 2005; Kuroyanagi et al., 2002, 2008; Eguchi et al., 2003). Despite this, large regional variations in depth preference and abundance have been observed within individual species, suggesting that there are regional discrepancies in the North Pacific assemblages which are not accounted for in paleo-records (Kuroyanagi et al., 2002; Field, 2004; Iwasaki et al., 2017). Three key species of planktic foraminifera dominate high-latitude assemblages in the North Pacific, *Neogloboquadrina pachyderma, Globigerina bulloides* and *Turborotalita quinqueloba*. Note that here and throughout, we refer to *N. pachyderma* sinistral as *N. pachyderma*, and previous references to *N. pachyderma* dextral as *Neogloboquadrina incompta* (Darling et al., 2006). *T. quinqueloba* is ubiquitous throughout subpolar and polar waters but is often under-represented in assemblage counts, due to its small size (Kandiano and Bauch, 2002). For this reason, it is rarely used in paleoceanographic reconstructions, unless a size fraction of >125 μm is used. Seasonally resolved data from the North East Pacific records the apparent affinity of specific species, particularly *G. bulloides,* to the spring upwelling conditions off the coast of southern California and Vancouver (Sautter and Thunell, 1989; Thunell and Sautter, 1991), which is accompanied by high phytoplankton abundance (Thunell and Honjo, 1987). In contrast, Davis et al. (2016) demonstrate the upwelling affinity of *N. pachyderma* over *G. bulloides* in the California coastal upwelling further to the north. Such contrasting differences between adjacent regional assemblages imposes complexity, which can be used to further refine paleoceanographic reconstructions.

Although detailed compilations of planktic foraminifera assemblages are available globally, the North Pacific is poorly represented (Rutherford et al., 1999; Fenton et al., 2016; Siccha and Kucera, 2017). The North Pacific has abyssal depths of >5500 m, resulting in poor preservation of foraminiferal calcite (Peterson, 1966; Berger, 1970). The lack of preservation, particularly in core-top material, has meant that the distribution and paleoecological significance of planktic foraminifera in the North Pacific is poorly constrained. The difficulty of constraining dissolution effects on sediment also impacts upon the use of North Pacific census data in downcore records (Berger, 1970). North Pacific planktic foraminiferal provinces, or faunal zones, were originally characterised by Bradshaw (1959) and further constrained by Coulbourn et al. (1980). The zones: subarctic; transitional; central and equatorial were defined broadly by the relative abundance of *N. pachyderma*, *T. quinqueloba*, *G. bulloides*, *Globorotalia inflata* and *Globigerinoides ruber* in core-top samples (Coulbourn et al., 1980).

In this study, we generate new planktic foraminifera assemblage data from plankton tows and core tops collected from 15 sites across the subpolar North Pacific. We combine these data with previously published planktic foraminifera core top, multinet and sediment trap assemblage data from the North Pacific, to characterise the ocean conditions associated with modern planktic foraminifera assemblages. This evidence is then used to constrain the depth habitat of individual subpolar species, for the better understanding of paleo-records. To do so, we first address the gap in North Pacific census data, particularly prevalent in the subpolar gyre (Rutherford et al., 1999), by re-evaluating North Pacific planktic foraminifera faunal provinces using our new data compilation. We then focus in detail on the two key subpolar North Pacific proxy carriers, *G. bulloides* and *N. pachyderma*. Through assessment of their dominant ecological drivers in the surface ocean, we suggest how best to interpret both the assemblage and geochemical records of these species downcore. Surface water and sediment assemblages are then compared, highlighting the effects of both seasonality and dissolution as potential biases within the sediment record.

2. Oceanographic setting

Oceanographic currents in the North Pacific are dominated by two large-scale gyres: the subpolar gyre and the subtropical gyre, separated by the Subarctic Front, which is marked by a pronounced latitudinal sea surface temperature gradient (Fig. 1). This gradient is also seen within salinity and nutrient records, with the subpolar gyre exhibiting higher nutrients and low salinity, whilst the subtropical gyre is comparatively saltier and nutrient poor (Locarnini et al., 2013; Zweng et al., 2013; Garcia et al., 2014).

The subpolar gyre can be further split into the West Pacific Gyre and the Alaskan Gyre (Harrison et al., 2004). The West Pacific Gyre is a high nutrient low chlorophyll zone (HNLC) which is fed predominantly by cool, nutrient rich waters from the Sea of Okhotsk and the Kamchatka Current (Locarnini et al., 2013; Garcia et al., 2014). The southern extent of this gyre is the Subarctic Current, a region along the Subarctic Front characterised by the confluence of a number of current systems (Fig. 1). These include the warm Kuroshio Current originating from the subtropical gyre, the cold Oyashio Current originating from the West Pacific Gyre together with a number of minor currents (Yasuda, 2003, Fig. 1). The Subarctic Current and Kuroshio Extension define, in part, the Subarctic Front (Fig. 1) which roughly follows 40°N latitude zonally across the North Pacific. In the eastern North Pacific, the California Current splits towards the south in the Subtropical Gyre, whilst the Alaskan Current forms the eastern limb of the Alaskan Gyre (Fig. 1). The Alaskan gyre, also a HNLC zone, is more nutrient limited than the West Pacific gyre (Harrison et al., 2004) and thus productivity is reduced. It feeds the Bering Sea which consists primarily of the Bering Slope current in the east and the Kamchatka current to the west (Fig. 1) (Stabeno and Reed, 1994). In the Subtropical Gyre, the California Current extends southward to the equator where it forms the North Pacific Equatorial Current. In the east Equatorial Pacific, the North Pacific Equatorial Current is characterised by upwelling of cooler nutrient rich waters (Locarnini et al., 2013; Zweng et al., 2013; Garcia et al., 2014), contributing to the formation of the east equatorial upwelling region where productivity is high (Wyrtki, 1981). The current continues along the equator to the west, where it enters the West Pacific warm pool (Yan et al., 1992) and continues to form the western limb of the Kuroshio Current.

3. Materials and methods

3.1. SO202 INOPEX cruise study area

Multinet and multicore samples from the SO202 INOPEX cruise (2009) with the German RV *Sonne* (Gersonde, 2012) were analysed from 15 North Pacific sites (6 multicore and 9 multinets) in combination with hydrographic CTD data (Table 1). The site locations range from the Subarctic Front through the Subpolar Gyre to the Bering Sea (Fig. 1). The spatial variation between the sites means the diverse regional hydrography affects individual sites differently (Fig. 1). Those lying within the Subarctic frontal region (sites SO202-02-40, SO202-05-34 and SO202-05-33) are predominantly bathed in waters derived from the westward extension of the Kuroshio Current. Sites SO202-04-27 and SO202-02-31 are influenced by the Alaskan Coastal Current, and sites SO202-05-02, SO202-02-06 and SO202-02-07 in the northwest Pacific are associated with the cooler Kamchatka Current and outflow from the Sea of Okhotsk. The Bering Sea sites (SO202-04-10, SO202-03-13,