DISPERSAL AND PROPAGULE BANKS OF BENTHIC FORAMINIFERA: SHELF TO BATHYAL SETTINGS, WESTERN NORTH ATLANTIC

by

DARIN MICHAEL LANG

(Under the Direction of Susan T. Goldstein)

ABSTRACT

Dispersal largely controls the distribution of foraminifera yet only a handful of studies have focused on it. Understanding dispersal is important to comprehend the ability of foraminifera to respond and recover from short and long-term events, by allowing for assemblages to change over time. The purpose of this study is to assess foraminiferal dispersal off the northeast coast of the United States. To do this, foraminiferal propagules were collected from four sites, ranging from 70 – 2200 m, south of Cape Cod, Massachusetts (USA). The propagules were incubated at non-ambient temperatures and foraminifera were allowed to grow. The resulting assemblages were compared to each other and to the assemblages found *in situ* at each of the sites. Results show that propagules of allochthonous taxa grew from all of the collecting sites. Opportunists dominated samples grown in this study. The results of this study suggest that foraminiferal dispersal varies by species.

INDEX WORDS: Benthic Foraminifera, dispersal, propagules, *Brizalina lowmani, Rosalina floridana, Textularia earlandi, Leptohalysis scottii, Bolivina variabilis, Prolixoplecta parvula.*

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DARIN MICHAEL LANG

B.S., Indiana State University, 2011

A Thesis Submitted to the Graduate Faculty of The University of Georgia in Partial Fulfillment of the Requirements for the Degree

MASTER OF SCIENCE

ATHENS, GEORGIA

2013

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DARIN MICHAEL LANG

Major Professor: Susan T. Goldstein

Committee: Steven M. Holland
Joan M. Bernhard

Electronic Version Approved:

Maureen Grasso
Dean of the Graduate School
The University of Georgia
December 2013

ACKNOWLEDGMENTS

The success of this research was in large part because of the helpfulness and patience of my advisor, Susan Goldstein. I would like to thank her along with the crew and participants of *RV Oceanus* cruise 461, which collected our samples, the Bernhard lab and the Goldstein lab for setting up, maintaining, and harvesting the experiments, as well as undergraduate researchers, Nicole Graham, James Thompson, and Dylan Radford who all put in countless hours picking many of the foraminifera used in this study.

Others I would like to thank are my committee members, Steven Holland and Joan Bernhard, for their patience and assistance, John Shields for his aid with SEM imaging, my family, and my friends in the Marine Science and Geology departments for their encouragement and support.

I would also like to thank the University of Georgia Geology department for awarding me with the John Sanford Levy Award. This research was funded by NSF grants OCE 0850505 to Susan T. Goldstein and OCE 0850494 to Joan M. Bernhard (Woods Hole Oceanographic Institution).

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CHAPTER 1

INTRODUCTION

This thesis is written as a manuscript and is intended for submission to *Marine Micropaleontology.* Chapter two contains the text of this manuscript and includes a statement on the research questions, previous literature, description of field sites, methods, results, discussion, and conclusion. Chapter 3 presents suggestions for future work.

To understand foraminiferal dispersal better, multi-species assemblages of foraminifera were grown from propagule banks (natural collections of small juveniles) collected from near shore (continental shelf) to offshore (bathyal) sites south of Cape Cod, Massachusetts (USA). A broad range of non-ambient temperatures were employed, and assemblages were grown either with exposure to light (to promote the growth of micro-algal food organisms) or in the dark. Those grown in the dark were fed a mixture of two common food organisms. These experiments were designed to promote the growth of foraminiferal propagules, both those of the *in situ* assemblages and allochthonous taxa otherwise absent from the sampling sites. This study examines the influence of temperature, potential food quality, and increasing offshore distance and water depth on the species composition of experimentally grown assemblages. Using these methods, I was able to manipulate the propagule bank to express taxa in assemblages that are not present in the corresponding *in situ* assemblages.

This study provides insight into whether foraminiferal dispersal is broad or restricted and provides an enhanced understanding of the environmental tolerances of the species present. This study also surveys *in situ* assemblages present in this region, assesses how they differ with increasing distance from shore and water depth, and how the stained (live plus recently dead) assemblage compares with the dead assemblage. This information will aid in the understanding of foraminiferal dispersal and can provide useful information for future experimental studies on benthic foraminifera.

Material used for this study was collected aboard the *RV Oceanus* 13–17 May, 2010. Experimental assemblages were grown and harvested in either the Bernhard Lab (Woods Hole Oceanographic Institution) or the Goldstein Lab (University of Georgia).

CHAPTER 2: DISPERSAL AND PROPAGULE BANKS OF BENTHIC FORAMINIFERA: SHELF TO BATHYAL SETTINGS, WESTERN NORTH ATLANTIC

Introduction

The application of foraminiferal assemblages to a broad range of environmental and paleoecological applications is based on an understanding of the factors that control foraminiferal occurrences in time and space. The distribution of foraminifera is determined largely by physical conditions of the environment, food availability, and dispersal (e.g., Gooday & Jorissen, 2012). Dispersal is important because it allows foraminiferal populations to recover or become established following short or long-term perturbations. Dispersal also provides a mechanism by which assemblages change over time in response to changing environments. Although benthic foraminifera are known to disperse beyond the distribution of source populations (Alve & Goldstein, 2003), the extent to which the dispersal varies among species is largely unknown.

Recent dispersal studies on benthic foraminifera from soft-sediment substrates (Alve, 1999; Alve, 2003; Alve & Goldstein, 2002, 2003; Alve & Goldstein, 2010; Goldstein & Alve, 2011) have examined foraminiferal dispersal, using sites that range from the intertidal zone to ~350 m water depth. Those studies found that foraminifera largely disperse as propagules in the water column. These small juveniles or propagules result largely, but not exclusively, from sexual reproduction. Likely, ocean currents

transport propagules passively until they settle onto the ocean floor (Alve & Goldstein, 2003; Alve & Goldstein, 2010; Goldstein & Alve, 2011). The collection of propagules present at a given location has been termed the "propagule bank", which may include propagules from both local and allochthonous populations. These studies experimentally manipulated propagule banks from different areas to determine which conditions allow for the growth of certain species. By growing propagules at non-ambient temperatures and/or salinities, allochthonous propagules were expressed in the experimental assemblage (Alve & Goldstein, 2003, 2010; Goldstein & Alve, 2011). The propagules also have the ability to remain dormant for some time, which can broaden the dispersal range for some species (Alve & Goldstein, 2003; Alve & Goldstein, 2010).

This study uses a similar experimental approach to assess foraminiferal dispersal. We examined assemblages of foraminifera grown at different temperatures from propagule banks collected south of Cape Cod, Massachusetts (USA) in the western Atlantic from four sites ranging in water depths from 70 to 2200 m. Building on previous studies, this work addresses several questions: To what extent do propagules originate from local or allochthonous sources at these sites? To what extent do coastal species disperse offshore? Do different taxa grow at different temperatures from the same propagule bank? Are opportunistic taxa present in the propagule bank? In addition to these questions, this experiment examined the environmental tolerances of the species present with respect to temperature, which will aid in the understanding the distribution of foraminiferal species.

This study also examined the stained (live plus recently dead) and unstained (dead) *in situ* assemblages at each of the four sites. This is among the first studies in this

region to distinguish the stained and dead benthic foraminiferal assemblages. Most previous studies in this region focused on the overall benthic foraminiferal assemblage and did not separate stained and dead. Such "total" assemblages can include significant numbers of transported foraminifera and under-report the abundances of fragile taxa (Kidwell, 2013).

Methods

Soutar box-core samples were collected south of Cape Cod from 13–17 May, 2010, at 70, 340, 740, and 2200 m (Fig. 1; Table 1). Locations were chosen to compare propagule banks from different depths and offshore distances. A CTD surrounded by a rosette of niskin bottles was used to collect bottom water at each of the sites. Samples were sieved at 53 μm using bottom water from each site immediately after collection. Sediments >53 μm were preserved in either 6% buffered paraformaldehyde or 90% ethanol and refrigerated. Sediments <53 μm collected from each site were maintained in a cold van at 7 ° C (approximating ambient temperature) and transferred to facilities at Woods Hole Oceanographic Institution (WHOI) immediately after the cruise.

Sediments >53 μm were stained with rose Bengal to distinguish individuals that were potentially alive or recently alive (Bernhard, 2000) at the time of collection. Stained samples were split, sieved using a 63-μm sieve, and picked in water for all stained and unstained foraminifera. Because there are far more dead foraminifera than stained foraminifera in all of the *in situ* samples, additional living foraminifera were picked from each site to better characterize the living assemblage. All foraminifera in each split were counted and identified to characterize the stained and dead assemblages. Splits from each

site were picked until >900 total foraminifera were counted, rather than from equal volumes of sediment.

The Propagule Method, modified from Goldstein & Alve (2011), was used to grow the experimental assemblages. Sediments <53 μm, which contain numerous foraminiferal propagules, were thoroughly mixed and divided into a series of 20-ml aliquots, each of which was placed in a transparent polypropylene growth chamber (118 ml) along with 40 ml of bottom water collected from the same site as the sediment. These aliquots of propagule-containing sediment from each site were incubated at 4 °, 7 °, 25 °C, and room temperature (22 °C) in the Bernhard lab at WHOI. In addition, some samples were transported to the University of Georgia after the cruise, and sediment aliquots (as described above, but incubated with artificial seawater rather than bottom water) from 740-m and 340-m were also incubated at 12 °C and 18 °C in the Goldstein lab. The 4 ° and 7 °C treatments were kept in the dark and fed a combination of algae (*Dunaliella* and *Isochrysis*) approximately every 10 days. Samples incubated at 12 °, 18 °, and 25 °C were exposed to 12 hours of light per day, which allowed for algal growth. Those grown at room temperature were exposed to natural light through windows.

Experimental assemblages in the Bernhard lab were allowed to grow from 21 May 2010 to 4 – 6 January 2011, and those in the Goldstein lab were grown from 1 June 2010 to 14 January 2011. Experimentally grown assemblages were harvested by sieving over a 63-μm stainless-steel sieve using either natural or artificial seawater. Any foraminifera retained on the 63-μm sieve after the growth interval would have grown at least 10 μm during the incubation period. Six replicates were prepared for each site at

each temperature. Four replicates were preserved in 4% paraformaldehyde and 2 replicates were preserved in 90% ethanol.

For this study, two replicates from each temperature were picked in water for foraminifera. Light microscopy was done using a Zeiss Stemi 2000 in the Goldstein Lab and scanning electron microscopy (SEM) was done using a Zeiss 1450EP variable pressure SEM at the University of Georgia's Center for Advanced Ultrastructural Research. These were used to identify taxa in the experimental and *in situ* assemblages. SEM images were taken to illustrate and compare the morphology of foraminifera found in this study.

Statistical analyses were performed using Primer Ver. 6.1.6 (Clarke & Gorley, 2006). Species abundance was converted to relative abundance, and similarity was calculated using the Bray-Curtis measure. A Q-mode cluster analysis was performed for each site to determine whether experimentally grown assemblages are most similar to a) others grown at the same temperature, b) others grown from the same propagule bank (site), or c) those that occur *in situ*. Multidimensional Scaling (MDS; Borg & Groenen, 2005; Jolliffe, 2005) was also performed using the Bray-Curtis similarity measure. The results of the cluster analysis were overlain on the MDS plot to illustrate the level of similarity among sites and samples. Bubble plots of species abundance were overlain onto the MDS plots to illustrate the abundances of key species (Mulrow, 2002) and to show similarity between different sites and temperatures. The two replicates from each site were combined for all analyses to create a more robust and complete sample.

Interpretation

The number of species (S) was used as species richness for the experimental assemblages because the entire sample was examined. Diversity and dominance were estimated using Primer Ver. 6.1.6. Shannon's H^1 ($\sum p_i \ln p_i$; Shannon, 1948) was used as a measure of diversity (e.g., Hayek & Buzas, 2010; 2013). Shannon's H^1 is the amount of uncertainty in predicting to which species an individual chosen at random will belong (Hayek & Buzas, 2010). A larger value for H^1 indicates greater uncertainty in predicting species membership for a randomly selected individual.

Dominance was estimated using the Berger-Parker index ($p_{i\ max}=N_{\ max}/N$; Berger & Parker, 1970 ; Hayek & Buzas, 2013). The value of p_i max is the proportion of the most abundant species. Larger values of p_i max signify greater dominance and lower evenness within the assemblage (Hayek & Buzas, 2010). Simpson's 1-λ (Simpson, 1949), E1 (e^H/S ; Buzas & Gibson, 1969), E2 ($1/\lambda S$; Buzas & Gibson, 1969), E3 ($1/\lambda e^H$; Buzas & Gibson, 1969), and Pielou's J ($H^1/\ln(S)$; Pielou, 1966) have been used or recommended for dominance/evenness estimations by various authors (Hayek & Buzas, 2010). Values for these were also calculated and plotted for comparison (Appendix II).

Results

In situ assemblages

To characterize the *in situ* assemblages, a total of >900 specimens (stained + dead) were picked randomly, identified, and tabulated as stained or dead per site (Table 2; Appendix 1). *In situ* assemblages have a species richness (S) that ranges from 16 to 26. Species richness of dead assemblages ranges from 17 to 26 with an average of 23.

Species richness of stained assemblages is generally less and ranges from 16 to 22 with an average of 18.5 (Table 2).

For *in situ* assemblages, H^1 ranged from 1.75–2.54 with an average of 2.15 (Table 2). H^1 of the dead assemblages shows no trend across the sampling sites but H^1 of the stained assemblages is lowest at 70-m, moderate and equal at 340-m and 740-m, and highest at 2200-m. At all sites the stained assemblages have higher H^1 values than dead assemblages.

The *in situ* assemblages had a p_i max value ranging from 0.165 to 0.536 with an average of 0.340 (Table 2). Dominance among the dead assemblages increased with offshore distance, with the exception of the 2200-m site. Dominance among the stained assemblages did not show a pattern with offshore distance, but for the 340-m, 740-m, and 2200-m sites, dominance was greater in the dead assemblage then the stained assemblage.

Stained and dead *in situ* assemblages for each site showed good fidelity and grouped together by site in both the cluster and MDS analyses (Fig. 2). The sites also grouped by geographic proximity (and increasing water depth) in the cluster analysis.

The 4 most common foraminifera from the 70-m stained assemblage are *Elphidium excavatum* (Terquem, 1875; 34%), *Globobulimina turgida* (Bailey, 1851; 19%), *Stainforthia fusiformis* Williamson, 1848 (12%), and *Bulimina marginata* d´Orbigny, 1826 (9%). These taxa account for 74% of the overall assemblage. Eighteen other rare taxa are present, including *Trochammina inflata* (Montagu, 1808; 4%), and *Veleroninoides* cf. *V. wiesneri* (Parr, 1950; 3%). *Elphidium excavatum* and *G. turgida* are present in the stained assemblage from the 70-m site and in the dead assemblages from the 70-m, 340-m, 740-m, and 2200-m sites. *Bulimina marginata* is also present in the 70-

m and 340-m stained and dead assemblages. The 70-m dead *in situ* assemblage (Figs. 3–4; Appendix I) is largely composed of *Elphidium excavatum* (32%; Fig. 3.2–3.3), *Bulimina marginata* (23%; Fig. 3.5–3.6), *Stainforthia fusiformis* (11%; Fig. 3.9), *Globobulimina turgida* (10%; Fig. 3.8), *Reophax curtus* Cushman, 1920 (5%). These 5 taxa account for 81% of the assemblage, which also includes twelve other rare taxa.

The 340-m stained assemblage is mainly composed of *Cassidulina carinata* Silvestri, 1896 (22%), *Bolivina spathulata* (Williamson, 1858; 14%), *Stainforthia fusiformis* (12%), *Reophax* cf. *R. gaussicus* (Rhumbler, 1913; 10%), *Ammobaculites* cf. *A. agglutinans* (d'Orbigny, 1846; 10%), and *Cribrostomoides* sp. (5%). These taxa account for 73% of the overall assemblage. Thirteen other rare taxa are present including *Prolixoplecta parvula* (Cushman, 1922; 4%). The 340-m dead *in situ* assemblage (Figs. 3–4; Appendix I) is largely composed of *Bolivina spathulata* (50%), *Stainforthia fusiformis* (17%), *Cassidulina carinata* (14%; Fig. 4.6–4.7), and *Melonis* sp. (5%). These taxa comprise 86% of the dead assemblage from 340 m. Twenty other taxa are present including *Nonionella auricula* (Heron-Allen & Earland, 1930), *Elphidium excavatum,* and *Nonion commune* (d´Orbigny, 1846) but each accounts for less then 2% of the overall assemblage.

The 740-m stained *in situ* assemblage is primarily composed of *Trifarina carinata* Cushman, 1923 (30%), *Bulimina aculeata* (10%), *Trochammina advena* (10%) Cushman, 1922, *Cyclammina cancellata* (Brady, 1879; 9%), *Valvulineria glabra* Cushman, 1927 (7%), *Epistominella exigua* (Brady, 1884; 6%), *Ammodiscus* sp. (6%), *Islandiella islandica* (Norvang, 1945; 5%), and *Nonionella iridea* (Heron-Allen & Earland, 1932; 5%; Fig. 3.1). These taxa combine to account for roughly 88% of the stained assemblage

at 740 m. Seven other taxa are present but each comprises <4% of the overall assemblage. *Trifarina carinata* is present in the 740-m and 2200-m stained and dead assemblages. The 740-m dead *in situ* assemblage (Figs. 3–4; Appendix I) is mostly composed of *Trifarina carinata* (54%; Fig. 4.3), *Islandiella islandica* (9%), *Stainforthia fusiformis* (8%), *Bulimina aculeata* d´Orbigny, 1826 (6%; Fig 3), *Valvulineria glabra* (6%; Fig 4.4–4.5), *Epistominella exigua* (5%), and *Cassidulina* cf. *C. teretis* (Tappan, 1951; 4%). These 7 taxa comprise 86% of the dead assemblage at the 740-m site. Eighteen other taxa are present, including *Bolivina spathulata,* but each comprise <2% of the assemblage.

The stained assemblage from 2200 m is largely composed of *Rhabdammina* sp. (17%), *Cribrostomoides jeffreysii* (Williamson, 1858; 16%), *Paratrochammina challengeri* (Parker & Jones, 1865; 15%), *Cyclammina cancellata* (10%), *Uvigerina peregrina* (Cushman, 1923; 8%), *Fursenkoina complanata* (Egger, 1893; 5%), and *Gyroidina orbicularis* (d'Orbigny, 1826; 4%). These taxa accounted for roughly 76% of the total assemblage. Twelve other taxa are present, including *Stainforthia fusiformis*. *Stainforthia fusiformis* is present in all of the dead *in situ* assemblages and most of the stained assemblages. Many of the taxa that appear at multiple sites are illustrated in Figures 3–4. The 2200-m dead *in situ* assemblage (Figs. 3–4; Appendix I) is composed of *F. complanata* (33%; Fig. 4.8), *Uvigerina peregrina* (19%; Fig. 4.2), *Stainforthia fusiformis* (13%), *Nonionella iridea* (6%), *Gyroidina orbicularis* (5%), and *Epistomina elegans* (d'Orbigny, 1826; 4%). These taxa comprise roughly 80% of the dead assemblage from 2200 m. Twenty other taxa are present but each comprises <3% of the overall assemblage.

Experimental assemblages

A total of 15,127 specimens representing 53 species were picked from the experimental assemblages. A total of 1,082 specimens grew from the 70 m site, 9,268 from the 340 m site, 4,735 from the 740 m site, and 87 from the 2200 m site (Fig. 5). Because sediment from the 2200 and 70 m sites were not grown at 12 ° and 18 °C, N is necessarily lower for these sites. Because the total N of the experimental assemblages grown from the 2200-m site is much lower than the others, it is not considered a robust representation of the propagule bank at this depth. Thus, the 2200-m assemblages are not included in the statistical comparisons with the other experimental assemblages. The other experimental assemblages group together by temperature on the MDS plot (Fig. 6).

At least 19 of 53 total species that grew experimentally from *in situ* sediments (Figs 7–11; Appendix I) are not found in any of the *in situ* assemblages (Table 3). Looking at these allochthonous species site-by-site, 33% of the species grown from the 70-m site are not found in the *in situ* assemblages, 52% from the 340-m site, and 54% from the 740-m site. Four allochthonous species grew from the 4 °C treatments, 8 from the 7 °C treatments, 11 from the 12 °C treatments, and 6 from the 18 °, 22 °, and 25 °C treatments.

Overall, the most abundant species that grew in the experimental assemblages include *Bathysiphon filiformis* (Sars, 1872; Fig. 7.3)*, Brizalina lowmani* (Phleger & Parker, 1951; Fig. 11.1–11.2), *Prolixoplecta parvula, Rosalina* cf. *R. floridana* Cushman, 1922 (Fig. 11.4–11.5), *Trochammina advena* (Cushman, 1922)*, Eggerella advena* Cushman, 1922 (Fig. 7.8–7.9), *Textularia earlandi* (Parker, 1952; Fig. 7.6–7.7), and *Leptohalysis scottii* (Chaster, 1892; Fig. 7.4; Figs. 5, 7–11, Tables 4–6).

Bathysiphon filiformis was able to grow in assemblages from all depths at all temperatures. It was most prevalent in assemblages grown from 7 °–18 °C but had low abundances in assemblages grown >18 °C. *B. filiformis* composed as much as 73% of an experimentally grown assemblage. It was also present in the *in situ* assemblages, but in low numbers and only from the 70-m site.

Brizalina lowmani was able to grow from every site and at every temperature. It grew most abundantly in the assemblages that received light, from 12 °–25 °C. *B. lowmani* was dominant in some of the experimentally grown assemblages, comprising up to 92%. It was not present in the *in situ* assemblages but has been identified in shallow water (<200 m) along the northeast coast of North America (Culver & Buzas, 1980).

Prolixoplecta parvula was able to grow from propagule banks collected from the 70, 340, and 740-m sites, and at all temperatures. It was most prevalent in assemblages that received light, grown at 12 ° or 18 °C. This species was frequently abundant, comprising as much as 38% of the specimens grown in a single assemblage. It was also present in low abundance in the stained *in situ* assemblages from 70-m and 340-m.

Rosalina cf. *R. floridana* was present in assemblages that grew from all depths at temperatures ranging from 12 °–25 °C. It was most prevalent in assemblages grown at warmer temperatures (18 °–25 °C) and light-dark cycles. It was not present in the *in situ* assemblages but has been identified in shallow water (<200 m) along the northeast coast of North America (Culver & Buzas, 1980).

Trochammina advena was present in assemblages grown from the 340- and 740-m sites at temperatures ranging from 7 °–25 °C. It was most prevalent in assemblages grown at 12 °C. It was also present in the stained *in situ* assemblage from the 740-m site.

Eggerella advena was present in assemblages grown from the 70-, 340-, and 740-m sites ranging from 7 °–18 °C. It was most prevalent in assemblages grown with light-dark cycles from 12 °–18 °C. It was not present in the *in situ* assemblages and is known as a shallow water (<200 m) taxon (Culver & Buzas, 1980).

Textularia earlandi was present in assemblages grown from the 70-, 340-, and 740-m sites at temperatures ranging from 7 °–25 °C. It was most abundant in assemblages grown at 25 °C constituting as much as 57% of the assemblage. It was also present in the dead *in situ* assemblage from the 70-m site but was not found in the stained assemblages.

Leptohalysis scottii was present in assemblages from all depths grown at temperatures ranging from 4 °–18 °C. It was most prevalent in assemblages grown at 4 °C, comprising as much as 87% of the assemblage. It was also present in the stained and dead *in situ* assemblages from 70 m and in low numbers in the stained *in situ* assemblages from 2200 m.

The cluster analysis groups the assemblages grown at 7 °C from every site together along with the assemblage grown at 12 °C from 340 m at the 30% similarity level (Fig. 6). This grouping reflects the high abundances of *Bathysiphon filiformis* in these assemblages. The cluster analysis groups the assemblages that grew at 4 °C from the 70-m and 340-m sites group together with 77% similarity. This grouping reflects the high abundances *Leptohalysis scottii* in both assemblages. The assemblages grown at 4 °C from the 740-m site have a species richness of 2 (Fig. 13), much lower than that of the other assemblages, and, this may explain why it does not cluster with the other assemblages grown at this temperature from other sites (Fig. 6). All experimental

assemblages grown from 12 °–25 °C, with the exception of the assemblage grown at 12 °C from the 340-m site, group together with at least 35% similarity in Bray-Curtis ordination. Experimental assemblages group separately from the *in situ* assemblages (Figs 14–19). Replicates of experimental assemblages did not always cluster together with their corresponding replicate (Fig. 19).

Some species that grew in the experimental assemblages are absent from the corresponding *in situ* assemblages at that site, but are nonetheless present at one or more of the other sites sampled in this study (Table 7). These species include *Bulimina marginata, Trochammina inflata, Bolivina spathulata, Bulimina aculeata, Gyroidina orbicularis* and *Uvigerina peregrina.*

Species richness and diversity

Species richness varies by site and by temperature (Table 8). The experimentally grown assemblages from the 340-m site have the highest species richness (5–17 at every temperature. The experimental assemblages from each site (except 2200-m) have high richness (12–17) from 7 °–18 °C. The same sites have low richness (2–7) in assemblages grown at 4 ° and 22 °C. The majority of these values are higher than the dominance values for the *in situ* assemblages. Diversity, measured by Shannon's H^1, has a range of 0.154 –1.997 with an average of 1.179 (2200-m site not included) in the experimental assemblages. The highest value for H for each site is from the assemblages grown at 4 °C (Table 8).

Dominance

Dominance in the assemblages ranged from a p_i max value of 0.964 to 0.298 and had an average of 0.609. The 4 °C treatments had the highest dominance for each site. Of

the other dominance values calculated, only Simpson's λ and 1- Pielou's J illustrated high dominance in the samples grown at 740 m from 4 °C and 22 °C (Appendix II). Evenness calculated using E1and E2 do not illustrate these outliers and E3 does not separate evenness from dominance as clearly.

Discussion

In situ assemblages

The *in situ* assemblages from each site are distinct, and the stained and unstained (dead) assemblages from each site have good fidelity, as indicated by the cluster and MDS analyses. The death assemblage from each of the sites is most similar to the stained assemblage from the same site. This indicates that taphonomic processes and the transport of empty tests by waves and currents do not produce death assemblages that differ substantially from the corresponding living assemblages in these shelf to bathyal settings.

Species richness (S) lacks obvious trends among these sites and assemblages, but abundance (N) varies considerably among the *in situ* samples. The increase in diversity (Shannon's H^1) with offshore distance and depth in the stained assemblages could be reflecting higher dominance in the shallower assemblages (as shown by p_i max). The high diversity of the dead assemblage at 2200 m could possibly be a result of time averaging, particularly at the deeper sites, which may accumulate over a longer time period due to a lower sedimentation rate. Although the stained and unstained assemblages from the same site closely group with statistical analysis, the stained assemblages had higher diversity than the unstained assemblages for each site. This difference may be

explained by an abundance of fragile tests (e.g., *Eggerelloides scaber* (Williamson, 1858), *Cyclammina cancellata* (Brady, 1879), *Glomospira charoides* (Jones & Parker 1860)) in the stained assemblages that could be susceptible to taphonomic degradation.

Experimental assemblages

Temperature is more important than site in determining the species' composition of the experimentally grown assemblages. The cluster and MDS analyses grouped assemblages by temperature.

Leptohalysis scottii dominated the assemblages grown at 4 °C from sediments collected at the 70-m and 340-m sites. This species is known from the North Atlantic and has been found off the coast of the northeastern United States and in the Arctic (Culver & Buzas, 1980), typically in waters shallower than 200 m (Culver & Buzas, 1980). *L. scottii* has also been documented in plankton tows (John, 1987), indicating that the sediments from which it originated were reworked strongly enough for *L. scottii* to be entrained in the water column. If propagules were similarly transported into the water column by a disturbance such as a large storm, it could give them greater range and would aid in foraminiferal dispersal. It is also possible that mature individuals entrained in the water column reproduced, producing propagules that subsequently settle to the seafloor. In this study, *L. scottii* was found stained *in situ* at the 70- and 2200-m sites. *L. scottii* grew from all sites at all temperatures except 22 °C. It was the most dominant species in the colder (4 ° and 7 °C) assemblages, but was able to grow well up to 18 °C.

Assemblages grown at 7 °C, from sediments collected from all sites, and 12 °C, from sediment collected from the 340-m site, grouped together in the MDS analysis, largely reflecting the high abundance of *Bathysiphon filiformis.* This species occurs along

the eastern coast of the United States, typically north of Cape Hatteras (Culver & Buzas, 1980). Highest abundances usually occur along the continental slope, however, it also occurs in shallower (<200 m) and deeper (>1000 m) waters (Gooday et al., 1992). Its distribution is patchy, and it forms dense "tube beds" along the eastern United States coast (Gooday et al., 1992). *B. filiformis* was abundant in samples collected at the 70-m site in September, 2009, but was rare at this site at the time of sampling (May, 2010) for this study. Such differences could indicate that *B. filiformis* has a seasonal cyclicity, that its distribution is highly patchy, or that patches shift position over time (e.g., Buzas et al., 2002). *B. filiformis* grew from all depths and all temperatures, but was the most dominant from 7 ° to 18 °C.

All other assemblages grown from 12 °–25 °C grouped together in the cluster and MDS analyses. These assemblages were all grown in the light, which could have facilitated the growth of a variety of potential food organisms. This grouping, therefore, may reflect the influences of either temperature or food quality, or both. These assemblages contained high percentages of *Brizalina lowmani, Prolixoplecta parvula, Rosalina* cf. *R. floridana, Eggerella advena,* and *Textularia earlandi*.

Prolixoplecta parvula has been documented from shallow waters (<200 m) in the Gulf of Mexico (Sen Gupta et al., 2009) and off the coast of North Carolina (Culver & Buzas, 1980), but its distribution is not well documented. *P. parvula* occurs in the *in situ* assemblages from the 70-m and 340-m sites in this study, and grew from sediments collected at the 70-, 340-, and 740-m sites and at all temperatures. *P. parvula* grew best in samples that received light and was most abundant in assemblages grown from the 340-m site. Possibly, more propagules of this species were present at the 340-m site at the time

of collection. Alternatively, competition or other biotic interactions may have curtailed its abundance in assemblages grown from the 70-m and 740-m sites.

Textularia earlandi is reported from the intertidal to the deep sea and is globally distributed (Murray, 2013). Among the *in situ* assemblages, *T. earlandi* occurs only in the dead assemblage from the 70-m site, however it was able to grow from the 70-, 340-, and 740-m sites at 7 °, 18 °, 22 °, and 25 °C. *T. earlandi* is broadly distributed as are its propagules. In previous studies, this species grew from propagule banks collected from a 320-m site in the Skagerrak (Alve & Goldstein, 2010) and from intertidal mudflats of Sapelo Island, Georgia (Goldstein & Alve, 2011). *T. earlandi,* however, seldom occurs as a dominant taxon in living *in situ* assemblages (Murray, 2013). Nonetheless, it grew abundantly from three of four sites and nearly all temperatures used in this study.

Allochthonous taxa

Nineteen of the 38 species identified in the experimentally grown assemblages were not present living or dead in the *in situ* assemblages from any site. Most of these species grew at temperatures greater than ambient temperatures at the corresponding site at the time of collection. Fifteen taxa grew only to the juvenile stage in the experimental assemblages. These could not be identified beyond genus and, therefore, were not included in the comparison of experimental and *in situ* assemblages. Of those taxa identified to species, 50% originated from allochthonous sources, and 50% originated from local sources. Allochthonous taxa include *Bolivina ordinaria* (Phleger & Parker, 1952), *Bolivina variabilis* (Williamson, 1858), *Bolivinellina pseudopunctata* (Höglund, 1947)*, Brizalina lowmani*, *Buliminella elegantissima* (d'Orbigny, 1839)*, Cornuloculina inconstans* (Brady, 1879)*, Eggerella advena, Globulina minuta* (Roemer, 1838)*,*

Loeblichopsis cylindrica (Brady, 1884)*, Miliammina fusca* (Brady, 1870)*, Nonionellina labradorica* (Dawson, 1860)*, Quinqueloculina stalkeri* Loeblich & Tappan, 1953*, Rosalina* cf. *R. floridana,* and *Deuterammina rotaliformis* (Heron-Allen & Earland, 1911). The other 5 allochthonous taxa could not be identified to species and none compare favorably to any of the taxa found *in situ*.

Bolivina ordinaria occurs on the continental shelf in the Gulf of Mexico (Sen Gupta et al., 2009) and European waters (Mendes et al., 2012). The Gulf of Mexico was the nearest confirmed report of this species to our study area. Among the experimentally grown assemblages, *B. ordinaria* grew only from the 340-m site at 7 ° and 12 °C.

Bolivina variabilis is genetically identical to the planktonic foraminifer *Streptochilus globigerus* (Schwager, 1866; Darling et al., 2009). Deemed tycopelagic, *B. variabilis* can live, grow, and reproduce in the water column or on the seafloor. This mode of life most likely facilitates dispersal. *B. variabilis* is broadly distributed and occurs in the North Atlantic (Culver & Buzas, 1980; Costello et al., 2001), Indian (Parker & Gischler, 2011) and Pacific (Debenay, 2012) Oceans. The biogeographic distribution of *S. globigerus* in the plankton, however, is not well documented, but Hemleben (1989) reports *S. globigerus* as tropical to subtropical. *B. variabilis* grew from the 340-m and 740-m sites at 18 °, 22 °, and 25 °C. These assemblages were all grown exposed to light and, therefore, had different food organisms than those grown from 4 ° and 7 °C. However, *B. variabilis* did not appear in assemblages grown at 12 °C, which were also grown exposed to light. It appears that this taxon is influenced by temperature. This supports the calcification estimates made by Darling et al. (2009) that indicate *B.*

variabilis may only calcify in warmer waters. The presence of *B. variabilis* propagules may be a result of an increased dispersal range because of its tycopelagic mode of life.

Bolivinellina pseudopunctata is broadly distributed across the North Atlantic (Culver & Buzas, 1980; Costello et al., 2001) and Gulf of Mexico (Sen Gupta et al., 2009). It only grew from the 740-m site at 12 ° and 18 °C. Even though *B. pseudopunctata* was not found in our *in situ* samples it has been identified in this region (Culver & Buzas, 1980). It is possible that *B. pseudopunctata* occurs seasonally or that it has a patchy distribution similar to *Bathysiphon filiformis*. Although *B. pseudopunctata* was absent from the *in situ* assemblages, its, propagules likely did not undergo long distances of transport.

Brizalina lowmani occurs in the Gulf of Mexico (Sen Gupta et al., 2009), along the United States coast as far north as North Carolina (Lueck & Snyder, 1997), and off the coast of Spain (Costello et al., 2001). Specimens have been found near our study area but it is unknown if those were stained or simply empty tests (Culver & Buzas, 1980). Stained specimens of *B. lowmani* have been found in <200 m water (Lueck & Snyder, 1997). *B. lowmani* grew from the 70-, 340-, 740-, and 2200-m sites. It also was able to grow at all temperatures, but grew in much higher abundances with exposure to light. It is likely that the presence of *B. lowmani* propagules at 2200-m is a result of offshore dispersal. *B. lowmani* has been documented in plankton tows in high abundances (Hueni et al., 1978) indicating that it may be easily entrained into the water column during large storms.

Buliminella elegantissima has a global distribution and has been reported from the Gulf of Mexico (Sen Gupta et al., 2009) to the Arctic Ocean (Costello et al., 2001) and all

along the continental shelf in the North Atlantic (Culver & Buzas, 1980). It is known as a shelf species and is typically found in <200 m of water. *B. elegantissima* grew from 740-m at 18 ° and 22 °C. This species most likely dispersed as propagules from near-shore to offshore settings. *B. elegantissima* has also been documented in plankton tows (Hueni et al., 1978).

Cornuloculina inconstans occurs along the eastern United States from Florida to North Carolina (Culver & Buzas, 1980) and along the mid oceanic ridge in the North Atlantic (Hermelin & Scott, 1985). It does not seem to be common in any setting and has been found from both shallow (<200 m) and deep (>2000 m) waters (Murray, 2013). *C. inconstans* grew from 740-m at 12 °C.

Eggerella advena is distributed globally. It has been identified off the northeast United States coast in mostly shelf (<200 m) settings, although it has also been reported from the deep sea (Murray, 2013). *E. advena* has been sampled seasonally in the nearby Long Island Sound. It was found that *E. advena* dominated the assemblages during seasonal food (spring bloom) influxes (Buzas, 1965). *E. advena* grew from the 70-, 340-, and 740-m sites at 7 °, 12 °, and 18 °C. Propagules of this species may be present seasonally or this species may have a patchy distribution at the *in situ* sites. It did not grow at the warmest or coldest temperatures, but was able to grow in both the light and the dark, suggesting that temperature may be the controlling factor for this species.

Globulina minuta occurs in the North Atlantic off the coast of Scotland in 900 m of water (Hughes & Gooday, 2004) though its overall distribution is not well documented. *G. minuta* grew from the 340-m site at 12 °C.

Loeblichopsis cylindrica occurs off the coast of Europe (Costello et al., 2001). The overall distribution is not well documented but the few reported occurrences are all from deep water. *L. cylindrica* grew from the 70-m site at 7 °C. The deep-water occurrences of this species are consistent with its growth at 7 °C. This species has not been documented in the Northwest Atlantic Ocean, and the source populations for this allochthonous species are unknown.

Miliammina fusca occurs off the Northeast coast of the United States in shallow-water settings (<200 m; Murray, 2013). It is particularly well known from salt marshes and mudflats in temperate settings (Scott & Medioli, 1980). In previous studies, it grew at both 12 ° and 22 °C but preferred the warmer temperature (Goldstein & Alve, 2011). It is also known to thrive under colder conditions (Scott & Medioli, 1980). *M. fusca* grew from the 70-m site at 4 °C. *M. fusca* does not typically occur below the shallow subtidal zone so propagules likely originated from near-shore.

Nonionellina labradorica occurs globally at high northern latitudes from both the continental shelf and the deep sea (Murray, 2013), especially along the North American coast north of Cape Hatteras (Culver & Buzas, 1980). It is known as a cold-water taxon (Murray, 2013). *N. labradorica* grew from 340-m at 12 °C. *N. labradorica* is known from this study region from all depths but may have a seasonal component that influenced its occurrence *in situ*. Its growth from 12 °C may have been because of food availability but it is hard to say without more occurrences in experimentally grown assemblages.

Quinqueloculina stalkeri occurs from Florida to Nova Scotia (Culver & Buzas, 1980) and is typically found in shallow water (<200 m). *Q. stalkeri* grew from the 340-m

site at 4 ° and 7 °C. *Q. stalkeri* grew only in the cold-water treatments that did not receive light. This response could be the result of a temperature constraint or a food preference.

Rosalina cf. *R. floridana* occurs off the US coast from Florida to Maine, typically in shallow water (<200 m; Culver & Buzas, 1980). Some species of *Rosalina* are known to have float chambers (e.g. Sliter, 1965). This would allow *Rosalina* to move into the water column and would increase the dispersal range of its propagules. *Rosalina* cf. *R. floridana* grew from the 70-, 340-, and 740-m sites at 12 °, 18 °, 22 °, and 25 °C. Its presence in assemblages from the 740-m site is likely a result of offshore dispersal. The growth of *Rosalina* cf. *R. floridana* from 12 °–25 °C could be the result of a temperature constraint or a result of food differences since the propagules at these temperatures were exposed to light.

Deuterammina rotaliformis occurs from the Gulf of Mexico (Sen Gupta et al., 2009) to Canada and is typically found in <200 m water depth (Culver & Buzas, 1980). *D. rotaliformis* grew from 340-m at 25 °C. The presence of *D. rotaliformis* propagules at 340-m could be the result of dispersal from shallower settings.

Many of these species are the dominant taxa of their respective assemblages and none were present *in situ*. From these results it seems that dispersal from allochthonous sources did occur but the geographic extent of this dispersal is unconstrained.

Propagule transport

As mentioned previously, some taxa grew experimentally from sites where they were not present *in situ*. Many of these species have been found in the region but at water depths ≤200 m. Two of the most abundant species that grew experimentally, *Brizalina lowmani* and *Rosalina* cf. *R floridana*, are typically found in <200 m water depth. In this

study they grew from sediments collected from 70–2200 m. This indicates that they were present as propagules in sediments from all of these sites and their propagules were dispersed offshore.

Nineteen of the taxa identified from the experimental assemblages were found within the *in situ* assemblages, however, in certain cases they grew from sites other then the site in which they were found *in situ*. For example, *Bulimina marginata* was only present in the stained assemblage from the 70 and 340-m sites, but grew in the experimental assemblages from the 340 m and 740 m sites where it was not found *in situ*. *Gyroidina orbicularis* was only present in the stained *in situ* assemblage from the 2200-m site, but grew experimentally from the 340-, and 740-m sites. These examples indicate potential near shore to offshore and shoreward transport respectively.

Many species in the *in situ* assemblages were only found stained closer to shore and were found in the dead assemblages away from shore. For example *Elphidium excavatum* and *Globobulimina turgida* were present in the stained assemblage from the 70-m site and in the dead assemblages from the 70-, 340-, 740-, and 2200-m sites. This likely indicates post mortem transport of tests offshore. This offshore transport could also carry propagules and aid in dispersal, though neither of these species grew in the experimental assemblages.

From the results of this study certain species disperse ubiquitously, others disperse offshore, and others disperse shoreward. More data are required to fully understand these processes. Recurring variability in ocean current direction over 2 week segments has been documented over a transect in close proximity to our study sites

(Fratantoni & Pickart, 2003). By reversing the direction of dominant current flow it provides a mechanism for propagules to disperse offshore, and shoreward.

Propagule growth

The greatest similarity among experimentally grown assemblages is among those grown under similar conditions rather than among those grown from a particular site. Temperature and/or food type are key factors. Food availability is believed to be one of the major factors influencing overall foraminiferal distribution (Gooday & Jorissen, 2012). Because all of the assemblages grown at >12 °C were also grown in the light, different food organisms were available to these assemblages. In some cases, it is therefore difficult to distinguish the effects of temperature from food. Although the experimentally grown assemblages grouped together in the MDS analysis by temperature, assemblages contained species that grew from only a single site. For example *Miliammina fusca* grew only from the 70-m site, and likely was only present in the propagule bank at that site. Such occurrences could signify restricted or limited dispersal (Goldstein & Alve, 2011). The results of this study indicate that dispersal mechanisms and patterns differ among species, and that temperature plays a key role in determining which propagules are expressed.

Variation did occur among the replicates. For example, the two assemblages grown at 12 °C from the 340-m site contained a total of 17 species, yet only four of these are common to both. This signifies that other variables may control which taxa are expressed in an experimentally grown assemblage. To better account for this, the replicates were combined in this study. However, taxa that composed >20% of the assemblage typically appeared in both replicates. This shows that a there are still

unknown variables controlling growth for some taxa. By changing additional environmental factors, it may be possible to more fully express the propagule banks at these sites. Many of the foraminifera found in the *in situ* assemblages did not grow in the experimental assemblages. *Stainforthia fusiformis,* for example was found in every stained *in situ* assemblage but did not grow in any of the experimental assemblages. It is unlikely that its propagules were not present. Rather, the experimental conditions employed most likely did not allow for its growth.

Other complications included foraminifera growing but not reaching maturity. This made identifying these taxa difficult. It may be useful in future studies to allow for a longer growth period especially for the growth of foraminifera from the deep (2200-m) site. This may or may not resolve the problem entirely, because it is possible that the foraminifera that did not reach maturity were outcompeted in certain assemblages, causing them to die before reaching maturity.

Opportunists

Bathysiphon filiformis, Leptohalysis scotti, Prolixoplecta parvula, Textularia earlandi, and *Brizalina lowmani* displayed opportunistic behavior, as they were present in samples grown from the 70- to 740-m sites at all or nearly all temperatures.

Bathysiphon filiformis occurs in patchy distributions of densely populated "tube beds" (Gooday et al., 1992) that suggest that *B. filiformis* behaves opportunistically. *Leptohalysis scottii* has been found to behave as an opportunistic early colonizer (Goineau et al., 2012), and *Textularia earlandi* was previously described as an opportunist (Alve & Goldstein, 2010). *Brizalina lowmani* and *Leptohalysis scottii* have

been found in plankton tows (Hueni et al., 1978; John, 1987) which, if still living, could allow them to release propagules over a larger range and greatly aid them in dispersal.

These opportunistic taxa dominated most of the experimental assemblages and were rare or absent in the *in situ* assemblages. This indicates favorable conditions for these opportunists and demonstrates their presence within the propagule banks across the sites. In many of the experimental assemblages a few opportunists were able to dominate the assemblage. This is reflected by the p_i max values, which had an average of 0.609 in the experimentally grown assemblages; greater than the 0.340 average from the *in situ* assemblages. Similar patterns also occurred in previous propagule experiments (Alve & Goldstein, 2010).

Conclusions

Although foraminiferal dispersal is complicated and difficult to assess, the propagule method (Goldstein & Alve, 2011) provides a tool for examining foraminiferal dispersal and identifying environmental parameters that are important for foraminiferal growth. In this study, foraminiferal propagules from four different sites ranging from 70 to 2200 m were incubated at non-ambient temperatures to express the propagule bank at each site. The results showed that:

1. Dispersal occurs from allochthonous and local sources.

2. Growth temperature was a more important factor than sampling site in determining the species composition of experimentally grown assemblages. This supports the findings of a previous study (Goldstein & Alve, 2011).

3. Presence of light may have played a key role for the experimentally grown assemblages by potentially allowing for different food types to grow. The assemblages from 12 °–25 °C were grown with light to allow for algal growth which, may have been different in type or quality than the experiments grown in the dark (<12 °C).

4. A longer growth interval may allow for higher abundances from the deeper sites and possibly a more diverse experimental assemblage.

5. Not all species present as propagules at a given site are represented within the *in situ* assemblages, indicating that the propagules can come from distant sources. Growing foraminifera from propagules at non-ambient temperatures, therefore, provides a method for documenting the presence of allochthonous taxa in propagule banks.

6. Experimental assemblages are mostly dominated by opportunistic taxa. This also occurred in previous experimental growth studies (Alve & Goldstein, 2010; Goldstein & Alve, 2011).

CHAPTER 3

FUTURE WORK

This study expanded on previous laboratory-based culturing studies to provide new information on foraminiferal dispersal and distributional restrictions. By using the experimental methods in this study we were able to control for specific variables and compare those to see how the propagule bank changes. This experiment focused specifically on expressing a wide variety of the propagule bank so only temperature, site, and food were employed as experimental variables. Each time we use these methods we learn more about them and are able to refine them for the next experiment. Future laboratory-based experiments may allow for a longer incubation period especially for the propagule banks from the deeper sites.

More experimental culturing studies may also be done to test for the effects of other variables. The results of this study gave insight into how temperature affects many species and revealed some opportunists that were affected very little by changes in temperature.

REFERENCES

Alve, E., 1999. Colonization of new habitats by benthic foraminifera: a review. *Earth-Science Reviews*, 46, 1-4, 167-185.

Alve, E., 2003. A common opportunistic foraminiferal species as an indicator of rapidly changing conditions in a range of environments. *Estuarine, Coastal and Shelf Science* 57, 501-514.

Alve, E. & Goldstein, S.T., 2002. Resting stage in benthic foraminiferal propagules: a key feature for dispersal? Evidence from two shallow-water species. *Journal of Micropalaeontology* 21, 95-96.

Alve, E. & Goldstein, S.T., 2003. Propagule transport as a key method of dispersal in benthic foraminifera (Protista). *Limnology and Oceanography*, 48, 6, 2163-2170.

Alve, E. & Goldstein, S.T., 2010. Dispersal, survival and delayed growth of benthic foraminiferal propagules. *Journal of Sea Research* 63, 36-51.

Berger, W.H. & Parker, F.L., 1970 Diversity of planktonic foraminifera in deep-sea sediments. *Science* 168, 1345-1347.

Bernhard, J.M., 2000. Distinguishing live from dead foraminifera: methods review and proper applications. *Micropaleontology*, *46*, 38-46.

Borg, I., & Groenen, P.J.F., 2005. *Modern Multidimensional Scaling: Theory and applications*. Springer.

Buzas, M.A., 1965. *The Distribution and Abundance of Foraminifera in Long Island Sound*. Smithsonian Institution.

Buzas, M.A. &. Gibson, T.G., 1969 Species diversity: benthonic foraminifera in western North Atlantic. *Science*, 163, 72-75.

Buzas, M.A., Hayek, L.A.C., Reed, S.A., Jett, J.A., 2002. Foraminiferal densities over five years in the Indian River Lagoon, Florida: a model of pulsating patches. *The Journal of Foraminiferal Research* 32, 68-92.

Clarke, K., & Gorley, R.N., 2006. PRIMER v6: User Manual/Tutorial. *PRIMER-E,* Plymouth.

Costello, M.J., Emblow, C., White, R.J., 2001. *European register of marine species: a check-list of the marine species in Europe and a bibliography of guides to their identification*. Collection Patrimoines Naturels, 50. Muséum national d'Histoire naturelle: Paris. ISBN 2-85653-538-0. 463 pp.

Culver, S.J. & Buzas, M.A., 1980. Distribution of recent benthic foraminifera off the North American Atlantic coast. *Smithsonian Contributions to the Marine Sciences.*

Darling, K.F., Thomas, E., Kasemann, S.A., Seears, H.A., Smart, C.W., Wade, C.M., 2009. Surviving mass extinction by bridging the benthic/planktic divide. *Proceedings of the National Academy of Sciences* 106, 12629-12633.

Debenay, J.P., 2013. *A guide to 1,000 Foraminifera from Southwestern Pacific: New Caledonia*. IRD editions, Publications scientifiques du Museum. Museum national d'Histoire naturelle. Paris France, ISBN 978-2-7099-1729-2, 384 p.

Fenchel, T. & Finlay, B.J., 2004. The ubiquity of small species: patterns of local and global diversity. *Bioscience* 54, 777-784.

Fenchel, T. & Finlay, B.J., 2006. The diversity of microbes: resurgence of the phenotype. *Philosophical Transactions of the Royal Society B: Biological Sciences* 361, 1965-1973.

Finlay, B.J., Esteban, G.F., Brown, S., Fenchel, T., Hoef-Emden, K., 2006. Multiple cosmopolitan ecotypes within a microbial eukaryote morphospecies. *Protist* 157, 377-390.

Foissner, W., 2006. Biogeography and dispersal of micro-organisms: a review emphasizing protists. *Acta Protozoologica* 45, 111-136.

Foissner, W., 2008. Protist diversity and distribution: some basic considerations. *Protist Diversity and Geographical Distribution*, 1-8.

Fratantoni, P. & Pickart, R., 2003 Variability of the shelf break jet in the Middle Atlantic Bight: Internally or externally forced? *Journal of Geophysical Research*, 108, 3166.

Goineau, A., Fontanier, C., Jorissen, F., Buscail, R., Kerhervé, P., Cathalot, C., Pruski, A., Lantoine, F., Bourgeois S., & Metzger, E., 2012. Temporal variability of live (stained) benthic foraminiferal faunas in a river-dominated shelf- Faunal response to rapid changes of the river influence (Rhone prodelta, NW Mediterranean). *Biogeosciences* 9, 1367-1388.

Goldstein, S.T. & Alve, E., 2011. Experimental assembly of foraminiferal communities from coastal propagule banks. *Marine Ecology Progress Series* 437, 1-11.

Gooday, A., Levin, L., Thomas, C. & Hecker, B., 1992. The distribution and ecology of *Bathysiphon filiformis* Sars and *B. major* de Folin (Protista, Foraminiferida) on the continental slope off North Carolina. *The Journal of Foraminiferal Research* 22, 129-146.

Gooday, A.J. &. Jorissen, F.J., 2012 Benthic foraminiferal biogeography: Controls on global distribution patterns in deep-water settings. *Annual Review of Marine Science*, 4, 237-262.

Google Earth, 2013. "39 40.048N, 70 40.030W".

Hayek, L.A.C. & Buzas, M.A., 2010. *Surveying Natural Populations: Quantitative Tools for Assessing Biodiversity*. Columbia University Press.

Hayek, L.A.C. & Buzas M.A., 2013 On the proper and efficient use of diversity measures with individual field samples. *The Journal of Foraminiferal Research*, 43, 305-313.

Hemleben, C., Spindler, M., Erson, O.R., 1989. Modern planktonic foraminifera. *Springer, Berlin.*

Hermelin, J.O.R. & Scott, D.B., 1985. Recent benthic foraminifera from the central North Atlantic. *Micropaleontology*, 31, 3, 199-220.

Hueni, C., Monroe, J.A., Gevirtz, J., Casey, R., 1978. Distribution of living benthonic foraminifera as indicators of oceanographic processes of the South Texas outer continental shelf. *Gulf Coast Association of Geological Societies Transactions* 28, 193-200.

Hughes, J.A. & Gooday, A.J., 2004. Associations between living benthic foraminifera and dead tests of *Syringammina fragilissima* (Xenophyophorea) in the Darwin Mounds region (NE Atlantic). *Deep Sea Research Part I: Oceanographic Research Papers* 51, 1741-1758.

John, A.W.G., 1987. The regular occurrence of *Reophax scottii* Chaster, a benthic foraminiferan, in plankton samples from the North Sea. *Journal of Micropalaeontology* 6, 61-63.

Jolliffe, I., 2005. *Principal component analysis*. Wiley Online Library.

Kidwell, S.M., 2013. Implications of Death Assemblages for Ecology and Conservation. Annual Review of Ecology, *Evolution, and Systematics* 44.

Lueck, K.L.O. & Snyder, S.W., 1997. Lateral variations among populations of stained benthic foraminifera in surface sediments of the North Carolina continental shelf (USA). *The Journal of Foraminiferal Research* 27, 20-41.

Massart, D.L. & Kaufman, L., 1983. *The interpretation of analytical chemical data by the use of cluster analysis*. Wiley.

Mendes, I., Dias, A.J., Schönfeld, J., Ferreira, Ó., 2012. Distribution of living benthic foraminifera on the northern Gulf of Cadiz continental shelf. *The Journal of Foraminiferal Research* 42, 18-38.

Microsoft, 2011. Microsoft Excel. Redmond, Washington: Microsoft, 2011.

Mulrow, E.J., 2002. The Visual Display of Quantitative Information. *Technometrics* 44, 400-400.

Murray, J.W., 2013. Living benthic foraminifera: biogeographical distributions and the significance of rare morphospecies. *Journal of Micropalaeontology* 32, 1-58.

Parker, J.H. & Gischler, E., 2011. Modern foraminiferal distribution and diversity in two atolls from the Maldives, Indian Ocean. *Marine Micropaleontology* 78, 30-49.

Pielou, E. C., 1966 The measurement of diversity in different types of biological collections. *Journal of theoretical biology*, 13, 131-144.

R Development Core Team., 2011. R: A language and environment for statistical computing. R Foundation for Statistical Computing. Vienna, Austria.

Scott, D.B. & Medioli, F.S., 1980. Living vs. total foraminiferal populations: their relative usefulness in paleoecology. *Journal of Paleontology*, 814-831.

Sen Gupta, B.K, Lobegeier, M.K., & Smith, L.E., 2009. Foraminiferal communities of bathyal hydrocarbon seeps, northern Gulf of Mexico: a taxonomic, ecologic, and geologic study. *United States Department of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, Louisiana, OCS Study MMS* 13, 385.

Shannon, C. E., 1948 A mathematical theory of communication. *Bell System Technical Journal*, 27, 379-423.

Simpson, E.H., 1949. Measurement of diversity. *Nature* 163, 688.

Sliter, W.V., 1965. Laboratory experiments on the life cycle and ecologic controls of *Rosalina globularis* d'Orbigny. *Journal of Eukaryotic Microbiology* 12, 210-215.

Figure 1: Map of sampling locations south of Cape Cod. (Google Earth, 2013).

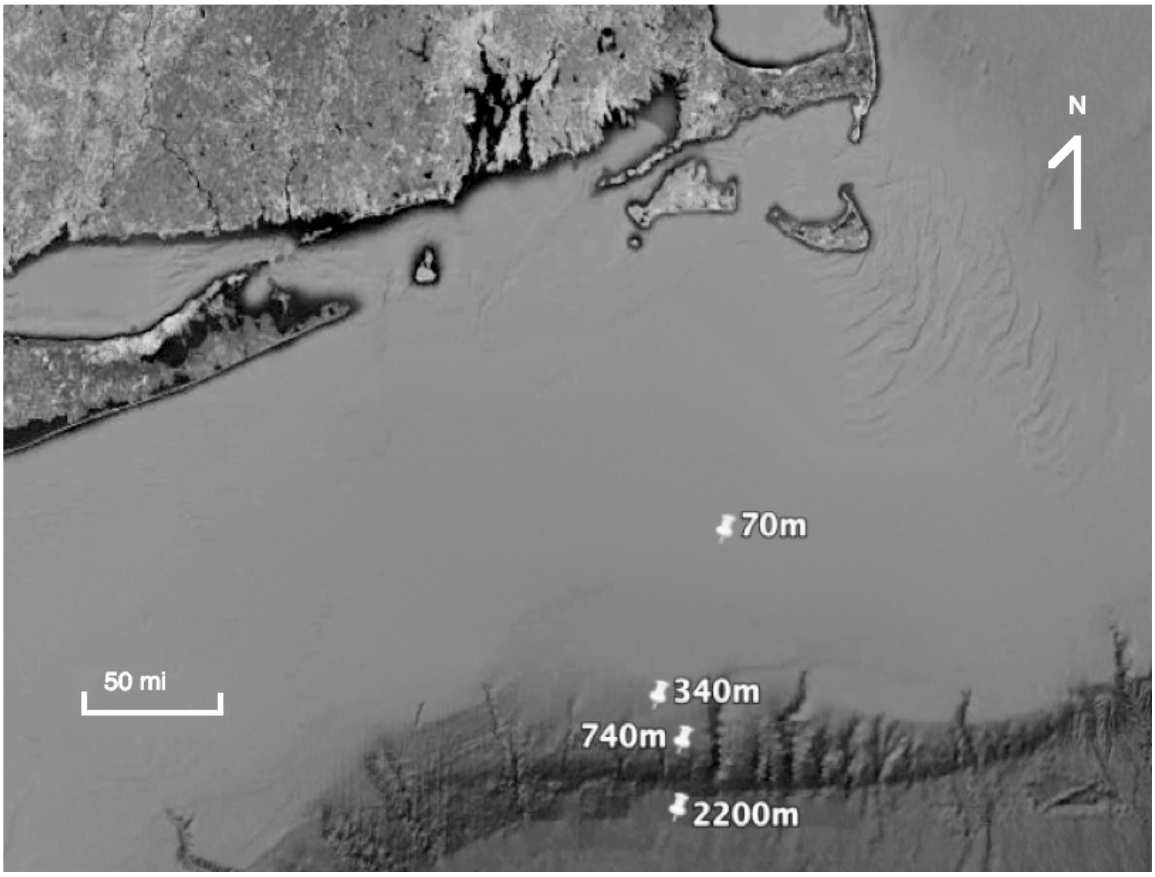

N
70m
50 mi
340m
740m
2200m

Figure 2: Cluster analysis (a) and MDS ordination (b) of the stained and dead *in situ* assemblages from each site. Results from the cluster analysis are overlain at a 25% similarity threshold on the MDS plot.

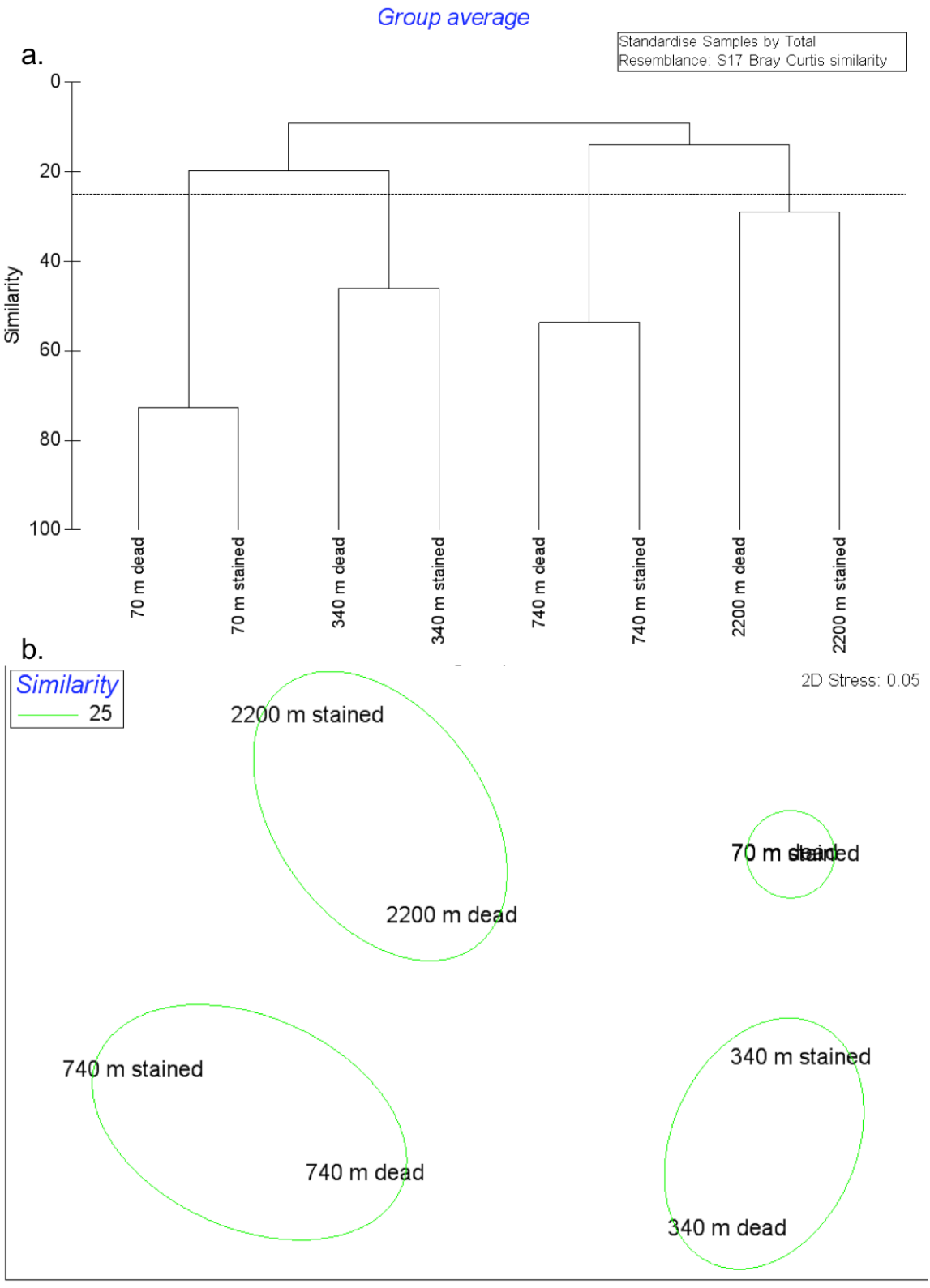

Group average
a.
Standardise Samples by Total
Resemblance: S17 Bray Curtis similarity
Similarity
0
20
40
60
80
100
70 m dead
70 m stained
340 m dead
340 m stained
740 m dead
740 m stained
2200 m dead
2200 m stained
b.
Similarity
25
2D Stress: 0.05
2200 m stained
2200 m dead
70 m stained
740 m stained
740 m dead
340 m stained
340 m dead

Figure 3: Micrograph of common species in *in situ* assemblages.1. *Nonionella iridea* (Heron-Allen & Earland). 2-3. *Elphidium excavatum* (Terquem). 4. *Bolivina hirsuta* (Rhumber) 5. *Bulimina aculeata* (d´Orbigny). 6-7. *Bulimina marginata* (d´Orbigny). 8. *Globobulimina turgida* (Bailey). 9. *Stainforthia fusiformis* (Williamson).

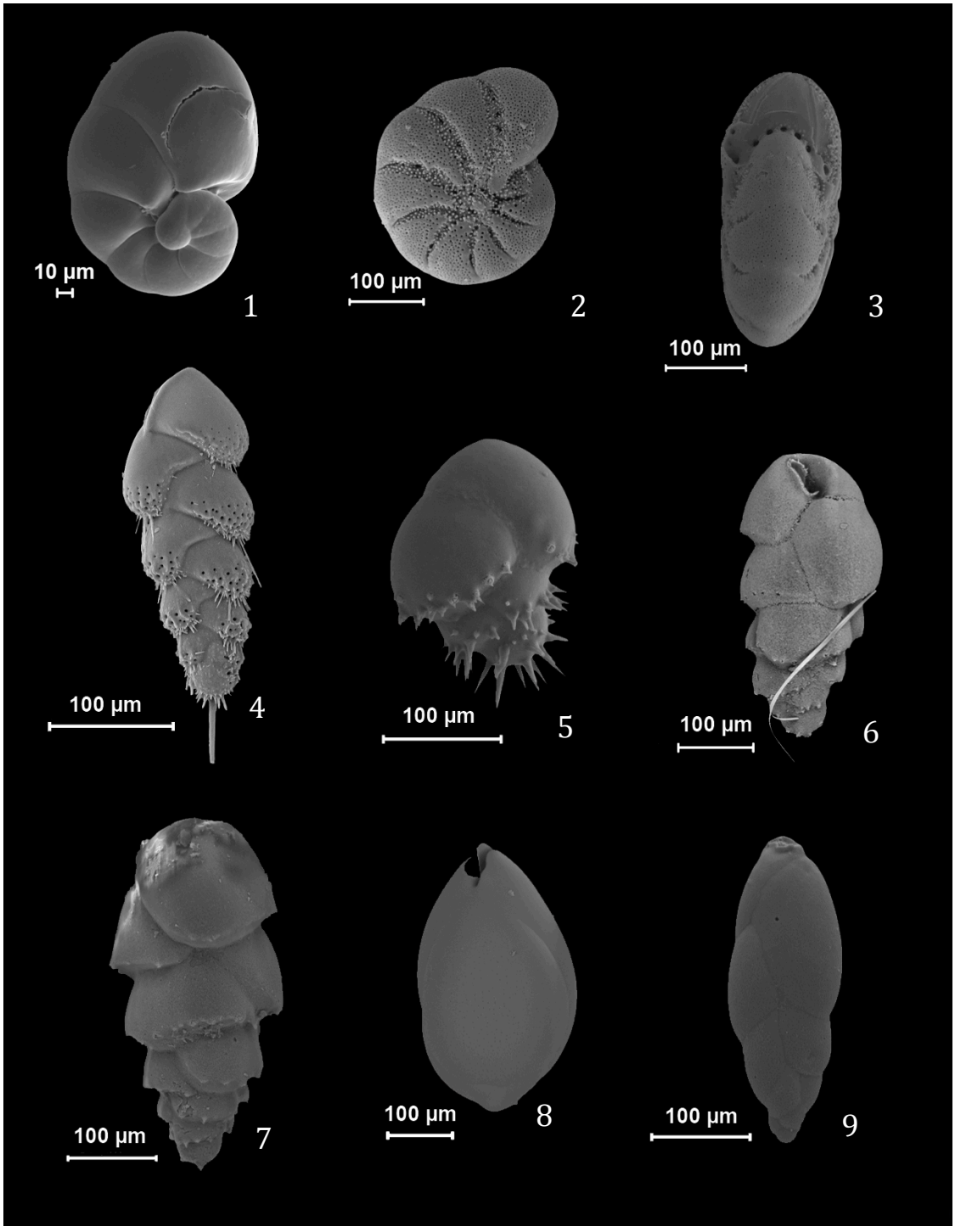

10 µm
1
100 µm
2
3
100 µm
100 µm
4
100 µm
5
100 µm
6
100 µm
7
100 µm
8
100 µm
9

Figure 4: Micrograph of common species in *in situ* assemblages.1. *Abditodentrix pseudothalmanni* (Boltovskoy & Guissani de Kahn). 2. *Uvigerina peregrina* (Cushman). 3. *Trifarina carinata* (Cushman). 4-5. *Valvulineria glabra* (Cushman). 6-7. *Cassidulina carinata* (Silvestri). 8. *Fursenkoina complanata* (Egger)

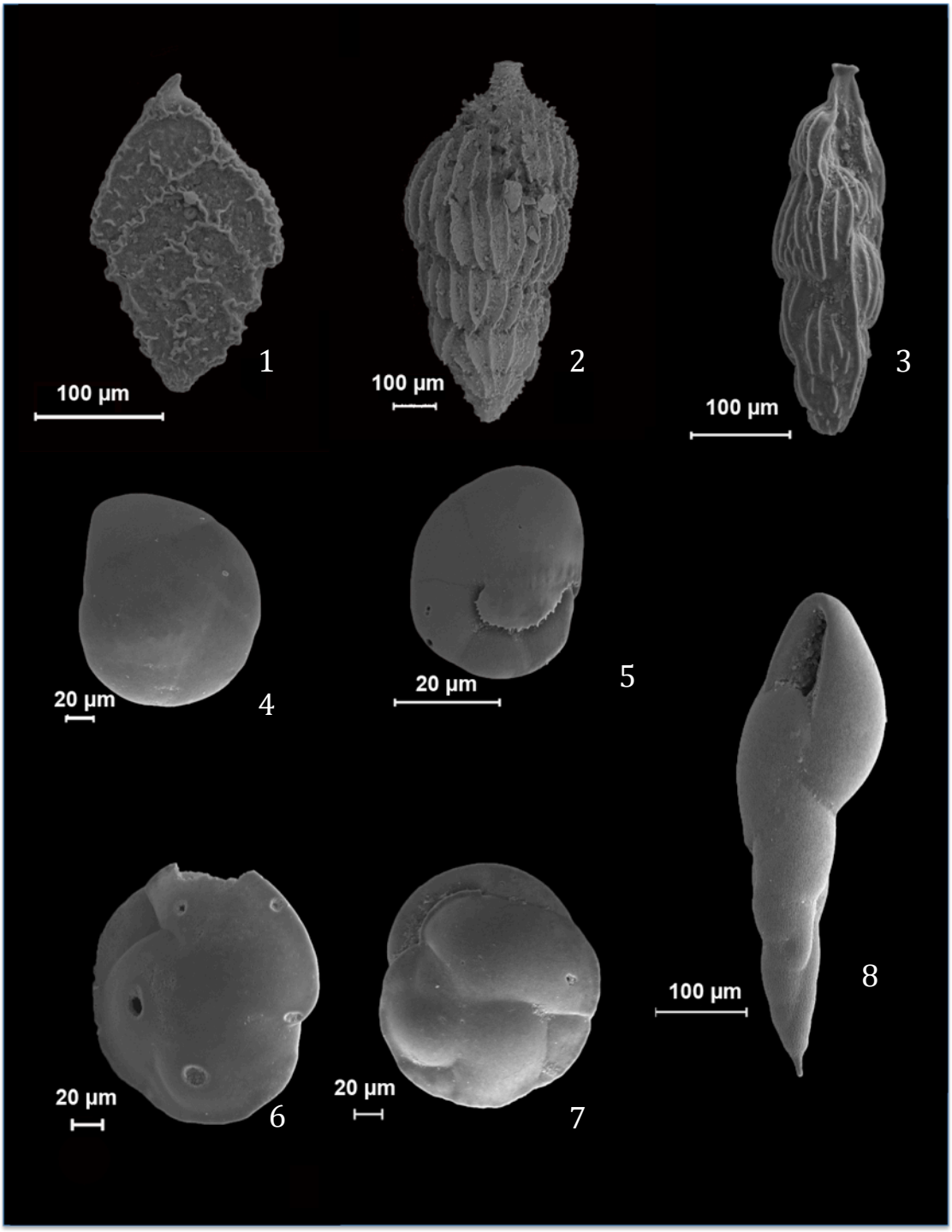

100 µm
1
100 µm
2
100 µm
3
20 µm
4
20 µm
5
100 µm
8
20 µm
6
20 µm
7

Figure 5: Abundances (sum of the 2 replicates per treatment) of foraminifera grown from each site organized by temperature. Assemblages from the 70-m and 2200-m sites were not grown at 12 °C or 18 °C.

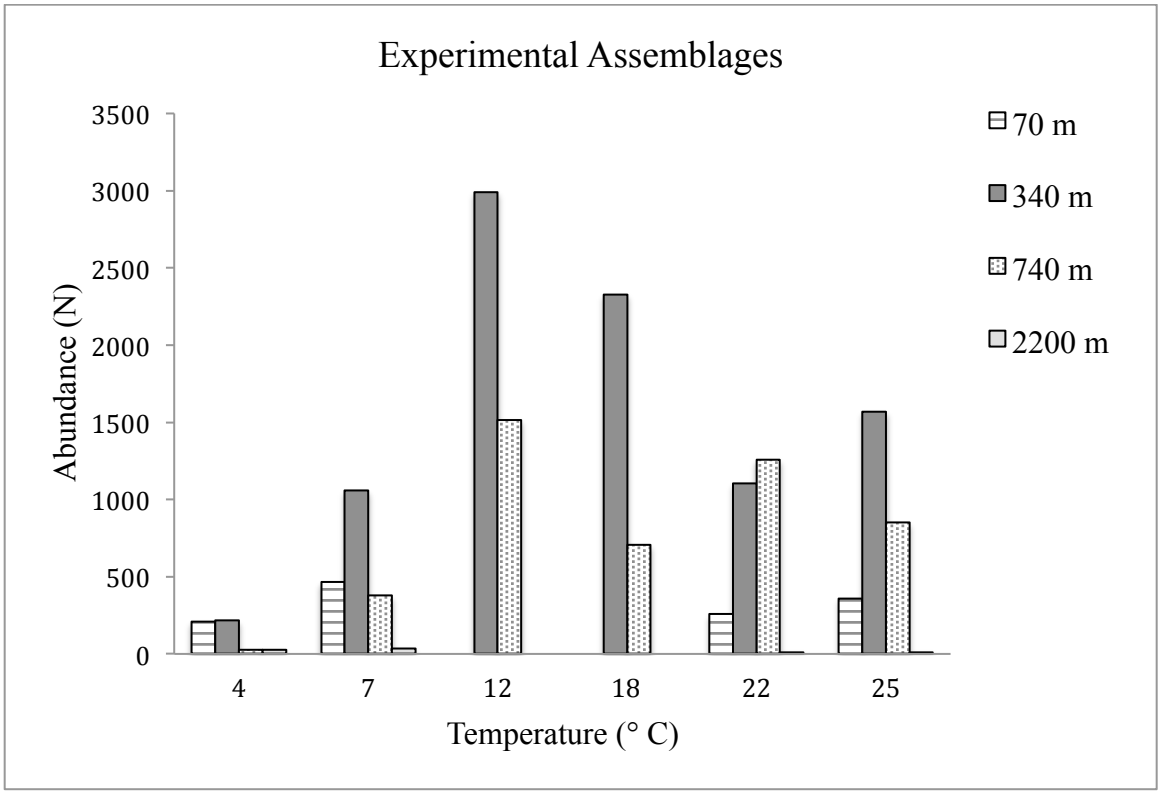

Experimental Assemblages
Abundance (N)
3500
3000
2500
2000
1500
1000
500
0
4
7
12
18
22
25
Temperature (° C)
70 m
340 m
740 m
2200 m

Figure 6: Cluster analysis (a) and MDS ordination (b) of the sum of the 2 replicates for each temperature for all experimentally grown assemblages. Results from the cluster analysis are overlain at the 30% similarity threshold on the MDS plot.

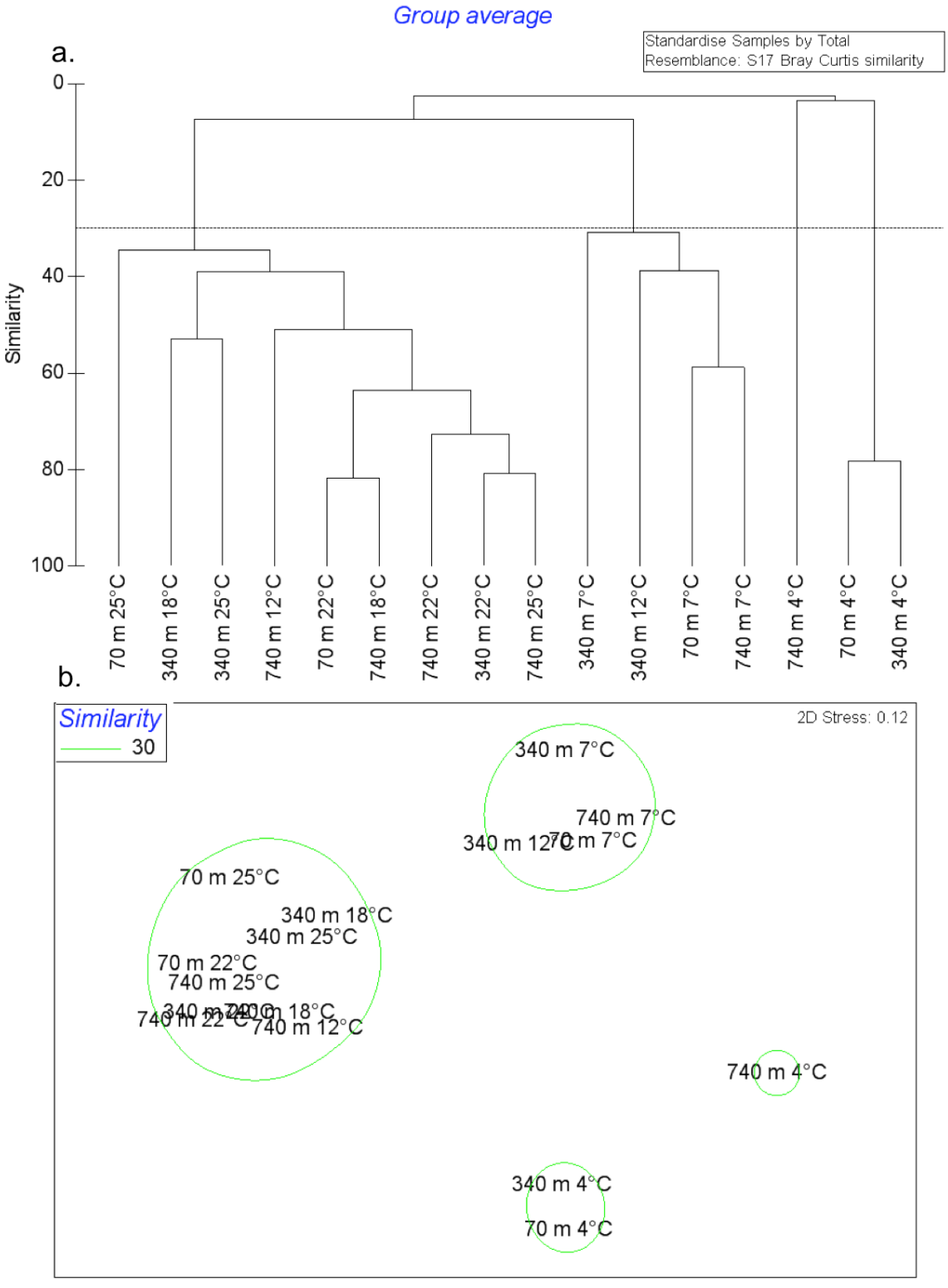

Group average
Standardise Samples by Total
Resemblance: S17 Bray Curtis similarity
a.
Similarity
0
20
40
60
80
100
70 m 25°C
340 m 18°C
340 m 25°C
740 m 12°C
70 m 22°C
740 m 18°C
740 m 22°C
340 m 22°C
740 m 25°C
340 m 7°C
340 m 12°C
70 m 7°C
740 m 7°C
740 m 4°C
70 m 4°C
340 m 4°C
b.
Similarity
30
2D Stress: 0.12
340 m 7°C
740 m 7°C
340 m 12°C
70 m 7°C
70 m 25°C
340 m 18°C
340 m 25°C
70 m 22°C
740 m 25°C
740 m 22°C
740 m 12°C
740 m 4°C
340 m 4°C
70 m 4°C

Figure 7: Micrograph of common species in experimentally grown assemblages. 1-2. *Loeblichopsis cylindrica* (Brady). 3. *Bathysiphon filiformis* (Sars). 4. *Leptohalysis scottii* (Chaster). 5. *Prolixoplecta parvula* (Cushman). 6-7. *Textularia earlandi.* 8-9. *Eggerella advena* (Cushman).

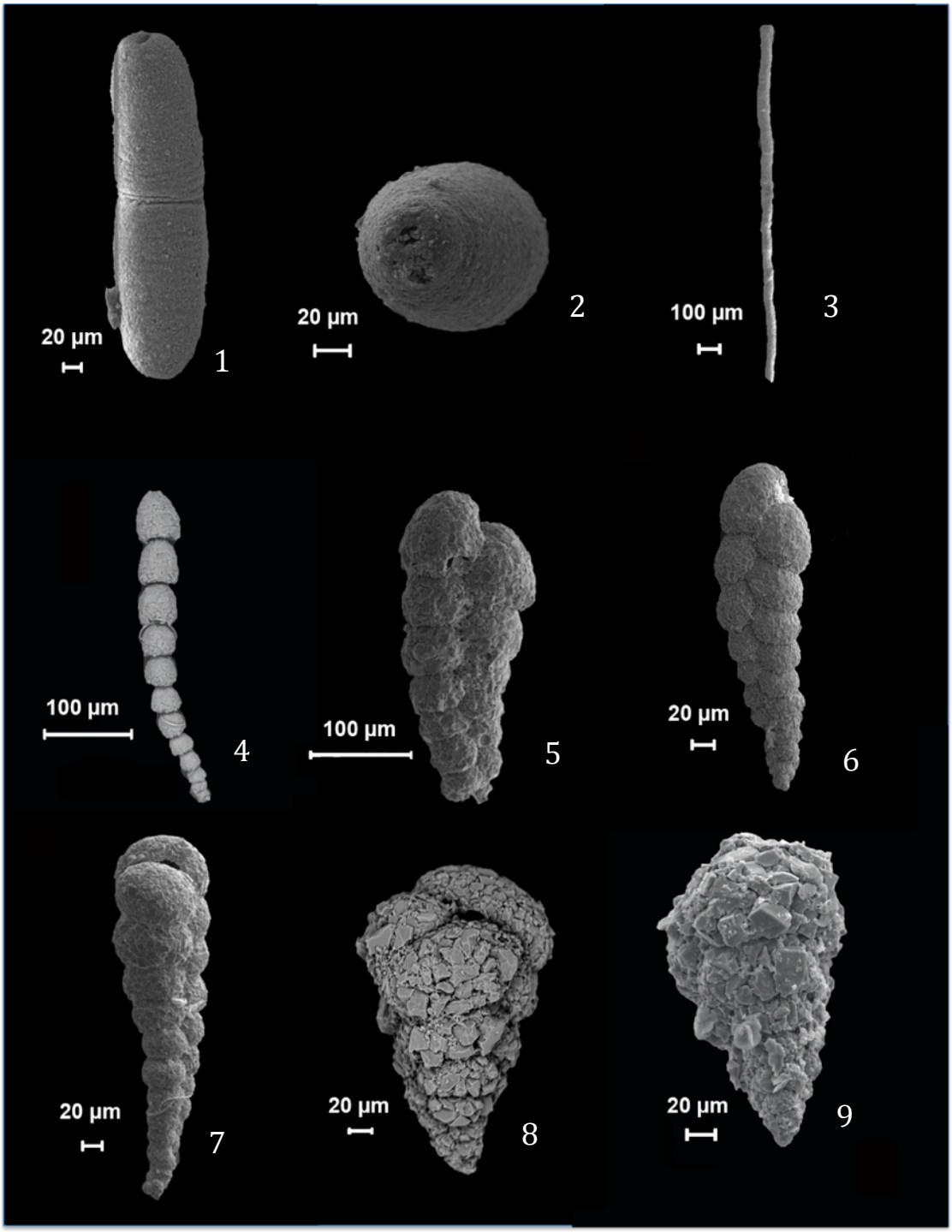

20 µm
1
20 µm
2
100 µm
3
100 µm
4
100 µm
5
20 µm
6
20 µm
7
20 µm
8
20 µm
9

Figure 8: Micrograph of common species in experimentally grown assemblages. 1-2. *Eggerelloides scaber* (Williamson). 3-4. *Miliammina fusca* (Brady) 5-6. *Quinqueloculina stalkeri* (Loeblich & Tappan) 7-8. *Cornuloculina inconstans* (Brady) 9. *Quinqueloculina cf. Q. bosciana malayensis* (Rasheed)

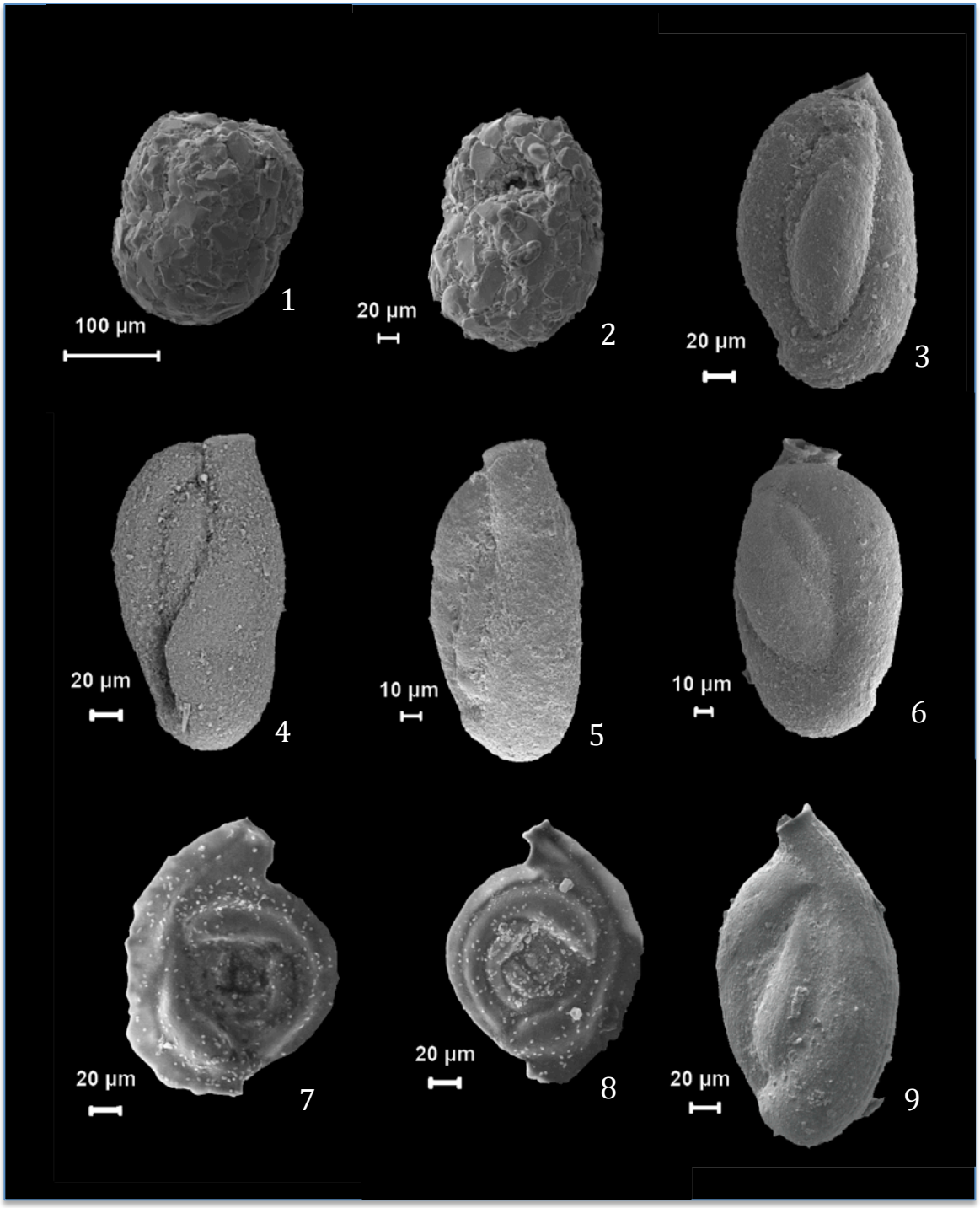

100 µm
1
20 µm
2
20 µm
3
20 µm
4
10 µm
5
10 µm
6
20 µm
7
20 µm
8
20 µm
9

Figure 9: Micrograph of common species in experimentally grown assemblages. 1. *Paratrochammina challengeri* (Parker & Jones). 2-3. *Trochammina inflata* (Montagu). 4-5. *Deuterammina rotaliformis* (Heron-Allen & Earland). 6. *Globulina minuta* (Roemer) 7. *Nonionella iridea* (Heron-Allen & Earland). 8-9. *Nonionellina labradorica* (Dawson)

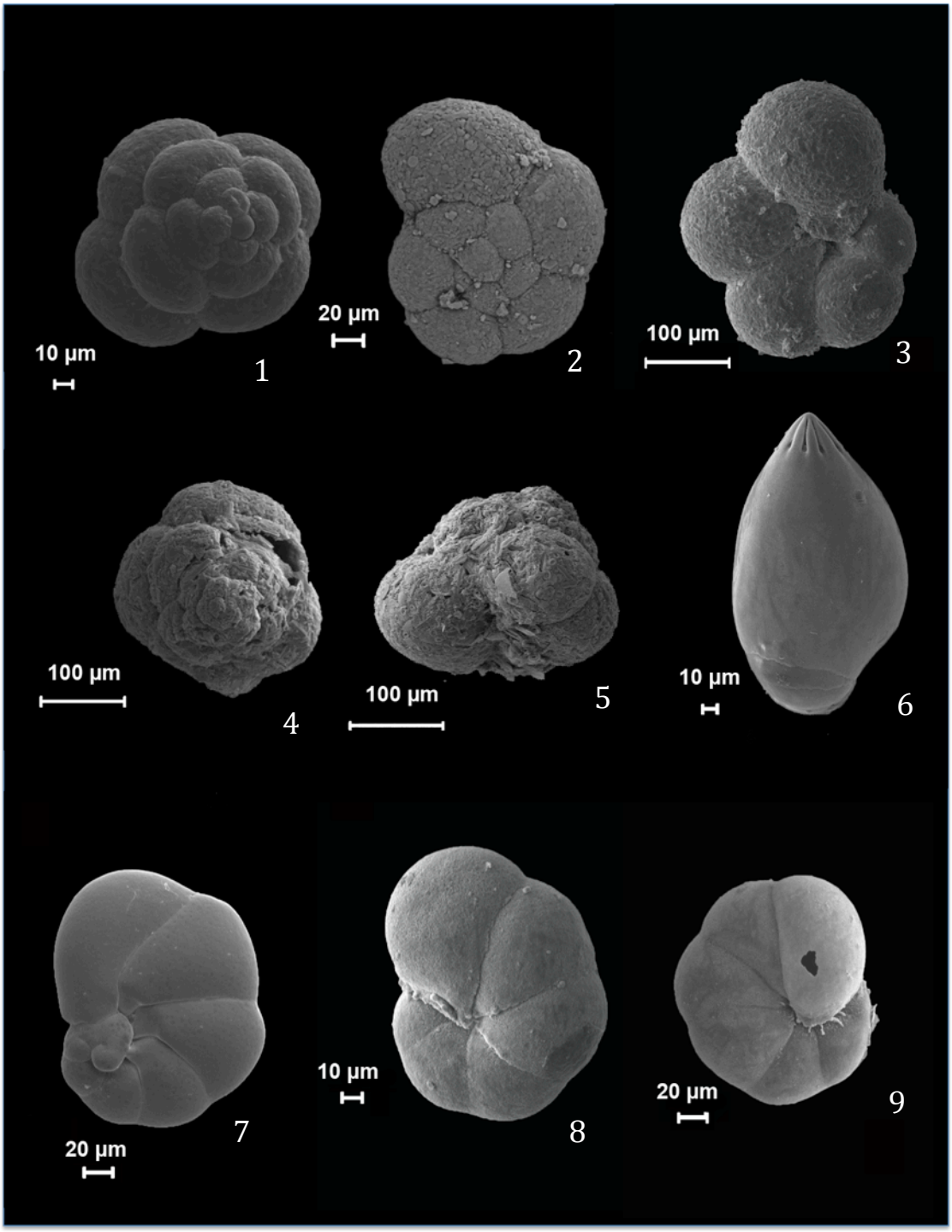

10 µm
1
20 µm
2
100 µm
3
100 µm
4
100 µm
5
10 µm
6
20 µm
7
10 µm
8
20 µm
9

Figure 10: Micrograph of common species in experimentally grown assemblages. 1. *Bulimina marginata* (d´Orbigny). 2. *Buliminella elegantissima* (d'Orbigny). 3. *Stainforthia* sp. 4. *Abditodentrix pseudothalmanni* (Boltovskoy & Guissani de Kahn). 5. *Bolivina ordinaria* (Phleger & Parker). 6. *Bolivina pseudoplicata* (Heron-Allen & Earland). 7. *Bolivina spathulata* (Williamson). 8. *Bolivina variabilis* (Williamson) 9. *Bolivinellina pseudopunctata* (Höglund)

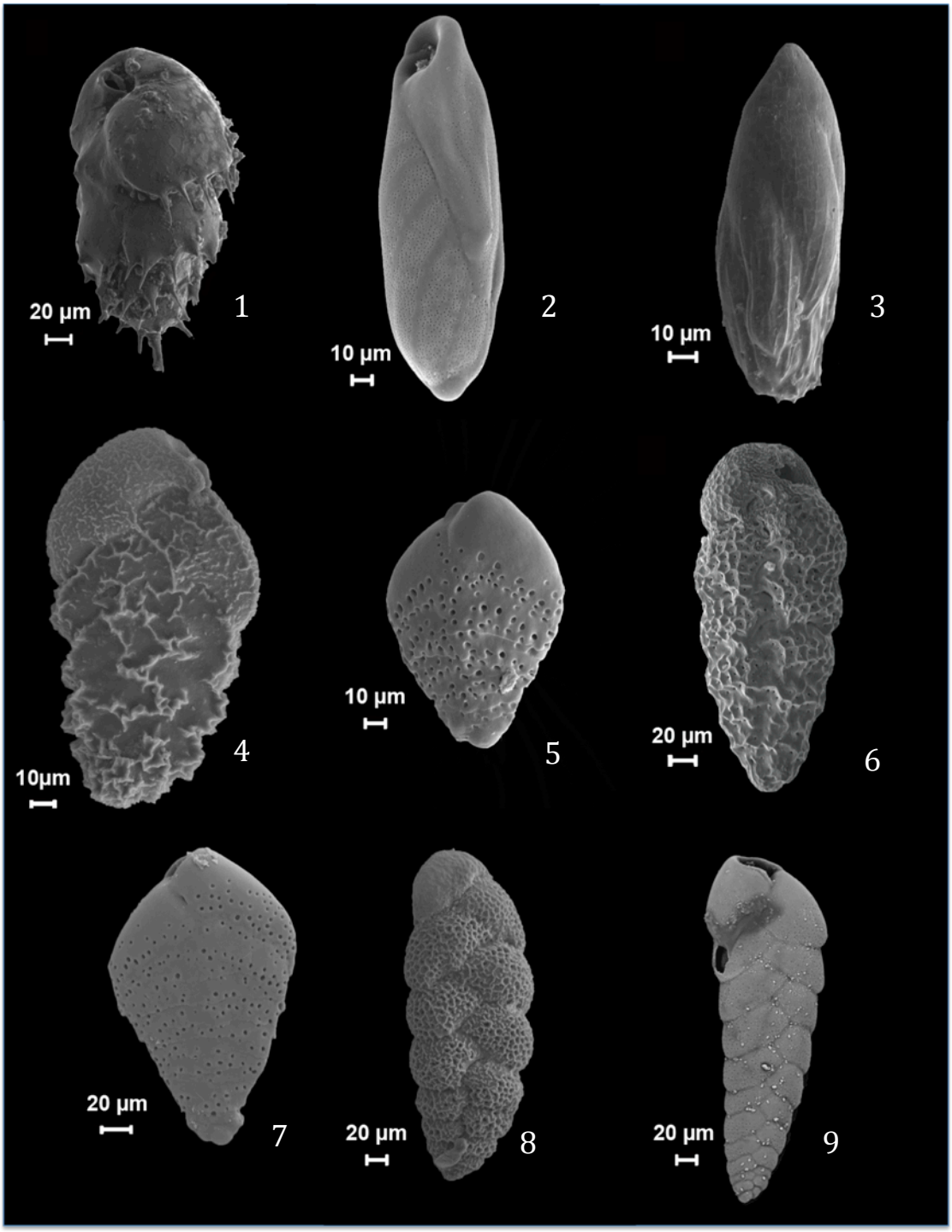

20 µm
1
10 µm
2
10 µm
3
10µm
4
10 µm
5
20 µm
6
20 µm
7
20 µm
8
20 µm
9

Figure 11: Micrograph of common species in experimentally grown assemblages. 1-2. *Brizalina lowmani* (Phleger & Parker). 3. *Uvigerina* cf. *U. peregrina* (Cushman). 4-5. *Rosalina* cf. *R. floridana* (Cushman) 6-8. *Gyroidina orbicularis* (d'Orbigny) 9. *Cassidulina obtusa* (Williamson)

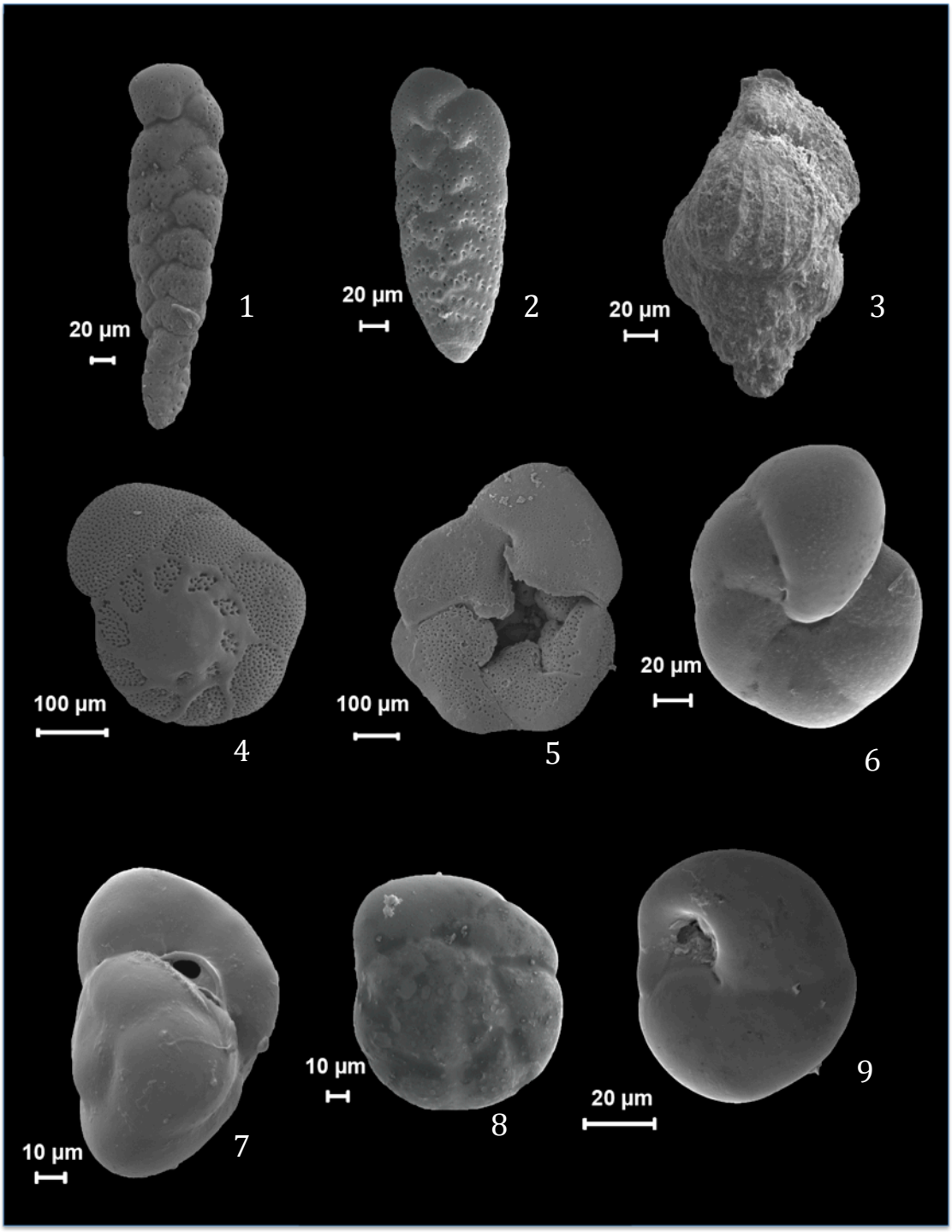
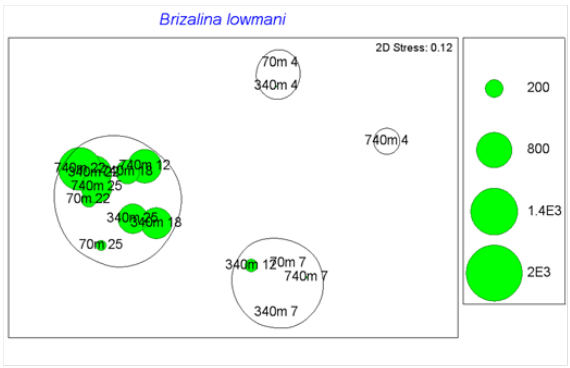
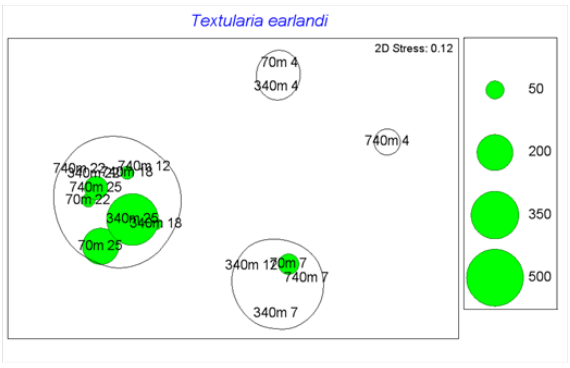
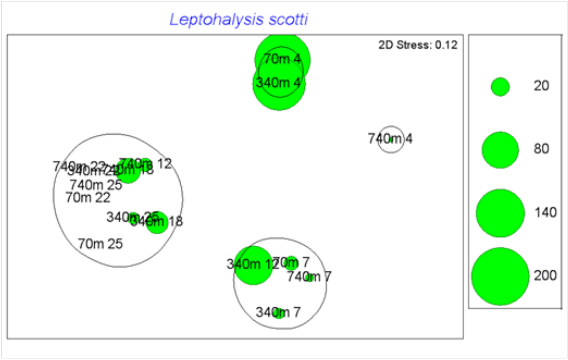
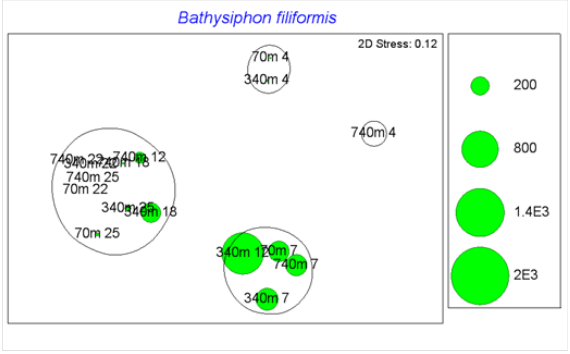

20 µm
1
20 µm
2
20 µm
3
100 µm
4
100 µm
5
20 µm
6
10 µm
7
10 µm
8
20 µm
9

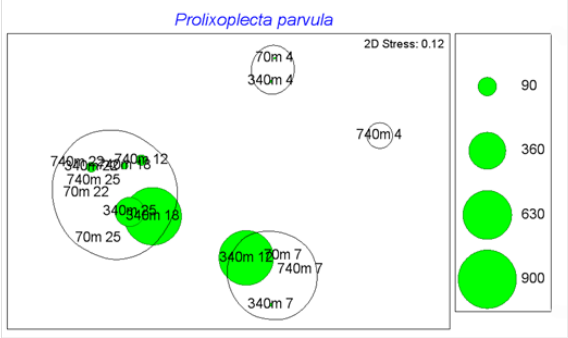
Figure 12: MDS ordination of the sum of the 2 replicates for each temperature with overlays of the cluster analysis (30% Bray Curtis similarity) and abundances of the 6 most common species grown in the experimental assemblages. 1. *Brizalina lowmani* 2. *Textularia earlandi.* 3.*Leptohalysis scottii.* 4. *Bathysiphon filiformis.* 5. *Prolixoplecta parvula.* 6. *Rosalina* cf. *R. floridana*. Key: "70 m" = water depth of the collection site; "7" = the temperature at which the experimental assemblage was grown in ° C.


Brizalina lowmani
2D Stress: 0.12
70m 4
340m 4
740m 4
740m 12
740m 25
70m 22
340m 25
340m 18
70m 25
340m 12
70m 7
740m 7
340m 7
200
800
1.4E3
2E3


Textularia earlandi
2D Stress: 0.12
70m 4
340m 4
740m 4
740m 12
740m 25
70m 22
340m 25
340m 18
70m 25
340m 12
70m 7
740m 7
340m 7
50
200
350
500


Leptohalysis scotti
2D Stress: 0.12
70m 4
340m 4
740m 4
740m 12
740m 25
70m 22
340m 25
340m 18
70m 25
340m 12
70m 7
740m 7
340m 7
20
80
140
200


Bathysiphon filiformis
2D Stress: 0.12
70m 4
340m 4
740m 4
740m 12
740m 25
70m 22
340m 25
340m 18
70m 25
340m 12
70m 7
740m 7
340m 7
200
800
1.4E3
2E3


Prolixoplecta parvula
2D Stress: 0.12
70m 4
340m 4
740m 4
740m 12
740m 25
70m 22
340m 25
340m 18
70m 25
340m 12
70m 7
740m 7
340m 7
90
360
630
900

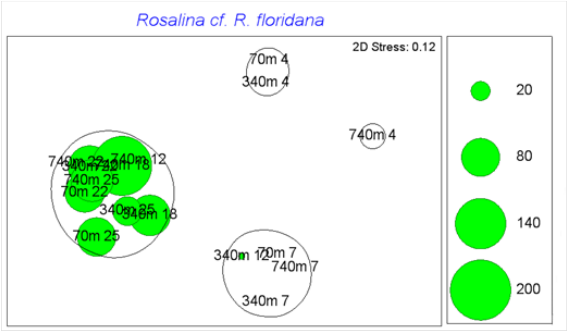

Rosalina cf. R. floridana
2D Stress: 0.12
70m 4
340m 4
740m 4
740m 12
740m 25
70m 22
340m 25
340m 18
70m 25
340m 12
70m 7
740m 7
340m 7
20
80
140
200

Figure 13: Species richness (S) of the experimentally grown foraminiferal assemblages from each temperature.

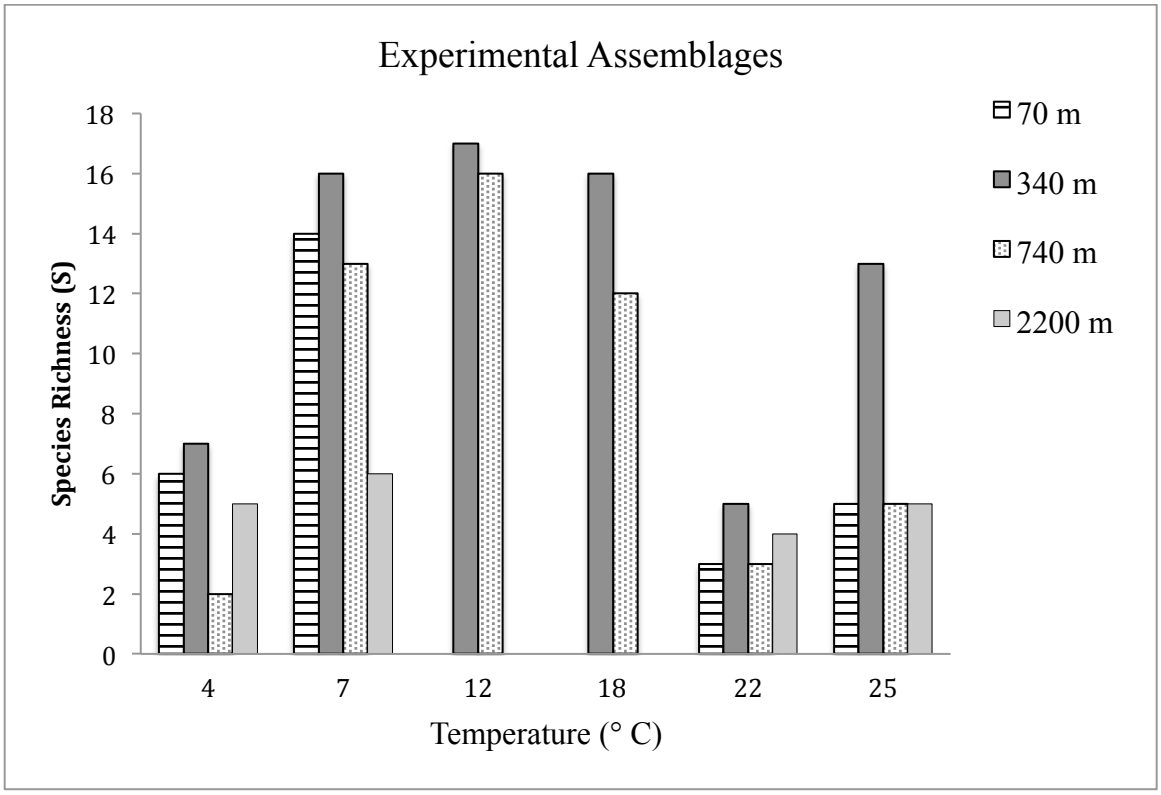
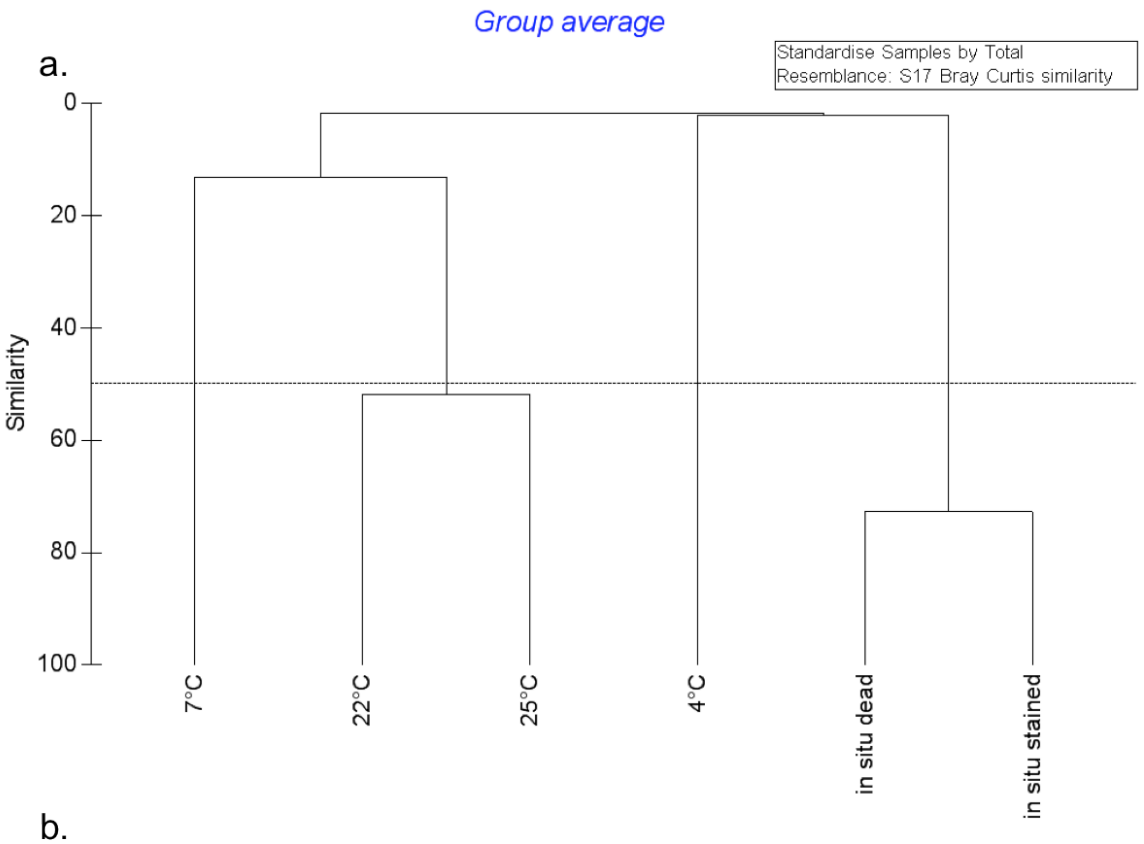

Experimental Assemblages
Species Richness (S)
18
16
14
12
10
8
6
4
2
0
4
7
12
18
22
25
Temperature (° C)
70 m
340 m
740 m
2200 m

Figure 14: Cluster analysis (a) and MDS ordination (b) of the sum of the 2 replicates for each temperature for all experimentally grown assemblages and the *in situ* assemblages from 70 m. Results from the cluster analysis are overlain at the 50% similarity threshold on the MDS plot.


Group average
a.
Standardise Samples by Total
Resemblance: S17 Bray Curtis similarity
Similarity
0
20
40
60
80
100
7°C
22°C
25°C
4°C
in situ dead
in situ stained

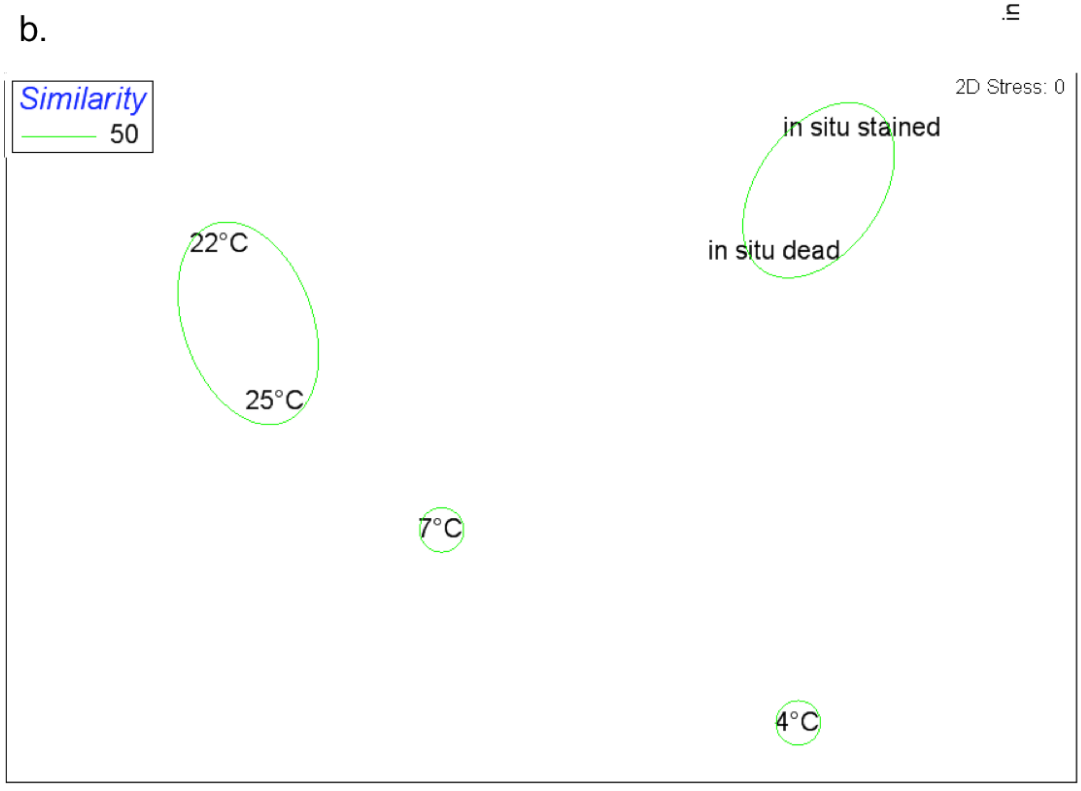
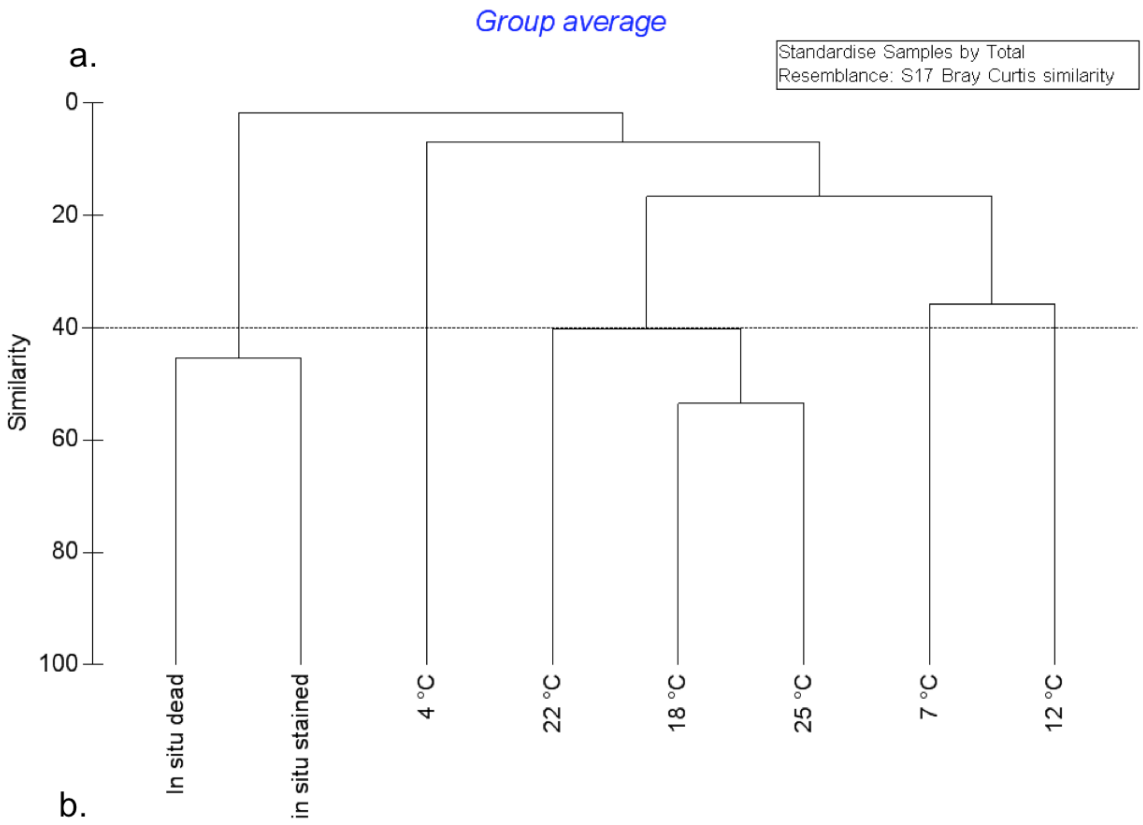

b.
Similarity
50
2D Stress: 0
in situ stained
in situ dead
22°C
25°C
7°C
4°C

Figure 15: Cluster analysis (a) and MDS ordination (b) of the sum of the 2 replicates for each temperature for all experimentally grown assemblages and the *in situ* assemblages from 340 m. Results from the cluster analysis are overlain at the 30% and 40% similarity thresholds on the MDS plot.


Group average
a.
Standardise Samples by Total
Resemblance: S17 Bray Curtis similarity
Similarity
0
20
40
60
80
100
In situ dead
in situ stained
4 °C
22 °C
18 °C
25 °C
7 °C
12 °C

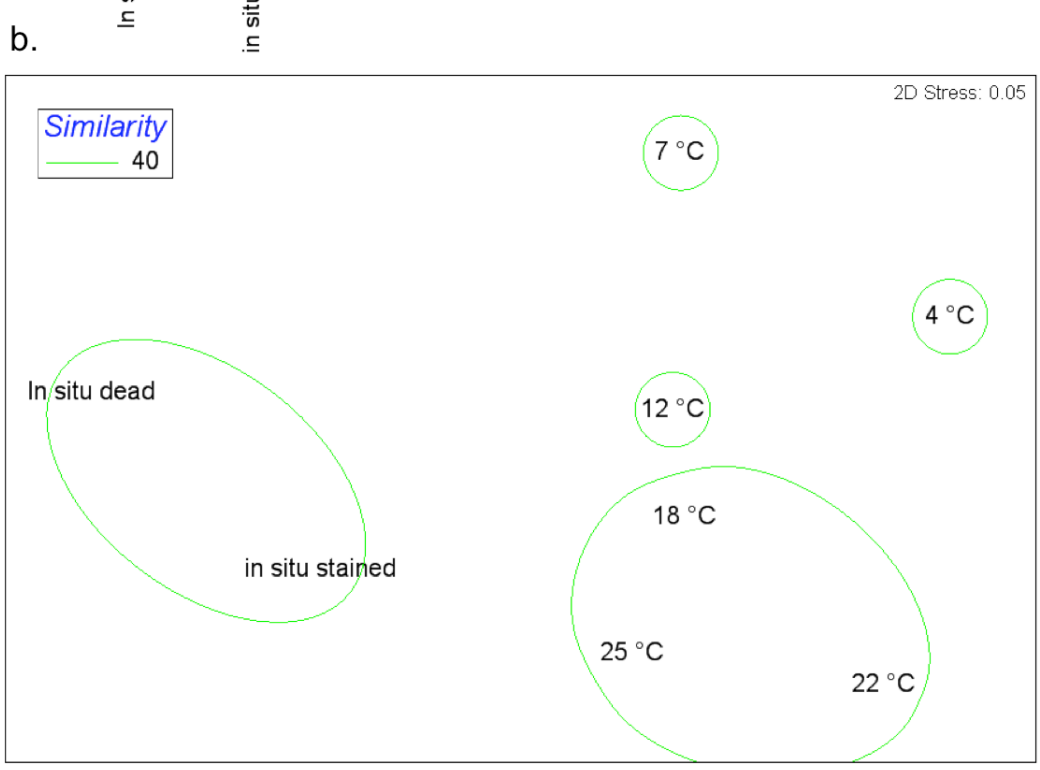

b.
2D Stress: 0.05
Similarity
40
7 °C
4 °C
In situ dead
12 °C
18 °C
in situ stained
25 °C
22 °C

Figure 16: Cluster analysis (a) and MDS ordination (b) of the sum of the 2 replicates for each temperature for all experimentally grown assemblages and the *in situ* assemblages from 740 m. Results from the cluster analysis are overlain at the 50% similarity threshold on the MDS plot.

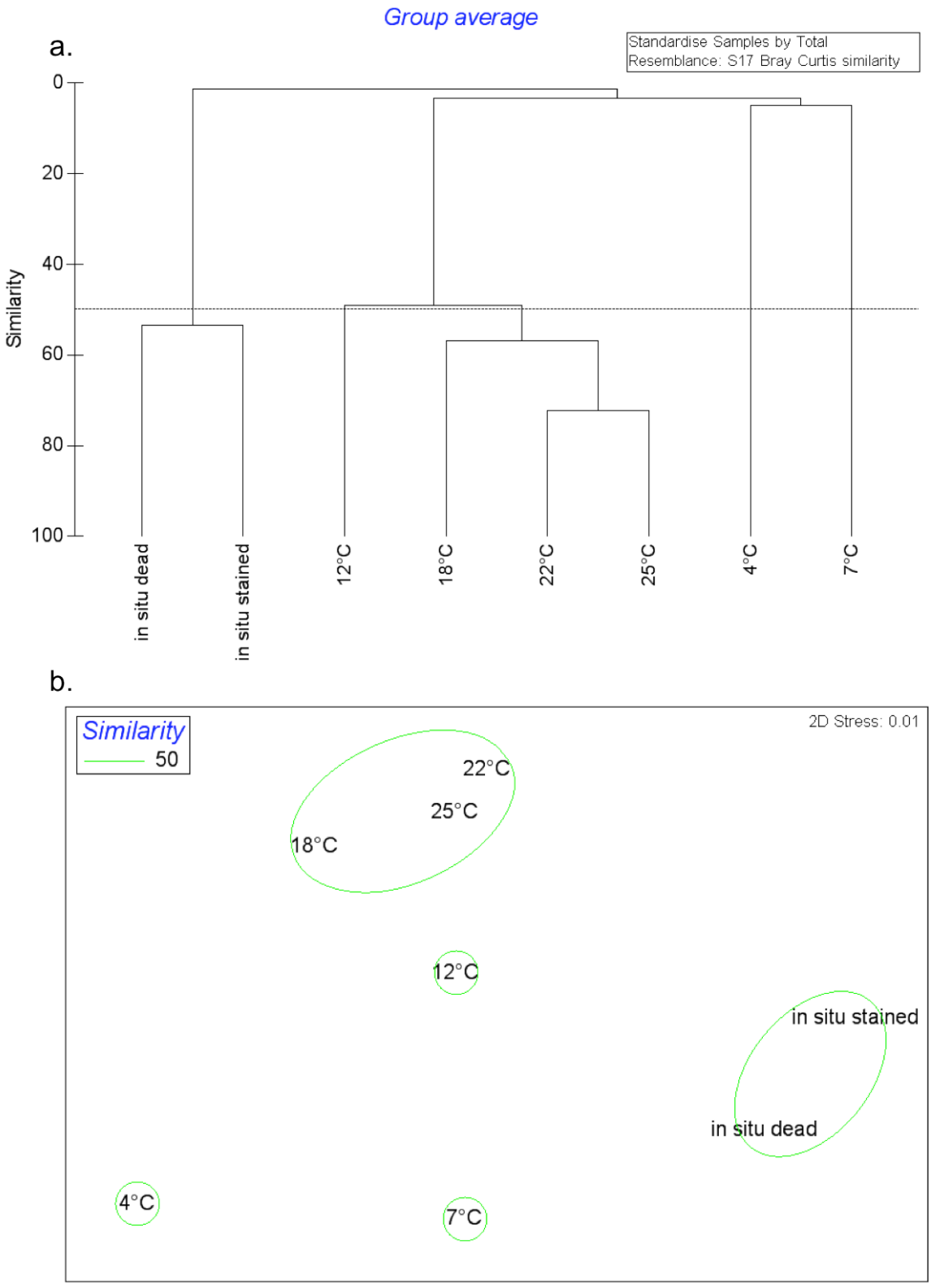
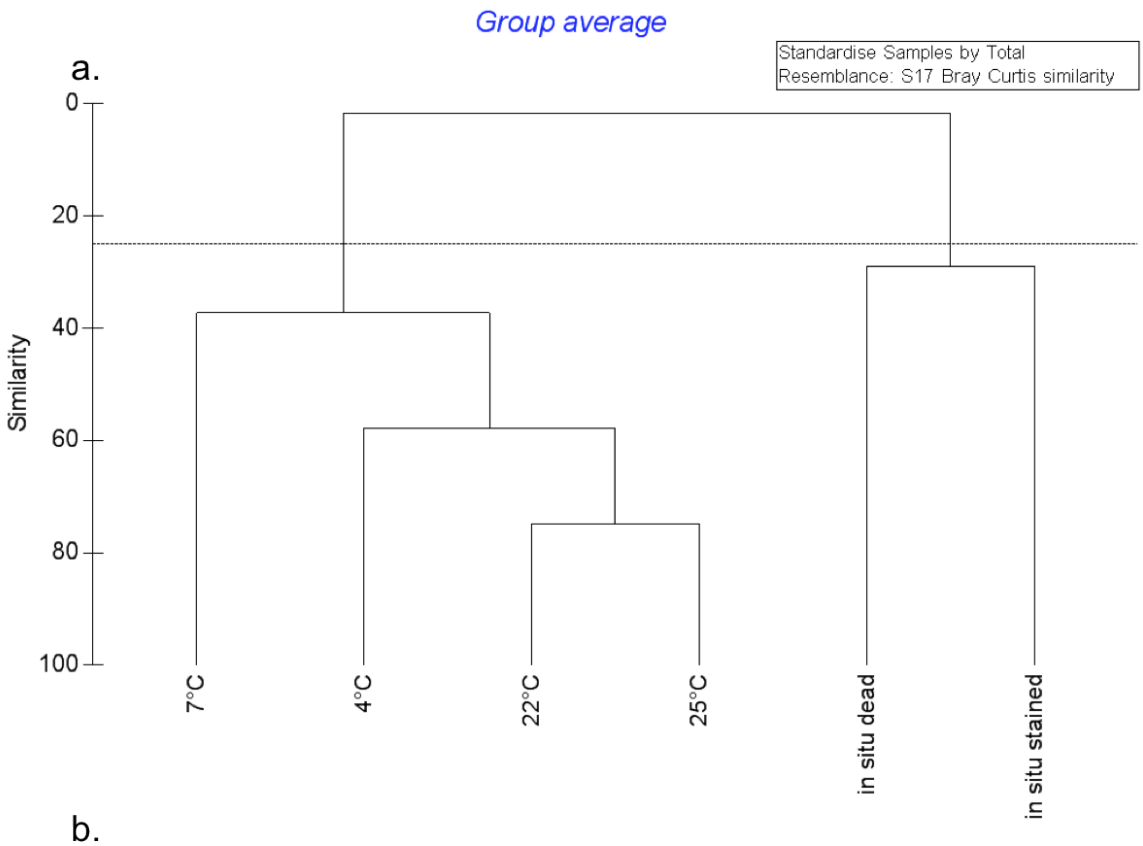

Group average
a.
Standardise Samples by Total
Resemblance: S17 Bray Curtis similarity
Similarity
0
20
40
60
80
100
in situ dead
in situ stained
12°C
18°C
22°C
25°C
4°C
7°C
b.
Similarity
50
2D Stress: 0.01
22°C
25°C
18°C
12°C
in situ stained
in situ dead
4°C
7°C

Figure 17: Cluster analysis (a) and MDS ordination (b) of the sum of the 2 replicates for each temperature for all experimentally grown assemblages and the *in situ* assemblages from 2200 m. Results from the cluster analysis are overlain at the 25% similarity threshold on the MDS plot.


Group average
Standardise Samples by Total
Resemblance: S17 Bray Curtis similarity
a.
Similarity
0
20
40
60
80
100
7°C
4°C
22°C
25°C
in situ dead
in situ stained

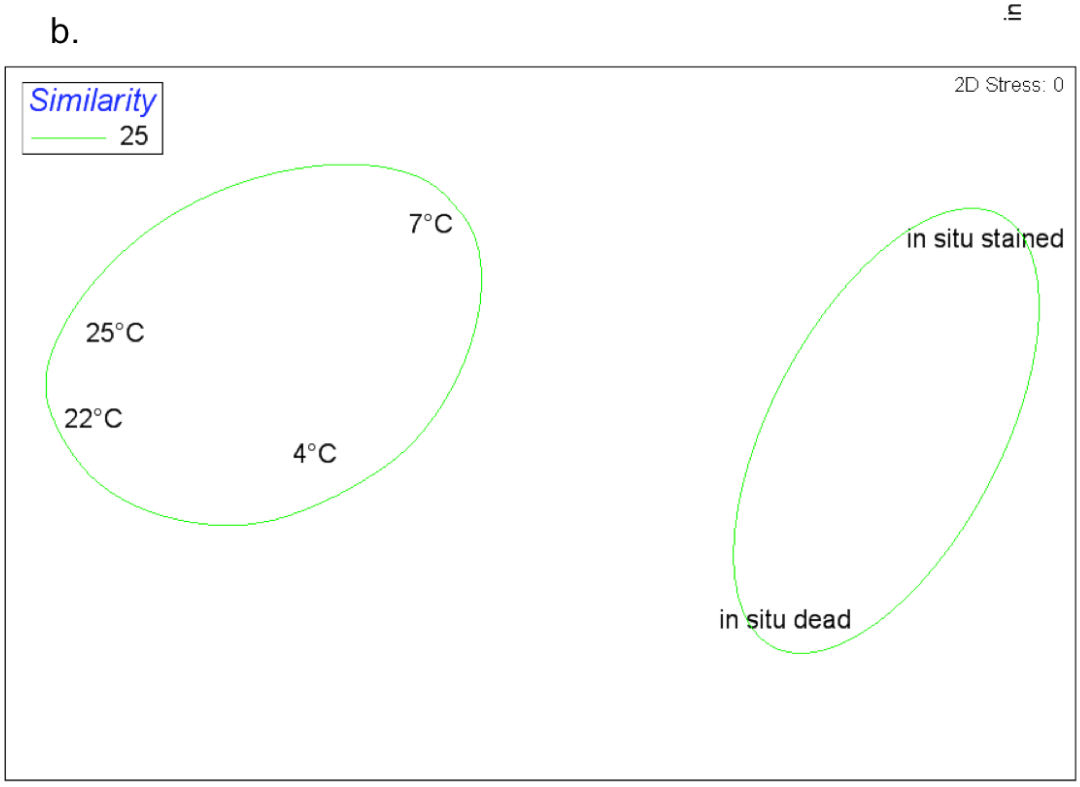

b.
Similarity
25
2D Stress: 0
7°C
25°C
22°C
4°C
in situ stained
in situ dead

Figure 18: Cluster analysis (a) and MDS ordination (b) of all *in situ* assemblages and combined replicates from each site grown at each temperature. Results from the cluster analysis are overlain at the 30% similarity threshold on the MDS plot.

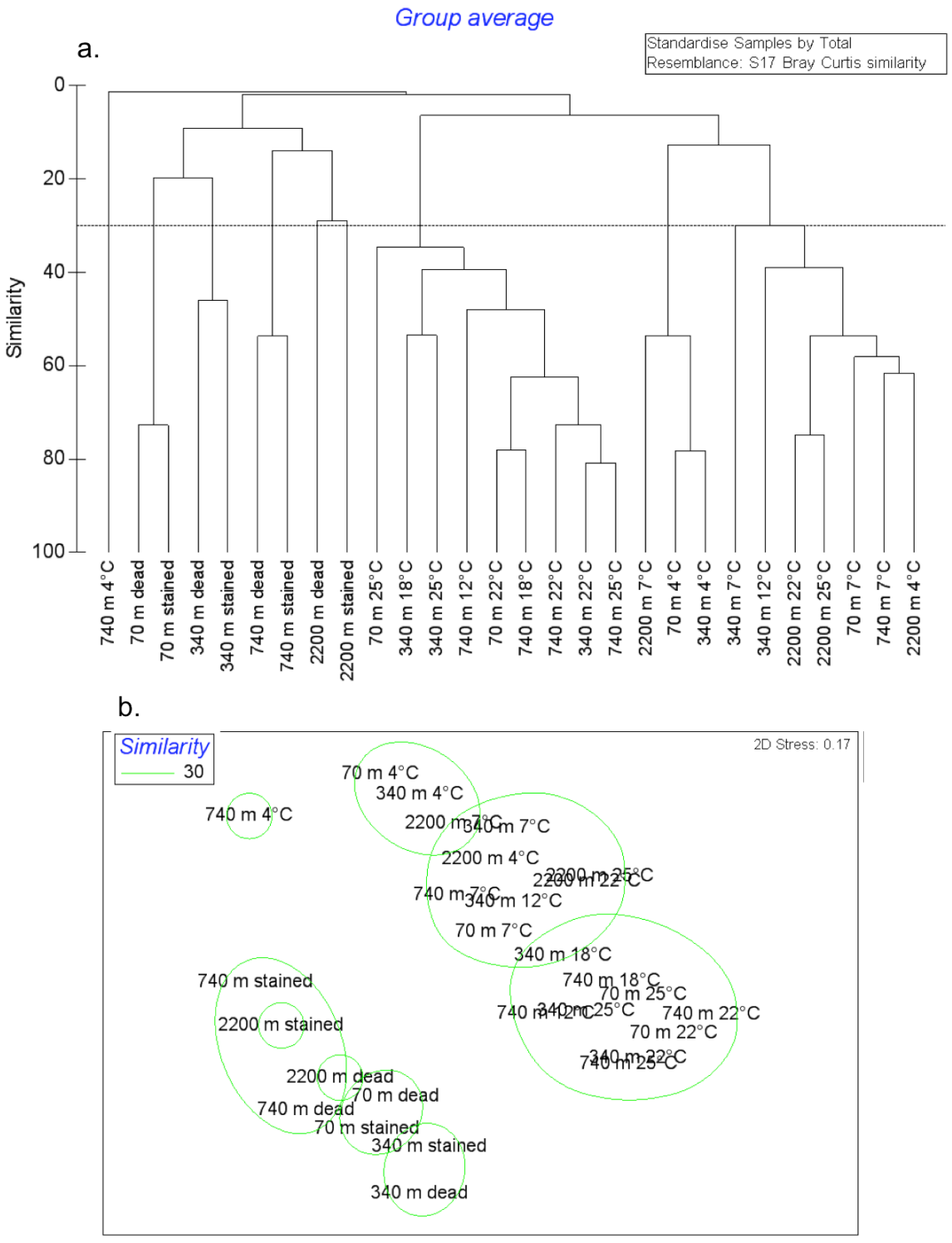

Group average
a.
Standardise Samples by Total
Resemblance: S17 Bray Curtis similarity
Similarity
0
20
40
60
80
100
740 m 4°C
70 m dead
70 m stained
340 m dead
340 m stained
740 m dead
740 m stained
2200 m dead
2200 m stained
70 m 25°C
340 m 18°C
340 m 25°C
740 m 12°C
70 m 22°C
740 m 18°C
740 m 22°C
340 m 22°C
340 m 25°C
2200 m 7°C
70 m 4°C
340 m 4°C
340 m 7°C
340 m 12°C
2200 m 22°C
2200 m 25°C
70 m 7°C
740 m 7°C
2200 m 4°C
b.
Similarity
30
2D Stress: 0.17
70 m 4°C
340 m 4°C
740 m 4°C
2200 m 7°C
340 m 7°C
2200 m 4°C
2200 m 25°C
2200 m 22°C
740 m 7°C
340 m 12°C
70 m 7°C
340 m 18°C
740 m stained
740 m 18°C
70 m 25°C
340 m 25°C
740 m 12°C
740 m 22°C
2200 m stained
70 m 22°C
340 m 22°C
740 m 25°C
2200 m dead
70 m dead
740 m dead
70 m stained
340 m stained
340 m dead

Figure 19: Cluster analysis (a) and MDS ordination (b) of all *in situ* assemblages and both replicates from each site grown at each temperature. Results from the cluster analysis are overlain at the 30% similarity threshold on the MDS plot.

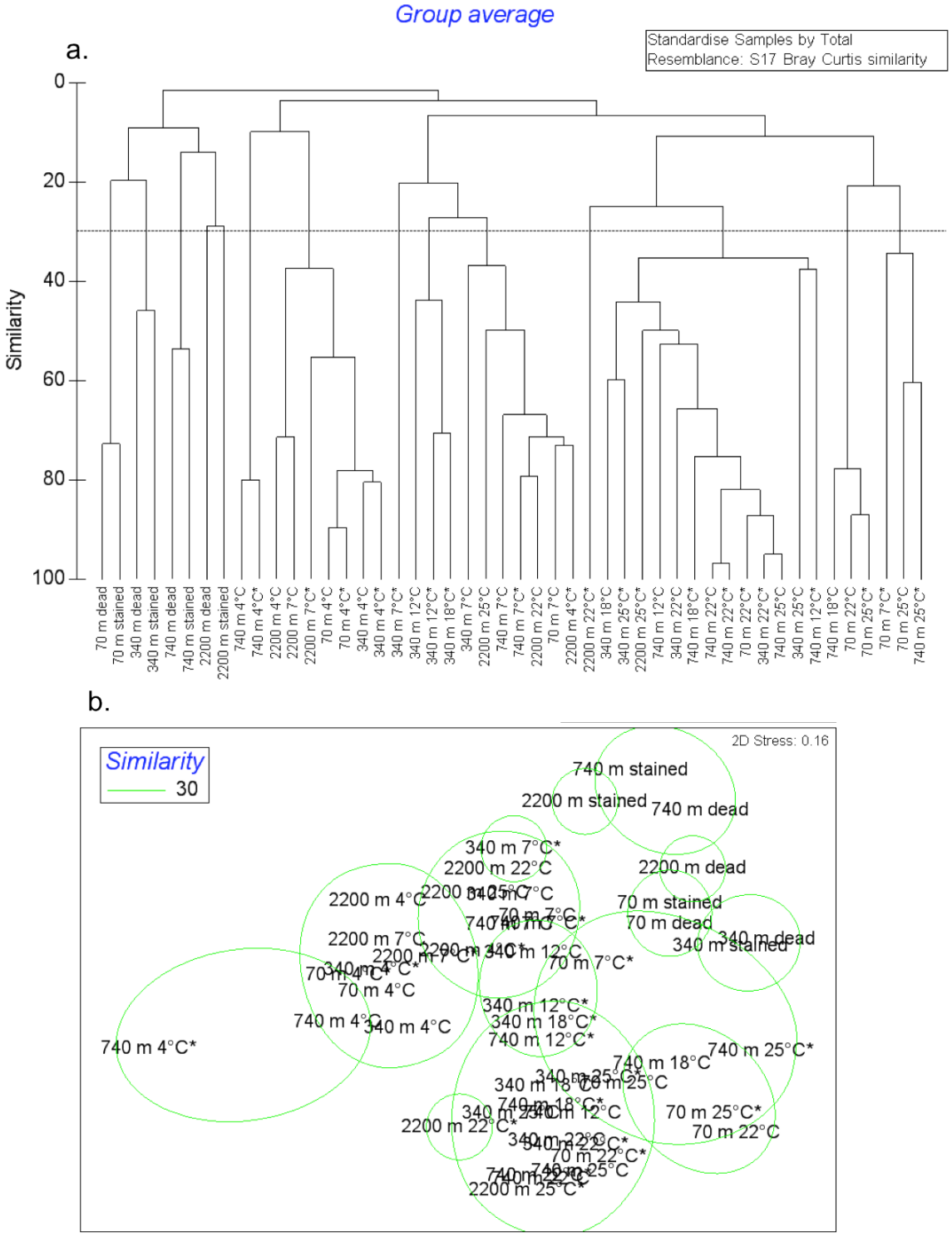

Group average
Standardise Samples by Total
Resemblance: S17 Bray Curtis similarity
a.
Similarity
0
20
40
60
80
100
70 m dead
70 m stained
340 m dead
340 m stained
740 m dead
740 m stained
2200 m dead
2200 m stained
740 m 4°C
740 m 4°C*
2200 m 4°C
2200 m 7°C
2200 m 7°C*
70 m 4°C
70 m 4°C*
340 m 4°C
340 m 4°C*
340 m 7°C*
340 m 12°C*
340 m 18°C*
340 m 7°C
2200 m 25°C
2200 m 7°C*
740 m 7°C*
2200 m 22°C
70 m 7°C
2200 m 4°C*
2200 m 22°C*
340 m 18°C
340 m 25°C*
2200 m 25°C*
740 m 12°C
340 m 22°C
740 m 18°C*
740 m 22°C
740 m 22°C*
70 m 22°C*
340 m 22°C*
740 m 25°C
340 m 25°C
740 m 12°C*
740 m 18°C
70 m 22°C
70 m 25°C*
70 m 7°C*
70 m 25°C
740 m 25°C*
b.
2D Stress: 0.16
Similarity
30
740 m stained
2200 m stained
740 m dead
340 m 7°C*
2200 m 22°C
2200 m dead
2200 m 4°C
70 m stained
70 m dead
340 m stained
340 m dead
2200 m 7°C
70 m 7°C*
340 m 12°C*
340 m 18°C*
740 m 12°C*
740 m 4°C*
740 m 18°C
740 m 25°C*
340 m 18°C
70 m 25°C
340 m 12°C
70 m 25°C*
2200 m 22°C*
70 m 22°C
70 m 22°C*
2200 m 25°C*

Table 1: Depth, latitude, longitude, and temperature at the sea floor for each of the sites.

Site	Latitude (Degrees N)	Longitude (Degrees W)	Depth (m)	Temperature (°C)
70 m	40 26.00	70 29.99	76	7.1
340 m	39 58.67	70 44.36	338	9.5
740 m	39 51.25	70 39.07	737	4.8
2200 m	39 39.80	70 40.06	2204	3.0

Table 2: Number of specimens (N), Species richness (S), Shannon's H^1, and p_i max of the in situ assemblages.

Site	N	S	Shannon's H[1]	p_i max
70 m *in situ* dead	490	17	2.04	0.320
70 m *in situ* stained	490	22	2.13	0.341
340 m *in situ* dead	808	24	1.75	0.498
340 m *in situ* stained	170	17	2.35	0.235
740 m *in situ* dead	774	25	1.82	0.536
740 m *in situ* stained	156	16	2.33	0.301
2200 m *in situ* dead	804	26	2.25	0.327
2200 m *in situ* stained	109	19	2.54	0.165

Table 3: Foraminifera that grew in the experimental assemblages but were absent from the in situ assemblages. The species are organized by the site of propagule origin and growth temperature.

Species present only in experimental assemblages	**Growth Temperature(s)**					
70 m site	4 °C	7 °C	12 °C	18 °C	22 °C	25 °C
Miliammina fusca	19					
Loeblichopsis cylindrica		18				
Eggerella advena		2				
Brizalina lowmani					145	67
Rosalina cf*. R. floridana*					85	82
340 m site	4 °C	7 °C	12 °C	18 °C	22 °C	25 °C
Quinqueloculina stalkeri	10	7				
Brizalina lowmani	1		101	616	792	554
Cassidulina sp. 2		24				
Bolivina ordinaria		13	45			
Quinqueloculina cf*. Q. bosciana malayensis*			178			
Eggerella advena			118	22		
Nonionellina labradorica			38			
Elphidium cf*. oceanensis*			9			
Globulina minuta			4			
Rosalina cf*. R. floridana*			2	91	102	46
Bolivina variabilis				103	18	70
Deuterammina rotaliformis						42
740 m site	4 °C	7 °C	12 °C	18 °C	22 °C	25 °C
Brizalina lowmani		2	723	360	1160	614
Eggerella advena			293	21		
Cornuloculina inconstans			33			
Bolivinellina pseudopunctata			5	33		
Rosalina cf*. R. floridana*			1	192		97
Bolivina variabilis				8	88	1
Buliminella elegantissima				3	9	
2200 m site	4 °C	7 °C	12 °C	18 °C	22 °C	25 °C
Stainforthia sp.	1	4			2	2
Brizalina lowmani	1				1	1
Cassidulina obtusa		4			1	3

Table 4: Abundant taxa grown from the 70 m site.

70 m	4 °C	7 °C	22 °C	25 °C
Dominant taxa	(87%) *Leptohalysis scottii* (9%) *Miliammina fusca*	(55%) *Bathysiphon filiformis* (14%) *Textularia earlandi* (7%) *Eggerelloides scaber* (5%) *Islandiella islandica*	(56%) *Brizalina lowmani* (33%) *Rosalina* cf. *R. floridana* (11%) *Textularia earlandi*	(57%) *Textularia earlandi* (23%) *Rosalina* cf. *R. floridana* (19%) *Brizalina lowmani*

Table 5: Abundant taxa grown from the 340 m site.

340 m	4 °C	7 °C	12 °C	18 °C	22 °C	25 °C
Dominant taxa	(77%) *Leptohalysis scottii* (13%) unidentified *Allogromia*	(30%) *Bathysiphon filiformis* (28%) unidentified *Allogromia* sp. 1 (27%) unidentified *Allogromia* sp. 2	(35%) *Bathysiphon filiformis* (26%) *Prolixoplecta parvula* (7%) *Trochammina advena* (6%) *Quinqueloculina* cf. *Q. bosciana malayensis* (5%) *Trochammina inflata* (4%) *Eggerella advena* (3%) *Eggerelloides scaber* (3%) *Brizalina lowmani*	(38%) *Prolixoplecta parvula* (26%) *Brizalina lowmani* (10%) *Bathysiphon filiformis* (4%) *Bolivina variabilis* (4%) *Trochammina advena*	(72%) *Brizalina lowmani* (15%) *Gyroidina orbicularis* (9%) *Rosalina* cf. *R. floridana*	(35%) *Brizalina lowmani* (26%) *Textularia earlandi* (14%) *Prolixoplecta parvula* (6%) juvenile *Uvigerina peregrina* (4%) *Bolivina variabilis* (4%) *Bolivina pseudoplicata*

Table 6: Abundant taxa grown from the 740 m site.

740 m Dominant taxa	4 °C (96%) unidentified *Saccammina* sp. 1 (4%) *Leptohalysis scottii*	7 °C (73%) *Bathysiphon filiformis* (7%) unidentified *Saccammina* sp. *2* (6%) unidentified *Allogromia* sp. 1 (3%) juvenile *Trochammina* cf *T. inflata*	12 °C (48%) *Brizalina lowmani* (19%) *Bolivina spathulata* (13%) *Eggerella advena* (5%) *Bathysiphon filiformis*	18 °C (51%) *Brizalina lowmani* (27%) *Rosalina* cf. *R. floridana*	22 °C (92%) *Brizalina lowmani* (7%) *Bolivina variabilis*	25 °C (72%) *Brizalina lowmani* (11%) *Rosalina* cf. *R. floridana* (10%) *Textularia earlandi* (6%) *Bolivina spathulata*

Table 7: Species that grew experimentally but not from the corresponding sampling site.

	Grew experimentally from			
Species; *in situ* depths	70 m	340 m	740 m	2200 m
Bulimina marginata; 70 m, 340 m		1	27	
Trochammina inflata; 70 m		152		
Bolivina spathulata; 340 m	10		353	
Bulimina aculeata; 340 m, 740 m	2			
Gyroidina orbicularis 2200 m		164	28	
Uvigerina peregrina; 740 m, 2200 m	2			

Table 8: Number of specimens (N), Species richness (S), Shannon's H^1, and p_i max from each of the experimental assemblages. They are ordered by depth and temperature.

Site	Temperature (°C)	N	S	Shannon's H[1]	p_i max
70m	4	210	6	0.485	0.876
70m	7	464	14	1.623	0.550
70m	22	257	3	0.926	0.564
70m	25	360	5	1.056	0.567
340m	4	216	7	0.812	0.773
340m	7	1058	16	1.676	0.298
340m	12	2991	17	1.997	0.349
340m	18	2328	16	1.889	0.376
340m	22	1106	5	0.902	0.716
340m	25	1569	13	1.826	0.353
740m	4	28	2	0.154	0.964
740m	7	377	13	1.163	0.727
740m	12	1515	16	1.701	0.477
740m	18	707	12	1.464	0.509
740m	22	1257	3	0.296	0.923
740m	25	851	5	0.897	0.722
2200m	4	27	5	1.097	0.593
2200m	7	36	6	1.437	0.528
2200m	22	12	4	0.983	0.667
2200m	25	12	5	1.424	0.417

APPENDIX I: FORAMINIFERA DATA

	in situ			experimental growth temperature (°C)							
70 m	dead	stained	additional stained	4 #3	4 #4	7 #3	7 #4	22 #6	22 #2	25 #4	25 #2
Abditodentrix pseudothalmanni	0	0	0	0	0	0	1	0	0	0	0
Ammobaculites cf. *A. agglutinans*	0	0	2	0	0	0	0	0	0	0	0
Aubignyna hamblensis	19	7	9	0	0	0	0	0	0	0	0
Bathysiphon filiformis	3	0	1	1	0	203	52	0	0	6	0
Bolivina spathulata	0	0	0	0	0	0	10	0	0	0	0
Bolivinellina translucens	8	4	6	0	0	0	0	0	0	0	0
Brizalina lowmani	0	0	0	0	0	0	0	145	0	66	1
Bulimina aculeata	0	0	0	0	0	0	1	0	0	1	0
Bulimina marginata	113	7	37	0	0	0	0	0	0	0	0
Cassidulina teretis	2	0	0	0	0	0	0	0	0	0	0
Cribrostomoides jeffreysii	0	0	1	0	0	3	3	0	0	0	0
Dentalina sp.	7	0	0	0	0	0	0	0	0	0	0
Eggerella advena	0	0	0	0	0	2	0	0	0	0	0
Eggerelloides scaber	0	1	3	1	0	13	20	0	0	0	0
Elphidium excavatum	157	29	138	0	0	0	0	0	0	0	0
Eratidus foliaceus	1	1	15	0	0	0	0	0	0	0	0
Fursenkoina complanata	23	0	13	0	0	0	0	0	0	0	0
Globobulimina turgida	49	21	72	0	0	0	0	0	0	0	0
Islandiella islandica	0	1	0	0	0	16	8	0	0	0	0
Leptohalysis scottii	11	0	2	55	129	10	2	0	0	0	0

	in situ			experimental growth temperature (°C)							
70 m cont.	dead	stained	additional stained	4 #3	4 #4	7 #3	7 #4	22 #2	22 #6	25 #4	25 #2
Loeblichopsis cylindrica	0	0	0	0	0	0	18	0	0	0	0
Miliammina fusca	0	0	0	6	13	0	0	0	0	0	0
Nonionella auricula	0	0	0	0	0	5	8	0	0	0	0
Nonionella iridea	2	0	2	0	0	0	0	0	0	0	0
Pleurostomella sp.	0	1	0	1	0	0	0	0	0	0	0
Prolixoplecta parvula	6	0	1	0	0	0	0	0	0	0	0
Pyrulina sp.	0	1	0	0	0	0	0	0	0	0	0
Reophax cf. *R. gaussicus*	0	0	9	0	0	0	0	0	0	0	0
Reophax curtus	26	2	6	0	0	0	0	52	33	0	82
Rosalina cf. *R. floridana*	0	0	0	4	0	22	0	0	0	0	0
Saccammina sp.	0	0	0	0	0	0	0	0	0	0	0
Stainforthia fusiformis	53	13	48	0	0	11	54	12	15	167	37
Textularia earlandi	8	0	0	0	0	0	0	0	0	0	0
Trochammina inflata	2	10	13	0	0	0	2	0	0	0	0
Uvigerina peregrina	0	0	0	0	0	0	0	0	0	0	0
Veleroninoides cf. *V. wiesneri*	0	0	16	0	0	0	18	0	0	0	0

	in situ			experimental growth temperature (°C)											
340 m	dead	stained	additional stained	4 #3	4 #5	7 #4	7 #2	12 #3	12 #2	18 #4	18 #6	22 #5	22 #6	25 #2	25 #6
Abditodentrix pseudothalmanni	6	0	0	0	0	4	0	0	0	0	1	0	0	0	0
Allogromia sp. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Allogromia sp. *2*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ammobaculites cf. *A. agglutinans*	1	3	14	0	3	209	82	832	211	54	174	0	0	0	15
Aubignyna hamblensis	4	2	0	0	0	13	0	45	0	0	0	0	0	0	0
Bathysiphon filiformis	0	0	0	0	0	0	0	0	77	13	14	0	0	70	0
Bolivina ordinaria	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bolivina pseudoplicata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bolivina spathulata	402	20	5	0	0	0	0	0	0	0	103	17	1	19	51
Bolivina subangularis lineata	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bolivina variabilis	0	0	0	1	0	0	0	0	101	488	128	330	462	70	484
Bolivinellina pseudopunctata	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Brizalina lowmini	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Bulimina aculeata	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bulimina marginata	2	2	1	0	0	24	0	0	0	0	0	0	0	0	0
Cassidulina carinata	114	14	26	0	0	0	0	0	0	0	0	0	0	0	0
Cassidulina obtusa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cibicides cf. *C. umbonatus*	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cibicides sp.	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
Cribrostomoides sp.	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0
Cyclammina cancellata	0	2	4	0	0	0	0	0	0	0	0	0	0	42	0
Dentalina sp.	4	0	0	0	0	0	0	104	14	22	0	0	0	0	0

	in situ			experimental growth temperature (°C)											
340 m cont.	dead	stained	additional stained	4 #3	4 #5	7 #4	7 #2	12 #3	12 #2	18 #4	18 #6	22 #5	22 #6	25 #2	25 #6
Eggerella advena	0	0	0	0	0	0	0	104	14	22	0	0	0	0	0
Eggerelloides scaber	0	0	0	0	0	0	0	102	0	0	0	0	0	0	0
Elphidium cf. *E. oceanensis*	0	0	0	0	0	0	0	3	6	0	0	0	0	0	0
Elphidium excavatum	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Eratidus foliaceus	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Evolvocassidulina bradyi	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Fursenkoina complanata	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Globobulimina turgida	3	0	5	0	0	0	0	0	0	0	0	0	0	0	0
Globulina minuta	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0
Globulotuba sp.	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gyroidina orbicularis	0	0	0	0	4	7	0	0	0	86	0	167	0	0	0
Juvenile Cribrostomoides sp.	0	0	0	0	0	28	0	0	0	0	0	0	0	0	0
Juvenile Melonis sp.	40	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Leptohalysis scottii	0	0	0	24	143	7	0	91	0	30	0	0	0	0	8
Nonion commune	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nonionella auricula	15	2	3	0	0	0	0	0	0	6	0	0	0	0	7
Nonionellina labradorica	0	0	0	0	0	0	0	38	0	0	0	0	0	0	0
Procerologena sp.	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Prolixoplecta parvula	0	1	6	2	0	0	3	490	299	391	484	0	27	19	206
Quinqueloculina cf. *Q. bosciana malayensis*	0	0	0	0	0	0	0	178	0	0	0	0	0	0	0
Quinqueloculina stalkeri	0	0	0	4	6	7	0	0	0	0	0	0	0	0	0
Reophax cf. *R. gaussicus*	11	8	9	0	0	0	0	0	0	0	0	0	0	0	0

	in situ			experimental growth temperature (°C)											
340 m cont.	dead	stained	additional stained	4 #3	4 #5	7 #4	7 #2	12 #3	12 #2	18 #4	18 #6	22 #5	22 #6	25 #2	25 #6
Reophax cf. *R. subfusiformis*	0	0	0	0	4	0	0	0	0	0	0	0	0	0	4
Reophax curtus	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0
Rosalina cf. *R. floridana*	0	0	0	0	0	2	0	53	38	44	58	0	46	0	0
Stainforthia fusiformis	135	17	5	0	0	0	0	0	0	0	0	0	0	0	0
Textularia cf. *T. skagerakensis*	3	2	5	3	0	12	0	8	8	0	0	0	15	3	0
Textularia earlandi	0	0	0	0	0	0	0	20	0	0	0	0	411	0	0
Trifarina bradyi	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trifarina sp.	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trochammina advena	0	0	0	0	56	0	197	0	95	0	0	16	0	0	56
Paratrochammina challengeri	0	0	0	0	7	0	33	0	61	0	0	0	0	0	7
Trochammina inflata	0	0	0	0	0	152	0	0	0	0	0	0	0	0	0
Deuterammina rotaliformis	0	0	0	288	0	0	0	0	0	0	0	0	0	288	0
Uvigerina peregrina	0	0	0	0	315	0	0	0	51	0	0	0	0	0	315
Veleroninoides cf. *V. wiesneri*	0	0	6	0	0	0	0	0	0	0	0	0	90	0	0

	in situ			experimental growth temperature (°C)											
740 m	dead	stained	additional stained	4 #3	4 #6	7 #2	7 #6	12 #5	12 #1	18 #3	18 #4	22 #2	22 #1	25 #4	25 #6
Abditodentrix pseudothalmanni	2	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Ammodiscus sp.	1	5	4	0	0	0	0	0	0	0	0	0	0	0	0
Bathysiphon filiformis	0	0	0	0	0	121	153	0	77	0	3	0	0	0	0
Bolivina albatrossi	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bolivina hirsuta	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Bolivina pseudoplicata	0	0	0	0	0	0	0	0	0	0	9	0	0	0	0
Bolivina sp.	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bolivina spathulata	15	0	0	0	0	0	7	291	0	0	0	0	0	0	55
Bolivina variabilis	0	0	0	0	0	0	0	0	0	4	4	40	48	1	0
Bolivinellina pseudopunctata	0	0	0	0	0	0	0	0	5	0	33	0	0	0	0
Brizalina lowmani	0	0	0	0	0	1	1	546	177	4	356	662	498	614	0
Bulimina aculeata	47	8	7	0	0	0	0	0	0	0	0	0	0	0	0
Bulimina marginata	10	0	0	0	0	1	2	0	24	0	0	0	0	0	0
Bulimina mexicana	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Buliminella elegantissima	0	0	0	0	0	0	0	0	0	0	3	9	0	0	0
Cassidulina teretis	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cornuloculina inconstans	0	0	0	0	0	0	0	0	33	0	0	0	0	0	0
Cribrostomoides jeffreysii	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Cyclammina cancellata	0	4	10	0	0	0	0	0	0	0	0	0	0	0	0
Eggerella advena	0	0	0	0	0	0	0	160	133	0	21	0	0	0	0
Elphidium excavatum	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Epistominella exigua	35	9	0	0	0	0	0	0	0	0	0	0	0	0	0

	in situ			experimental growth temperature (°C)											
740 m cont.	dead	stained	additional stained	4 #3	4 #6	7 #2	7 #6	12 #5	12 #1	18 #3	18 #4	22 #2	22 #1	25 #4	25 #6
Fursenkoina complanata	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gyroidina orbicularis	0	0	0	0	0	0	0	0	26	0	2	0	0	0	0
Hormosinella sp.	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
Islandiella islandica	69	8	0	0	0	0	3	0	0	0	0	0	0	0	0
Trochammina cf. *T. inflata*	0	0	0	0	0	0	12	0	0	0	0	0	0	0	0
Karreriella bradyi	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Leptohalysis scottii	0	0	0	1	0	2	2	0	11	15	23	0	0	0	0
Martinottiella sp.	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Melonis sp.	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nonion commune	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nonionella iridea	5	1	7	0	0	0	3	0	35	0	0	0	0	0	0
Plectofrondicularia sp.	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0
Procerologena sp.	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Prolixoplecta parvula	0	0	0	0	0	0	0	0	30	0	13	0	0	0	0
Reophax cf. *R. Bradyi*	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Reophax fusiformis	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0
Rosalina cf. *R. floridana*	0	0	0	0	0	0	0	1	0	147	45	0	0	97	0
Saccammina sp. 1	0	0	0	4	23	10	0	45	0	0	0	0	0	0	0
Saccammina sp. 2	0	0	0	0	0	27	0	0	0	0	0	0	0	0	0
Saccammina sphaerica	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Stainforthia fusiformis	61	0	0	0	0	0	0	0	0	0	0	0	0	0	0

	in situ			experimental growth temperature (°C)											
740 m cont.	dead	stained	additional stained	4 #3	4 #6	7 #2	7 #6	12 #5	12 #1	18 #3	18 #4	22 #2	22 #1	25 #4	25 #6
Texrularia earlandi	0	0	0	0	0	0	0	0	0	27	0	0	0	0	84
Trifarina carinata	415	27	20	0	0	0	0	0	0	0	0	0	0	0	0
Trochaminna cf. *T. advena*	0	0	15	0	0	0	0	0	15	0	0	0	0	0	0
Trochamminella sp.	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Unidentified discorbid	0	0	0	0	0	0	0	0	0	28	3	0	0	0	0
Unidentified juvenile Rotalid	0	0	0	0	0	0	9	0	0	0	0	0	0	0	0
Unknown Allogromia sp.	0	0	0	0	0	22	0	0	0	0	0	0	0	0	0
Glomospira charoides	0	2	4	0	0	0	0	0	0	0	0	0	0	0	0
Uvigerina peregrina	5	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Valvulineria glabra	46	2	9	0	0	0	0	0	0	0	0	0	0	0	0
Wiesnerella auriculata	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0

	in situ			experimental growth temperature (°C)							
2200 m	dead	stained	additional stained	4 #5	4 #4	7 #7	7 #5	22 #5	22 #6	25 #6	25 #5
Ammodiscus sp.	0	3	0	0	0	0	0	0	0	0	0
Bathysiphon filiformis	0	0	0	0	16	0	4	8	0	5	0
Bolivina cf. *B. pusilla*	6	0	0	0	0	0	0	0	0	0	0
Bolivina hirsuta	8	0	0	0	0	0	0	0	0	0	0
Bolivina sp.	4	1	0	0	0	0	0	0	0	0	0
Bolivina spathulata	20	0	0	0	0	0	0	0	0	0	0
Brizalina lowmani	0	0	0	0	1	0	0	0	1	0	1
Bulimina mexicanas	7	1	1	0	0	0	0	0	0	0	0
Buzasina ringens	3	0	4	0	0	0	0	0	0	0	0
Cassidulina obtusa	0	0	0	0	0	0	4	0	1	3	0
Cibicidoides bradyi	2	0	0	0	0	0	0	0	0	0	0
Cribrostomoides jeffreysii	0	0	17	0	0	0	0	0	0	0	0
Cyclammina cancellata	0	0	11	0	0	0	0	0	0	0	0
Triloculina tricarinata	3	0	0	0	0	0	0	0	0	0	0
Elphidium excavatum	16	0	0	0	0	0	0	0	0	0	0
Epistomina elegans	31	0	3	0	0	0	0	0	0	0	0
Epistominella exigua	22	4	0	0	0	0	0	0	0	0	0
Fursenkoina complanata	263	6	0	0	0	0	0	0	0	0	0
Globobulimina sp.	13	2	0	0	0	0	0	0	0	0	0
Globobulimina turgida	10	0	0	0	0	0	0	0	0	0	0
Gyroidina orbicularis	38	2	3	0	0	0	0	0	0	0	0
Hormosinella sp.	0	1	2	0	0	0	0	0	0	0	0
juvenile *Trochammina* sp.	0	0	0	0	0	0	2	0	0	0	0
juvenile *Trochammina* sp. *2*	0	0	0	0	0	0	0	0	0	0	1
Karreriella bradyi	5	0	0	0	0	0	0	0	0	0	0
Leptohalysis scottii	0	0	1	1	6	7	12	0	0	0	0

	in situ			experimental growth temperature (°C)							
2200 m cont.	dead	stained	additional stained	4 #5	4 #4	7 #7	7 #5	22 #5	22 #6	25 #6	25 #5
Melonis sp.	11	0	0	0	0	0	0	0	0	0	0
Nonion commune	3	0	0	0	0	0	0	0	0	0	0
Nonionella iridea	51	0	0	2	0	3	0	0	0	0	0
Paratrochammina sp.	0	0	1	0	0	0	0	0	0	0	0
Quinqueloculina sp.	4	0	0	0	0	0	0	0	0	0	0
Reophax cf. *R. Bradyi*	1	0	0	0	0	0	0	0	0	0	0
Rhabdammina sp.	0	4	14	0	0	0	0	0	0	0	0
Spiroloculina sp.	2	0	0	0	0	0	0	0	0	0	0
Stainforthia fusiformis	107	2	0	1	0	0	0	0	0	0	0
Stainforthia sp.	0	0	0	1	0	4	0	0	2	2	0
Textularia cf. *T. skagerakensis*	3	0	0	0	0	0	0	0	0	0	0
Trifarina carinata	16	0	0	0	0	0	0	0	0	0	0
Paratrochammina challengeri	0	2	14	0	0	0	0	0	0	0	0
Glomospira charoides	0	0	1	0	0	0	0	0	0	0	0
Uvigerina peregrina	155	4	5	0	0	0	0	0	0	0	0

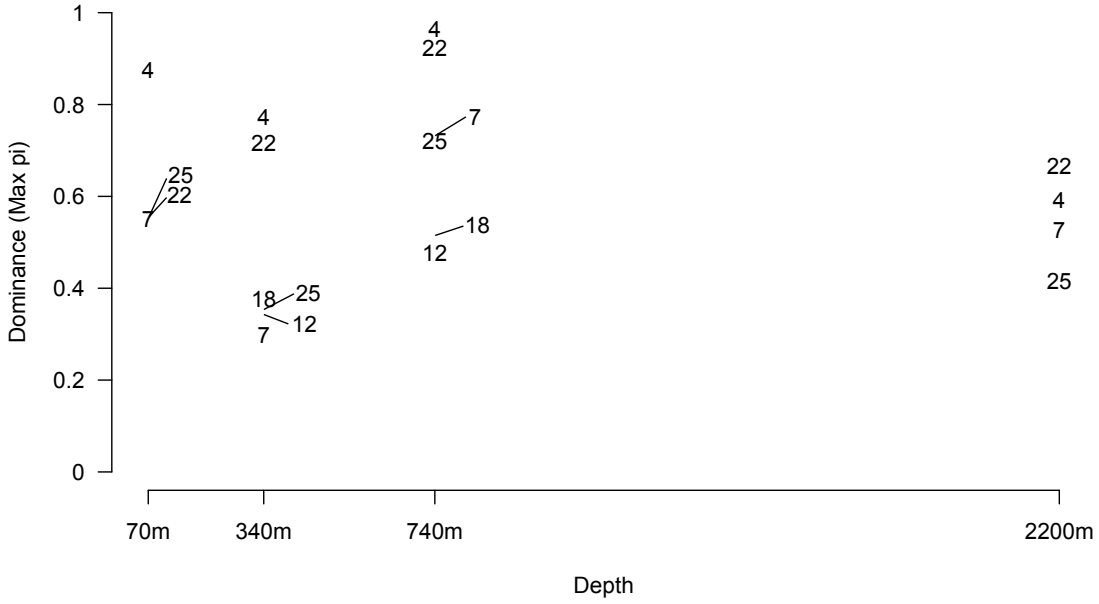
APPENDIX II: DOMINANCE CALCULATION COMPARISON

Literature has suggested Simpson's λ (Simpson, 1949), the Berger-Parker index (Hayek & Buzas, 2013), Pielou's J (Pielou, 1966), and E1, E2, and E3 (Hayek & Buzas, 2010) to calculate dominance/evenness. For this study all of these evenness/dominance indices were considered and compared. Each index was calculated using Primer (Clarke, 2006) then plotted by site and by temperature using R (R Development Core Team, 2011) for comparison. Equations are as follows: Simpson's $\lambda=\sum_{i=1}^{R} p_i^2$, Berger-Parker index= p_i max $=n_{max}/n$, 1-Pielou's J=1-(Shannon's $H^1/\ln(S)$), E1= e^H/S, E2=$1/\lambda S$, and E3=$1/\lambda e^H$.

The Berger-Parker index was able to identify two samples from the experimental assemblages that had clear dominance (740 m 22 °C and 740 m 4 °C). 1-Pielou's J identified the two samples with high dominance. However, Pielou's J uses ln(S) in the denominator and was not used because this makes it difficult to compare samples with large differences in S with high dominance. Simpson's λ has been mentioned as an estimate of dominance but may better suited as a diversity measure because it is the probability that two individuals drawn randomly from a population will belong to the same species. Simpson's λ identified the two samples that had clear dominance but does not seem as easy to interpret and compare as the Berger-Parker index. The other 3 indices used were E1, E2, and E3 that are all evenness calculations based on Hill's diversity indices. E1 and E2 both use S in the denominator which makes it difficult to interpret the results. Samples approach zero as the number of species increases regardless of how even/dominant the sample is. E3 ($1/\lambda e^H$) seemed to be the best of the evenness

calculations in terms of interpretation and was able to express the two samples that had clear dominance. E3 however did not seem to show a large difference between dominant and even samples which makes it more difficult to use for comparison. The Berger-Parker index (p_i max) was chosen because the formula shows dominance with a simplistic easy to interpret value and was the most unbiased measure of dominance.

Figure 1: Plots of dominance calculated using the Berger-Parker index (p_i max=n_{max}/n) Values closer to 1 display higher dominance.


Dominance (Max pi)
1
0.8
0.6
0.4
0.2
0
70m
340m
740m
2200m
Depth

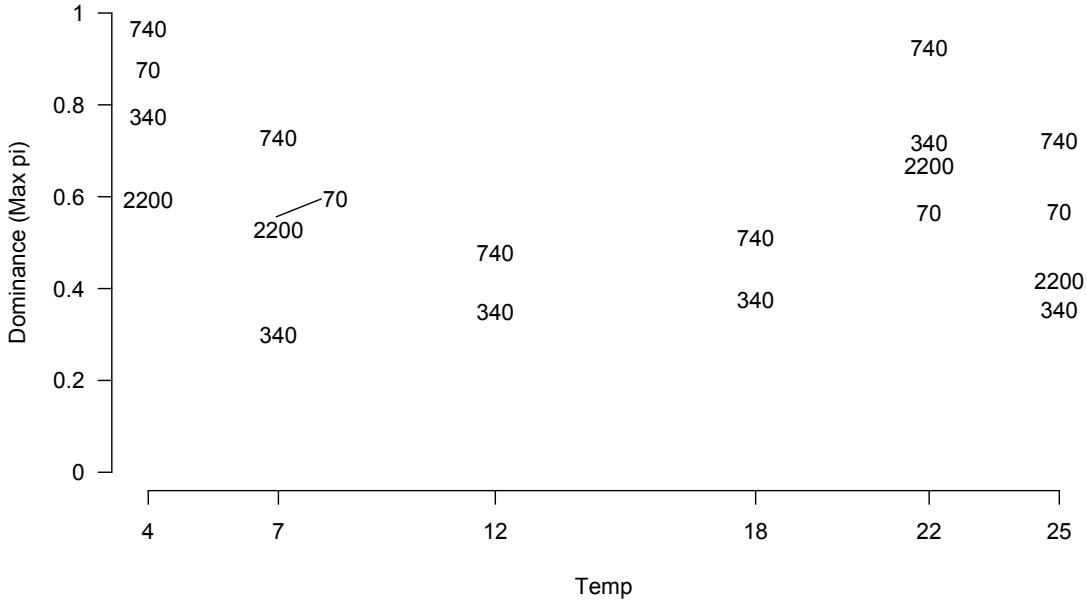
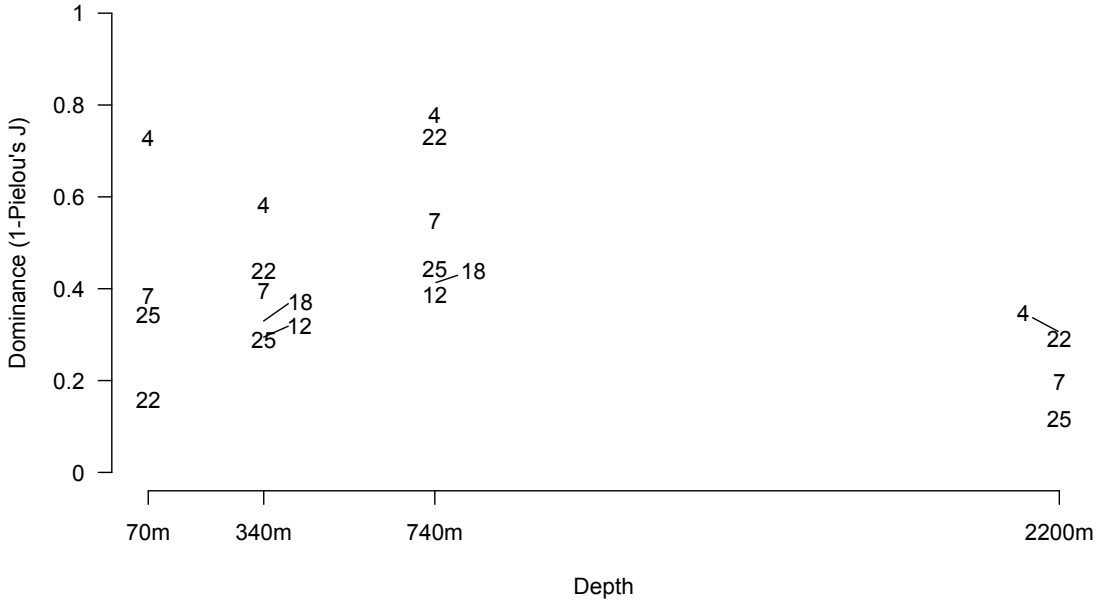

Dominance (Max pi)
1
0.8
0.6
0.4
0.2
0
4
7
12
18
22
25
Temp

Figure 2: Plots of dominance calculated using 1-Pielou's J=1-(Shannon's H^1/ln(S)). Values closer to 1 display higher dominance.


Dominance (1-Pielou's J)
1
0.8
0.6
0.4
0.2
0
70m
340m
740m
2200m
Depth

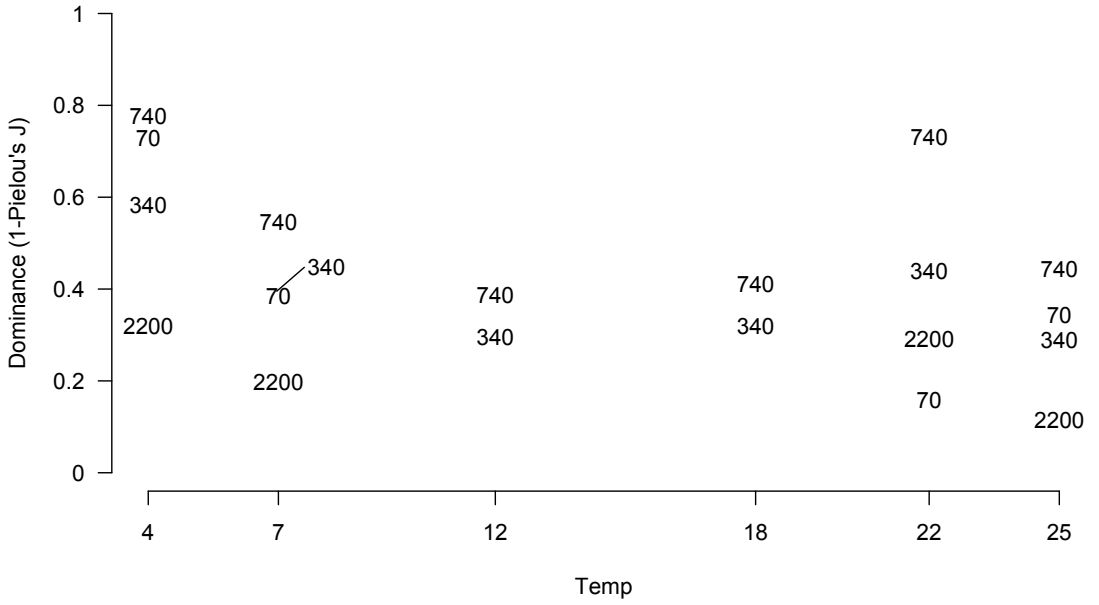
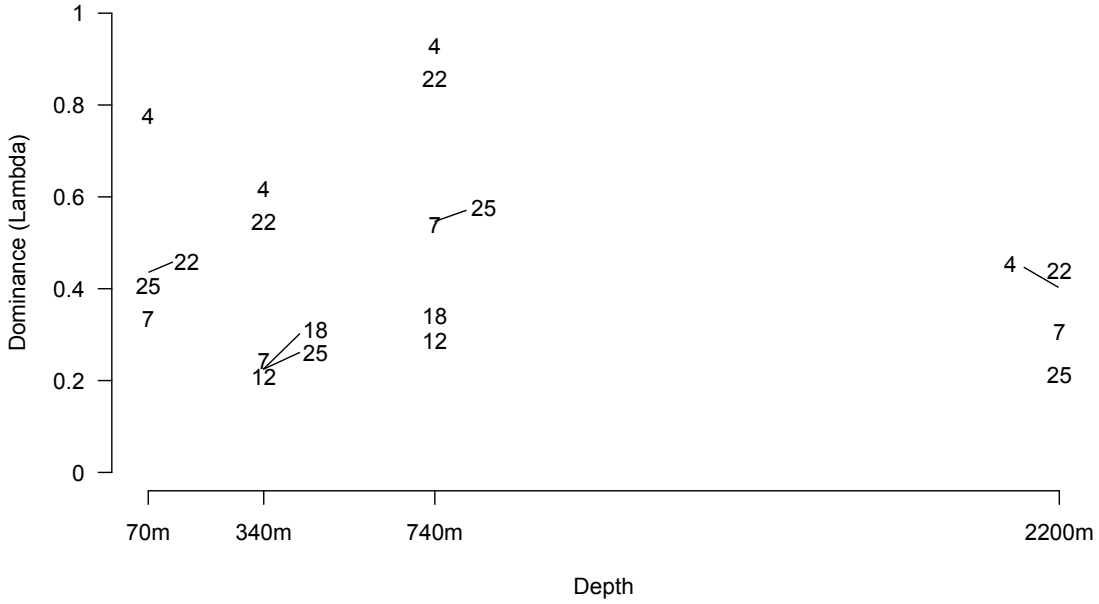

Dominance (1-Pielou's J)
1
0.8
0.6
0.4
0.2
0
4
7
12
18
22
25
Temp

Figure 3: Plots of dominance calculated using Simpson's $\lambda = \sum_{i=1}^{R} p_i^2$
Values closer to 1 display higher dominance.


Dominance (Lambda)
1
0.8
0.6
0.4
0.2
0
4
22
4
4
22
25
7
22
25
7
18
25
12
18
12
4
22
7
25
70m
340m
740m
2200m
Depth

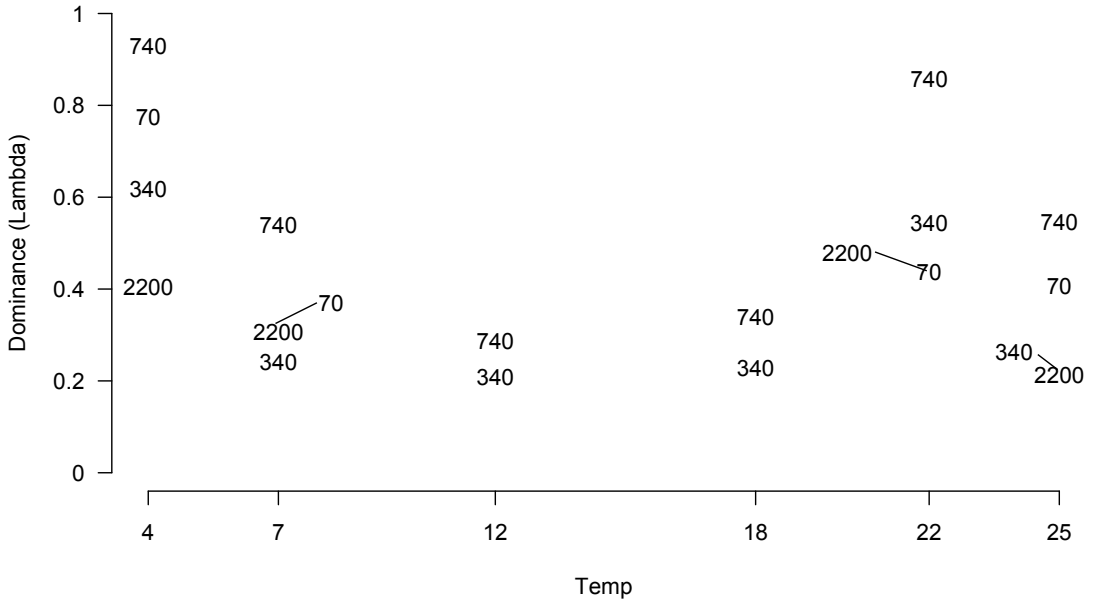
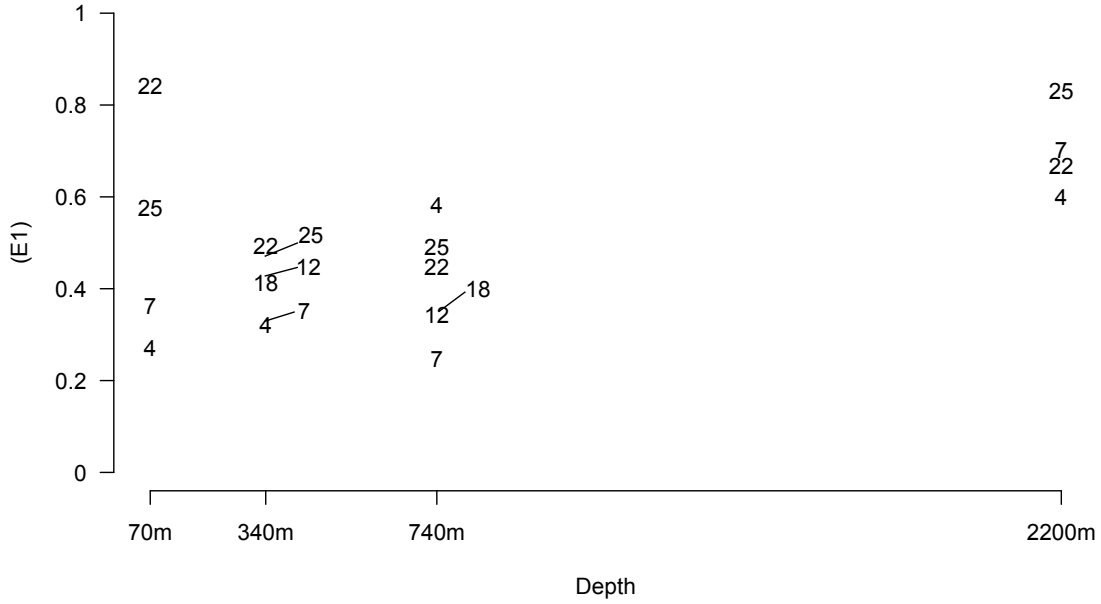

Dominance (Lambda)
1
0.8
0.6
0.4
0.2
0
740
70
340
2200
740
70
2200
340
740
340
740
340
740
2200
70
70
340
2200
4
7
12
18
22
25
Temp

Figure 4: Plots of evenness calculated using $E1=e^{H}/S$.


1
0.8
0.6
0.4
0.2
0
(E1)
22
25
7
22
4
25
22
25
12
18
7
4
4
25
22
18
12
7
70m
340m
740m
2200m
Depth

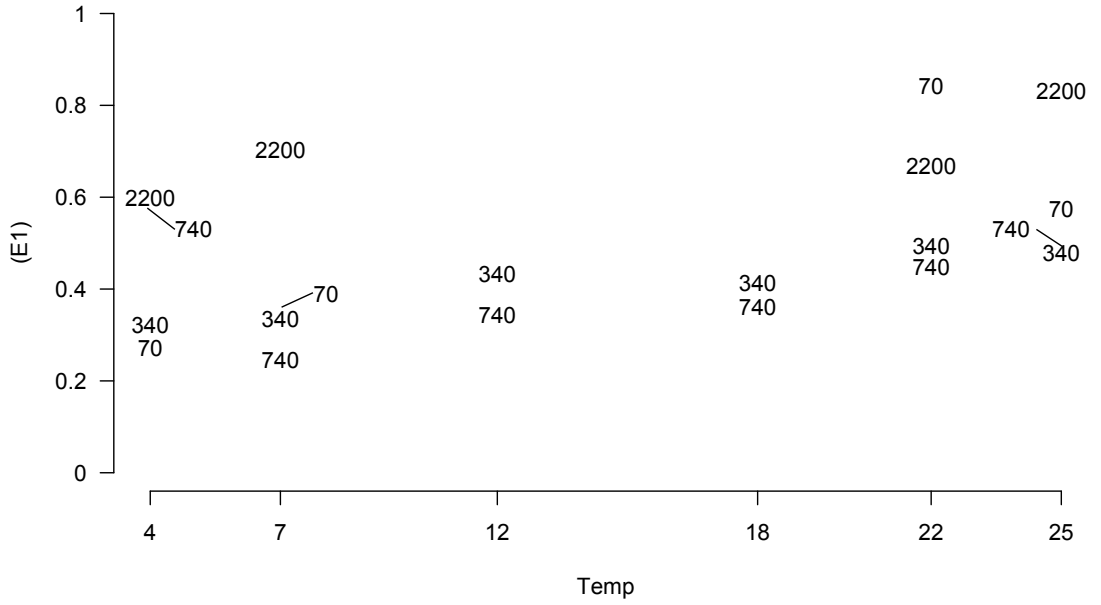
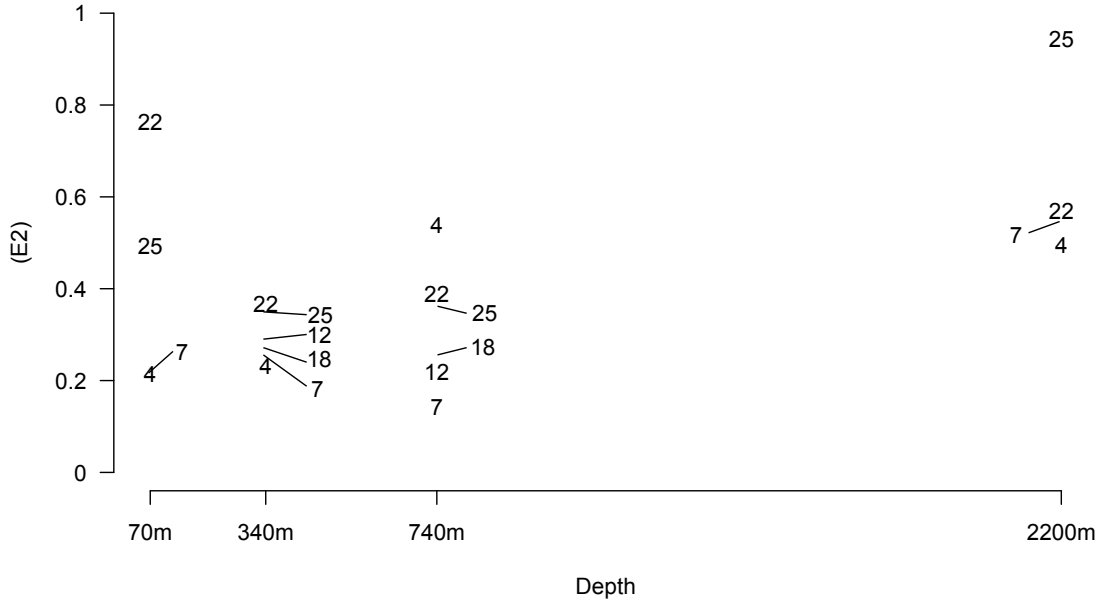

1
0.8
0.6
0.4
0.2
0
(E1)
70
2200
2200
2200
740
2200
70
740
340
740
340
340
740
340
740
70
340
70
340
740
4
7
12
18
22
25
Temp

Figure 5: Plots of evenness calculated using $E2=1/\lambda S$


1
0.8
0.6
0.4
0.2
0
(E2)
22
25
4
22
25
12
18
7
4
22
25
18
12
7
7
22
4
25
70m
340m
740m
2200m
Depth

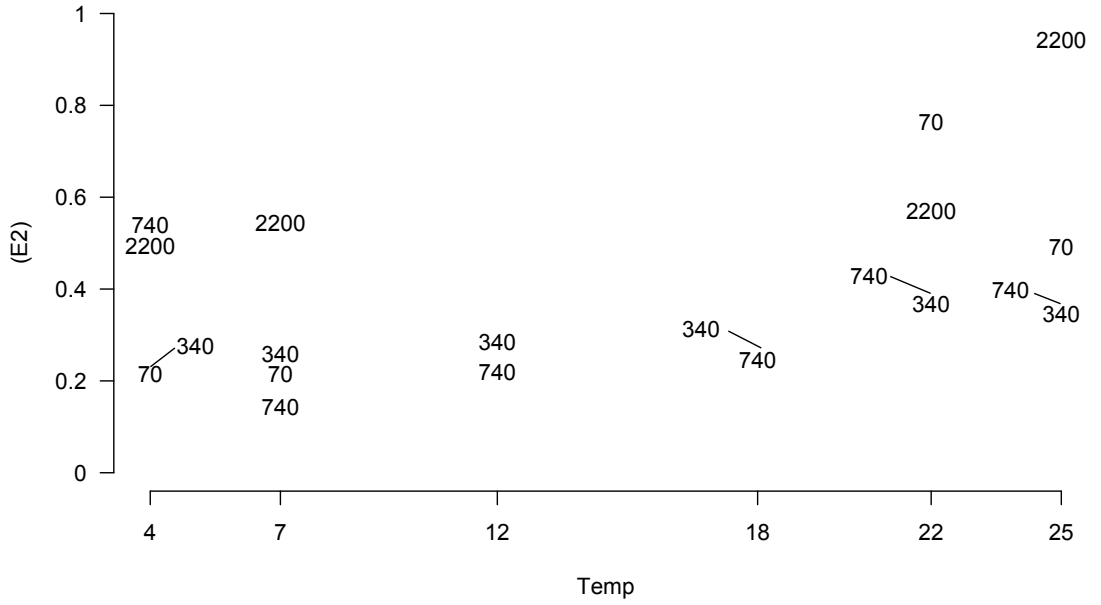
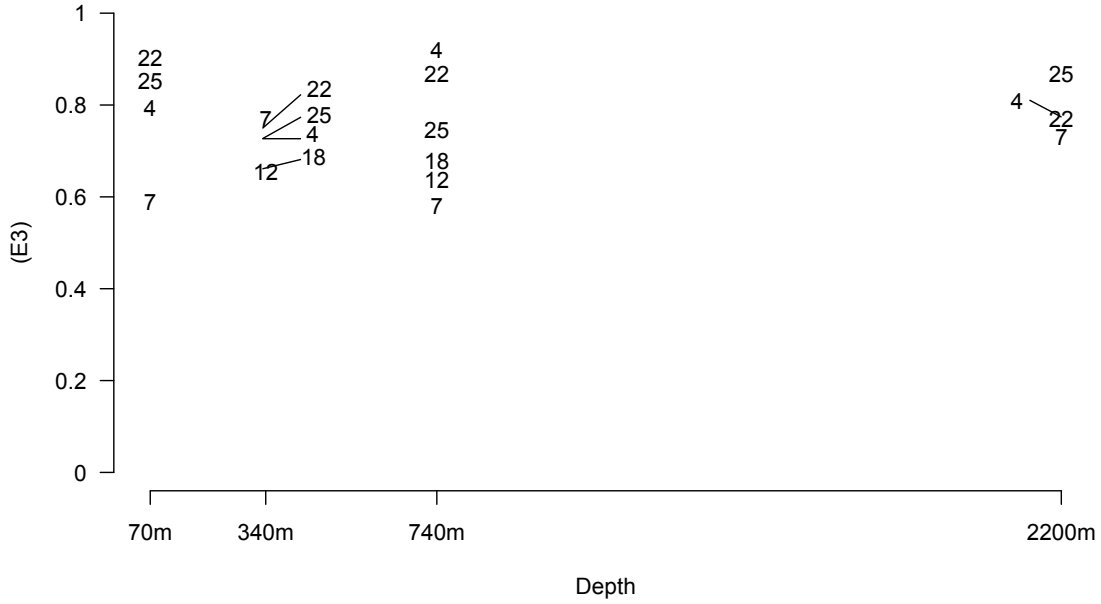
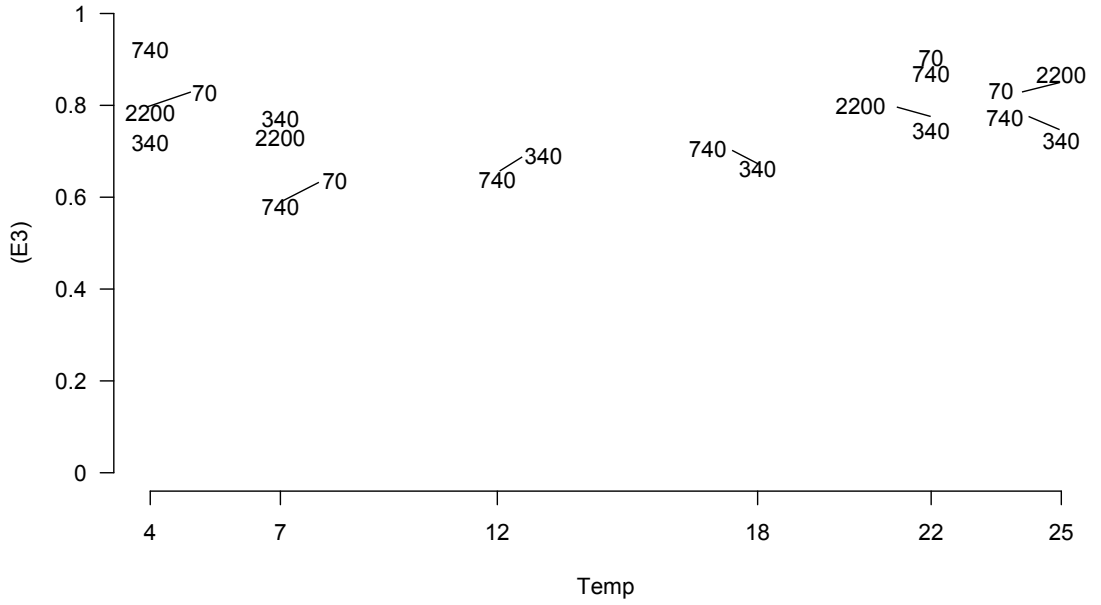

1
0.8
0.6
0.4
0.2
0
(E2)
740
2200
340
70
2200
340
70
740
340
740
340
740
70
2200
740
340
740
340
2200
70
4
7
12
18
22
25
Temp

Figure 6: Plots of evenness calculated using $E3=1/\lambda e^{H}$


1
0.8
0.6
0.4
0.2
0
(E3)
22
25
4
7
22
25
4
18
12
7
4
22
25
18
12
7
25
4
22
7
70m
340m
740m
2200m
Depth


1
0.8
0.6
0.4
0.2
0
(E3)
740
70
2200
340
340
2200
70
740
340
740
340
740
70
740
2200
340
70
2200
740
340
4
7
12
18
22
25
Temp