# Habitat and geochemical characterization of living planktonic foraminifera in the Caribbean

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Kiel, 20.12.2016

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# Abstract

Planktonic foraminifera are unicellular organisms that precipitate their calcite tests from the seawater in which they live. The distribution patterns of species, as well as the trace elemental and isotopic composition of the tests, reflect the environmental conditions of the ambient seawater. Thus, fossil tests of planktonic foraminifera from sediments are widely used to reconstruct past ocean temperature and salinity variations. Studies on living planktonic foraminifera collected under natural conditions are essential for the interpretation of fossil data assessing the relationship between living specimens and *in-situ* ocean parameters. This study focused on the habitat patterns of tropical and subtropical living foraminifera and the isotopic ($\delta^{18}O$ and $\delta^{13}C$) and Mg/Ca compositions of their tests. Plankton net samples were collected from the surface to a maximum 400 m water depth in the Caribbean Sea, Gulf of Mexico, Florida Straits and Santaren Channel. The data of living specimens were related to ambient seawater conditions (temperature, salinity, chlorophyll concentration and $\delta^{18}O_{seawater}$) and compared to fossil tests retrieved from the underlying surface sediments.

Foraminiferal census data indicate that living planktonic foraminiferal assemblage compositions have a strong relationship to seawater temperatures. Species-specific living depths were determined, and single species point to an ontogenetic migration within the water column. In spring 2009, a high standing stock was observed in the eastern Caribbean Sea close to a transient mega-patch of high chlorophyll concentrations. In contrast, high turbidity with low salinity was likely responsible for the sparseness of planktonic foraminifera in the Gulf of Paria and close to the Orinoco river plume. The species compositions of the living assemblages are similar to the fossil assemblages from underlying surface sediments, indicating no major change over the last millennia. Exceptions are the observed decline of *Globigerinoides ruber* (white) since the late 1990s off the coast of Puerto Rico, and a large number of *Globorotalia ungulata* in the Florida Straits in spring 2009, indicating a unique seasonal occurrence or a distinct increase in its population density. Further, different proportions in the foraminiferal assemblage composition point to seasonal fluctuations in the abundances of single species, probably related to riverine outflow, i.e. variable nutrient input, or temperature variability. Beside these seasonal effects, the study also shows that short storm events, in particular hurricanes, affect the habitat of planktonic foraminiferal populations over several days.

Analyses of stable oxygen isotope compositions and Mg/Ca ratios of planktonic foraminifera show that temperature strongly influences the isotopic fractionation of oxygen and the incorporation of $Mg^{2+}$ in foraminiferal tests. In general, increasing $\delta^{18}O$ values and decreasing Mg/Ca ratios are related to lower *in-situ* temperatures of the ambient seawater. Mg/Ca-values from *Globigerinoides sacculifer* in fossil tests are seasonally biased. In the Caribbean Sea, the Mg/Ca-temperature of *G. sacculifer* point to a high accumulation rate of empty tests on the seafloor in early spring, and in the Florida Straits later in the year, most likely in May. Combined $\delta^{18}O$ and Mg/Ca in foraminiferal tests was used to estimate $\delta^{18}O$ of the seawater, which is used as proxy for seawater salinity. The surface dweller *G. sacculifer* shows a positive linear relationship between the estimated $\delta^{18}O_{seawater}$ and *in-situ* $\delta^{18}O_{seawater}$ as well as salinity. However, the study also indicates that "vital effects" due to symbiont activity and test-growth strongly influence the isotopic fractionation of oxygen and the incorporation of $Mg^{2+}$ in foraminiferal tests. Negative disequilibrium values between the ambient seawater and $\delta^{18}O$ of foraminiferal tests indicate most likely symbiont activity. Mg/Ca compositions reveal a large scatter in samples of living specimens. It might be related to high and low $Mg^{2+}$ bands across single chambers and point to a variable incorporation of $Mg^{2+}$ during the calcification process.

# Kurzfassung

Planktonforaminiferen sind einzellige Lebewesen, die ein Gehäuse aus Kalzit bilden. Sowohl die Artenverteilung im Ozean als auch die Zusammensetzung der stabilen Isotope und Spurenelemente in den Gehäusen reflektieren die Umweltparameter im umgebenden Meerwasser. Aus diesem Grund werden fossile Planktonforaminiferen aus Sedimenten weltweit genutzt, um Temperatur- und Salinitäts-Schwankungen der Ozeane in der geologischen Vergangenheit zu rekonstruieren. Untersuchungen an lebenden Planktonforaminiferen, welche in ihrer natürlichen Umgebung gesammelt werden, sind essenziell für die Interpretation fossiler Daten, da sie den Zusammenhang zwischen lebenden Foraminiferen und *in-situ* gemessenen Umweltparametern widerspiegeln. Diese Studie befasst sich mit den Habitaten von lebenden tropischen und subtropischen Foraminiferen und untersucht die stabilen Isotopen ($\delta^{18}$O und $\delta^{13}$C) und Mg/Ca-Verhältnisse in den Gehäusen. Das Untersuchungsgebiet umfasst die Karibik, den Golf von Mexiko, die Florida Straße und den Santaren Channel. Plankton-Netzfänge wurden an der Oberfläche bis zu maximal 400 m Wassertiefe durchgeführt. Die Ergebnisse wurden mit den Umgebungsparametern im Meerwasser (Temperatur, Salinität, Chlorophyll-Konzentration und $\delta^{18}$O) sowie den fossilen Foraminiferen aus Oberflächensedimenten naheliegender Stationen verglichen.

Die Zähldaten von lebenden Planktonforaminiferen zeigen einen starken Zusammenhang zwischen der Artenzusammensetzung und der umgebenden Wassertemperatur. Artenspezifische Habitattiefen konnten ermittelt werden. Einzelne Arten weisen auf eine ontogenetische Migration innerhalb der Wassersäule hin. Im Frühling 2009 wurde in der östlichen Karibik entlang eines Meeresgebietes mit hoher Chlorophyll-Konzentration im Oberflächenwasser eine hohe Populationsdichte von Foraminiferen gefunden. Im Gegensatz dazu war eine starke Trübung des Wassers im Zusammenspiel mit niedrigeren Salzgehalten im Golf von Paria und vor der Orinoco Mündung der wahrscheinlichste Grund für eine verringerte Populationsdichte. Die Artenzusammensetzung der lebenden und fossilen Foraminiferenvergesellschaftung ist sehr ähnlich und weist darauf hin, dass es keine wesentliche Veränderung in den letzten tausend Jahren gegeben hat. Ausnahmen bilden ein Rückgang in der Populationsdichte von *Globigerinoides ruber* (white) während der letzten Jahre an der Küste von Puerto Rico sowie viele Exemplare von *Globorotalia ungulata* in der Florida Straße im Frühling 2009. Diese Art zeigt vermutlich ein saisonales Vorkommen oder eine starke Zunahme der

Populationsdichte in den letzten Jahren. Prozentual unterschiedliche Zusammensetzungen zwischen den lebenden und fossilen Foraminiferenvergesellschaftungen deuten auf unterschiedliche saisonale Vorkommen der einzelnen Arten hin. Diese werden hauptsächlich durch saisonal wechselnde Umweltbedingungen (z.B. Nährstoffeintrag, Temperatur) beeinflusst. Neben einem saisonalen Effekt zeigt diese Studie auch, dass tropische Wirbelstürme das Habitat von Planktonforaminiferen für einige Tage stark beeinflussen können.

Analysen von stabilen Sauerstoffisotopen und Mg/Ca in Planktonforaminiferen zeigen, dass die Temperatur einen starken Einfluss auf das $\delta^{18}O$ und Mg/Ca Verhältnis im Gehäuse hat. Während sinkender *in-situ* Temperaturen steigen in der Regel die $\delta^{18}O$-Werte und Mg/Ca-Verhältnisse werden niedriger. Mg/Ca-Werte von fossilen *Globigerinoides sacculifer*-Gehäuse weisen auf unterschiedliche saisonale Vorkommen hin. So deuten die Mg/Ca-Temperaturen auf eine erhöhte Akkumulation von *G. sacculifer* auf dem Meeresboden am Frühlingsbeginn in der Karibik bzw. im Mai in der Florida Straße hin. Mithilfe kombinierter Messungen von stabilen Sauerstoffisotopen und Mg/Ca-Verhältnissen in Foraminiferen-Gehäusen können Sauerstoffisotopensignale des Meerwassers berechnet und als Proxy für die Salinität genutzt werden. Die flachlebende Art *G. sacculifer* zeigt einen positiven linearen Zusammenhang zwischen den berechneten $\delta^{18}O_{Meerwasser}$ und der *in-situ* gemessenen $\delta^{18}O_{Meerwasser}$-Werten sowie der Salinität. Aber die Studie zeigt ebenfalls, dass „Vitaleffekte", die höchstwahrscheinlich durch Symbionten-Aktivität und Wachstum erzeugt werden, einen großen Einfluss auf die Isotopenfraktionierung und den Einbau von $Mg^{2+}$ in das Gehäuse haben. Eine negative Abweichung des $\delta^{18}O$-Wertes der Foraminiferen zum umgebenden Meerwasser weist am wahrscheinlichsten auf Symbionten-Aktivität hin. Eine starke Streuung der Mg/Ca-Werte in lebenden Foraminiferen, sowie $Mg^{2+}$ Bänder mit wechselnder Konzentration in den einzelnen Kammern deuten auf einen unterschiedlichen Einbau von $Mg^{2+}$ in das Gehäuse während der Kalzifizierungsprozesse hin.

# CHAPTER 1

# Introduction

## 1.1 Motivation and main objectives of the study

Geochemical compositions (e.g. Mg/Ca or $\delta^{18}O$) in planktonic foraminiferal tests are widely used and established proxies for paleoceanographic studies to reconstruct temperature and salinity variabilities in the past ocean. However, Mg/Ca ratios in fossil foraminiferal tests reveal a high scatter in recent core top sediments (e.g. Caribbean Sea, Regenberg et al., 2006). This scatter infers unwanted uncertainties when applying Mg/Ca as palaeo-proxy and raises the question about the factors influencing the isotopic fractionation and incorporation of $Mg^{2+}$ in foraminiferal tests.

Numerous studies observed that planktonic foraminifera migrate vertically within the water column (Erez et al., 1991; Schiebel and Hemleben, 2005). These contributions linked the distribution pattern to different water mass properties and seasonal productivity (Hemleben et al., 1989; Schmuker and Schiebel, 2002; Jonkers and Kučera, 2015). Biological controlled processes, so called "vital effects", and environmental parameters (e.g. salinity, ocean pH) of the ambient seawater may modify the signals of Mg/Ca or stable isotope composition in foraminiferal calcite (e.g. Nürnberg, 1995; Spero and Lea, 1993; Regenberg et al., 2006; Spero et al., 2015). Yet, there is still need of further investigations to improve the reliability of palaeoceanographic reconstructions based on planktonic foraminifera. This applies to both, census counts of assemblages and trace-elemental or isotopic composition of their tests.

The current study focuses on habitat patterns and geochemical compositions (Mg/Ca, $\delta^{18}O$ and $\delta^{13}C$) of living planktonic foraminifera that were collected in the Caribbean Sea, the eastern Gulf of Mexico, Florida Straits and Santaren Channel. The data obtained strictly from living specimens were related to *in-situ* hydrographical measurements and compared to fossil tests from underlying surface sediments. The following major objectives and research questions are addressed:

(1) How is the vertical and horizontal distribution of living foraminiferal species in the Caribbean and which environmental parameters affect their distribution patterns?

(2) How strong is the "vital effect" under natural conditions, and what is the impact of environmental parameters on the fractionation of stable isotopes ($\delta^{18}O$ and $\delta^{13}C$) and incorporation of $Mg^{2+}$ in tests of the living foraminifera?

(3) Is there a difference between data of the living planktonic foraminifera collected in the water column and fossil tests obtained from surface sediments in i) the assemblage composition and ii) geochemical composition of the tests?

To assess these objectives, plankton tows, sediment and water samples were analysed which were collected during the cruises SO164 (RV Sonne) in 2002, M78/1 (RV Meteor) in 2009, M94 and M95 in 2013, and during a sampling campaign off Puerto Rico in 2012.

**Chapter 2** of this thesis describes the habitat patterns and life cycles of living planktonic foraminiferal populations collected in the surface and subsurface waters (max. 400 m water depth), which were compared to the fossil assemblages from surface sediments. The study also determined the influence of environmental parameters (temperature, salinity and chlorophyll-*a* concentration) on the assemblage composition and distribution.

**Chapter 3** focuses on the geochemical (isotopic) composition ($\delta^{18}O$ and Mg/Ca) of foraminiferal tests. Species-specific $\delta^{18}O$-paleotemperature equations and Mg/Ca calibrations were applied on living foraminifera and compared to measured *in-situ* seawater properties (temperature, salinity and $\delta^{18}O_{seawater}$) and to $\delta^{18}O$ and Mg/Ca values of fossil tests.

**Chapter 4** presents the dynamics of planktonic assemblages off the southern coast of Puerto Rico during two weeks in autumn 2012. Hurricane "Sandy" passed the area by chance and allowed to assess the impact of this event to the planktonic fauna. Furthermore, the isotopic signal ($\delta^{18}O$ and $\delta^{13}C$) in tests of *Globigerinoides ruber* (pink) was analysed. The results of this study were compared to measured *in-situ* environmental parameters and to an earlier study carried out in 1994/1995 at the same sampling sites.

**Chapter 5** describes an observation that was made during processing of the plankton net samples. Small holes in tests of living planktonic foraminifera indicate borings of predators, which attack the foraminifera in the open ocean.

## 1.2 Declaration of contribution

Basic ideas and research questions of Chapter 2 and Chapter 3 are based on the project proposal to the DFG (Deutsche Forschungsgemeinschaft): "Geochemical characterisation of living planktonic foraminifera in the Caribbean" (SCHO605/8-1, Applicants: Joachim Schönfeld and Dirk Nürnberg).

### Chapter 2:  Habitats of living planktonic foraminifera in the Caribbean

*Statement:*

I collected the samples on RV Meteor cruises M94 and M95. Joachim Schönfeld, Margret Bayer and Julia Schwab collected the samples on RV Meteor cruise M78/1. I picked the foraminifera of all samples with help of student assistants. All foraminifera were identified and counted by myself. I interpreted the data and wrote the manuscript. Joachim Schönfeld helped improving and revising the manuscript.

### Chapter 3:  Mg/Ca and $\delta^{18}$O in living planktonic foraminifera from the Caribbean, Gulf of Mexico and Florida Straits

*Statement:*

Foraminiferal tests were identified and selected by myself. I cleaned and prepared all foraminiferal tests for laser ablation and stable isotope analyses by myself. LA-ICP-MS derived element/Ca ratios were measured by myself with support from Ed Hathorne, Jan Fietzke and Steffanie Nordhausen. Nadine Gehre helped cleaning the bulk samples and measured the samples on the ICP-OES. Fynn Wulf and Sebastian Fessler measured $\delta^{18}O_{calcite}$ and $\delta^{13}C_{calcite}$ in foraminiferal tests. The laboratory of GeoZentrum Nordbayern carried out $\delta^{18}O_{seawater}$ and $\delta^{13}C_{DIC}$. I interpreted the data with major input of Dirk Nürnberg. I wrote the manuscript by myself. Dirk Nürnberg, Joachim Schönfeld and Ed Hathorne discussed the results and helped improving the manuscript.

### Chapter 4: Short and long-term dynamics of planktonic foraminiferal assemblages off Puerto Rico (Caribbean Sea)

*Statement:*

I designed this study together with Joachim Schönfeld and pursued it in cooperation with the working group of Michal Kučera (MARUM, Univ. Bremen). I collected all samples by myself with help of Agnes Weiner during a sampling campaign in October-November 2012. Planktonic foraminifera were identified and counted by myself with support of Michal

Kučera. Joachim Schönfeld identified, counted and discussed the benthic foraminiferal assemblages. Fynn Wulf measured $\delta^{18}O_{calcite}$ and $\delta^{13}C_{calcite}$ in foraminiferal tests. The laboratory of Hydroisotop carried out $\delta^{18}O_{seawater}$ analyses. I interpreted the data and wrote the manuscript with major input of Joachim Schönfeld.

**Chapter 5: Predators of living planktonic foraminifera**

*Statement:* I wrote this chapter by myself with a few comments of Joachim Schönfeld.

## 1.3 Planktonic foraminifera

Planktonic foraminifera are marine protozoa with granuloreticulose pseudopodia, which precipitate a shell (test) of calcite carbonate ($CaCO_3$) (Fig. 1.1). They are abundant in the world oceans and important for the global marine carbonate production. On average 2.9 Gt yr$^{-1}$ $CaCO_3$ of planktonic foraminiferal tests is globally exported at 100 m water depth in the pelagic oceans (Schiebel, 2002). Of this 0.36–0.87 Gt yr$^{-1}$ $CaCO_3$ is estimated to accumulate on the seafloor.

The first appearance of the planktonic foraminifera is recorded in the early Jurassic. They descended from a benthic ancestor (Hart et al., 2003). It is assumed that they first gained a meroplanktonic lifestyle (i.e. partially benthic) before a holoplanktonic mode of life was established. Up to date, approximately 46 extant planktonic species with a holoplanktonic lifestyle and several cryptic genotypes have been described (e.g. Bé, 1967; Hemleben et al., 1989, Darling et al., 2009; Aurahs et al., 2011; Weiner, 2014).
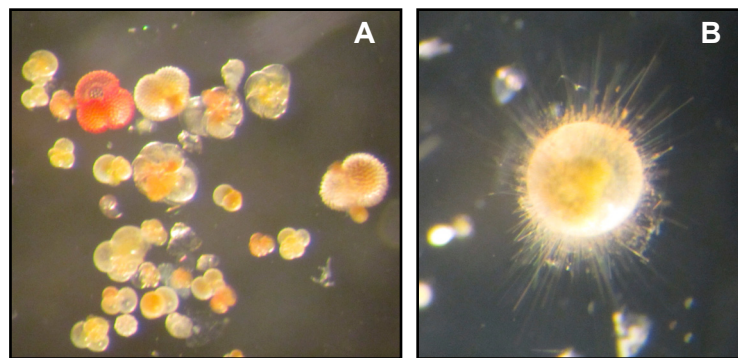


**Figure 1.1:** Photos of living planktonic foraminifera taken during RV Meteor cruises M94 and M95. **A)** Different species from a plankton sample. **B)** *Orbulina universa* with a spherical chamber. Brownish, yellowish and orange colours indicate the cytoplasm (Photo: T. Mildner and A. Jentzen).

The classification of planktonic foraminifera is based on characteristic morphological features of their test shape and wall texture. They build a multi chamber test with a mono- or bilamellar wall with pores, spines or pustules. During ontogeny, chambers are added to the test one by one (Hemleben et al., 1989). For chamber formation the external rhizopodial network of the foraminiferal cell built the primary organic membrane (POM), which is the site of the initial calcification process. For bilamellar test walls, calcite layers are secreted at the outer and inner side of the POM. By thickening of the new chamber additional calcite layers are also secreted over the outer surface of previous chambers (Bé, 1977; Hemleben et al., 1989). Three morphogroups with a bilamellar test are defined as:

macroperforate spinose (Globigerinoidea), macroperforate nonspinose (Globorotaloidea) and microperforate nonspinose (Heterohelicoidea) species. The species of the family Hastigerinidae produce a monolamellar test wall and can be considered as own taxonomic group (Schiebel and Hemleben, 2005).

Different feeding behaviours of planktonic foraminifera were observed. Spinose species are mainly carnivorous and prey on zooplankton (e.g. calanoid copepods), non-spinose species are mainly herbivorous and prefer phytoplankton (e.g. diatoms) (Spindler et al., 1984). Some species host algal symbionts such as dinoflagellates or chrysophycophytes, which provide energy from their photosynthesis (Gastrich, 1987). Photosymbionts restrict the planktonic habitat to the euphotic zone since they are dependent on light. Smaller foraminiferal tests and premature gametogenesis was observed for specimens grown under low irradiance or without symbionts (Bé et al., 1982). Furthermore symbionts alter the chemical foraminiferal microenvironment at the site of the calcification processes due to their photosynthesis-respiration rate (e.g. Jørgensen et al., 1985).

The distribution pattern of living planktonic foraminifera in the ocean is depending on factors such as temperature, salinity and food availability (Bé and Tolderlund, 1971). Five major faunal provinces are defined: polar, subpolar, transitional, subtropical and tropical, where the diversity shows increasing trend from the polar to the tropical regions (Bé, 1977). The highest standing stock is found in the upper water column (photic zone) and single species follow a distinct depth habitat depending on ecological factors, but they also migrate vertically in the water column during their life cycle (Schiebel and Hemleben, 2005). Solely sexual reproduction has been observed in the life cycle of the planktonic foraminifera and during their reproduction up to hundred thousands of gametes are released from a single parent cell. The life span of single species varies between days to one year, and after the reproduction the empty tests sink to the seafloor (Hemleben et al., 1989).

## 1.4 Temperature proxies in foraminiferal tests ($\delta^{18}$O and Mg/Ca)

Several elemental and isotopic compositions of planktonic foraminiferal tests are used as proxies to reconstruct environmental parameters of the past. Of those, $\delta^{18}$O and Mg/Ca are established and widely applied proxies to estimate past ocean temperature and salinity variabilities.

The stable oxygen isotope ratio is depending on the fractionation between $^{18}$O and $^{16}$O during calcification processes of the foraminiferal test. This is controlled by temperature, while higher temperature results in a lower incorporation of the heavier isotope $^{18}$O (Urey,

1947; McCrea, 1950; Shackleton, 1974). Not only temperature but also the oxygen isotope composition of the ambient seawater controls the $\delta^{18}O$ ratio in foraminiferal calcite. The $\delta^{18}O$ ratios of the seawater itself is influenced by the global continental ice volume and for surface seawaters by the local evaporation and precipitation balances that correlate with the salinity of the seawater (Craig and Gordon, 1965). Earlier studies showed that biogenic calcite is not precipitated in equilibrium as defined by inorganic precipitation experiments (e.g. Kim and O´Neil, 1997) and certain "vital effects" (such as symbiont activity, ontogenetic variations (growth)) influence the signal of the calcite test (Spero and Lea, 1993; Bemis et al., 1998). Erez and Luz (1983) developed the first empirical $\delta^{18}O$-temperature relationship for planktonic foraminifera (*Globigerinoides sacculifer* grown under laboratory conditions) and further species-specific $\delta^{18}O$-paleotemperature equations were established (e.g. Bouvier-Soumagnac and Duplessy, 1985; Bemis et al., 1998).

Calcite tests of planktonic foraminifera are build from low Mg-calcite (<5 mole % $MgCO_3$) (Bentov and Erez, 2006 and references therein). The temperature of the seawater in which the foraminifera calcify appears to be the primarily abiotic factor controlling the incorporation of $Mg^{2+}$ in foraminiferal tests and numerous empirical calibrations show the exponential relationship between Mg/Ca ratios and temperature (e.g. Nürnberg, 1995; Nürnberg et al., 1996; Lea et al., 1999; Anand et al., 2003). Other parameters such as salinity or carbonate dissolution processes may influence the Mg/Ca composition (e.g. Nürnberg et al., 1996; Brown and Elderfield, 1996; Regenberg et al., 2006; Kisakürek et al., 2008; Arbuszewski et al., 2010). Large heterogeneity of Mg/Ca ratios observed in single foraminiferal tests is related to physiological processes such as variable $Mg^{2+}$ uptake by mitochondria (e.g. diurnal high and low $Mg^{2+}$ bands in *Orbulina universa*) (Spero et al., 2015).

# CHAPTER 2

# Habitats of living planktonic foraminifera in the Caribbean

A. Jentzen, J. Schönfeld
*This chapter is going to be submitted to Journal of Foraminiferal Research*

## Abstract

Habitat patterns of subtropical and tropical planktonic foraminifera in the Caribbean were obtained by using 136 plankton samples collected in spring 2009 and 2013. The spatial distribution in surface waters (3.5 m water depth) and depth habitat patterns (0–400 m) of 33 species were compared with prevailing water mass conditions (temperature, salinity and chlorophyll-*a* concentration) and with fossil planktonic assemblages in surface sediments.
The distribution patterns of planktonic foraminiferal assemblages point to a significant relationship to seawater temperature. Close to the Orinoco river plume and in the Gulf of Paria, high turbidity and concomitant low surface-water salinity probably effected a reduction in the standing stock. In contrast, a transient mega-patch of high chlorophyll concentrations in the eastern Caribbean Sea triggered a higher standing stock in near surface waters, with higher abundances of *Globigerinita glutinata* and *Neogloboquadrina dutertrei*. The species *Globorotalia truncatulinoides* (dextral) mainly lives close to the upper thermocline and can be linked to cold winter temperatures (~20°C). A large number of *Globorotalia ungulata* dwelled in the Florida Straits and probably indicate an increase in its population density, or a unique seasonal occurrence. *Globigerinoides sacculifer* and *Globoturborotalita rubescens* are linked to oligotrophic offshore conditions in the Caribbean Sea during early spring. The living assemblages in the water column show a similar faunal composition to the fossil assemblages in the surface sediments and give a reliable picture of the recent distribution, indicating no major change over the past millennia. Differences in the percentage distribution of single species are probably due to seasonal variabilities.

## 2.1 Introduction

Planktonic foraminifera are marine protists that live in the surface to mid-depth ocean and are widely distributed across the globe. They are sensitive to the biological and hydrographical parameters of the ambient seawater, for example food supply, light availability and temperature (Schiebel and Hemleben, 2005; Kučera, 2007). The calcite shells (tests) of planktonic foraminifera have a high preservation potential in sedimentary archives and are the most important group of microfossils for the reconstruction of paleoenvironmental conditions (Fischer and Wefer, 1999). To improve these reconstructions, it is necessary to understand the relation between the distribution of living planktonic foraminifera and the environmental conditions in the ambient seawater. For this reason, plankton net catches were investigated in early studies worldwide (e.g. Schott, 1937; Bradshaw, 1959; Jones, 1968; Duplessy et al., 1981a) and large faunal provinces were assigned, from polar to tropical areas (Bé, 1977). This biogeographical zoning showed that species prefer different habitat characteristics, presumably linked to prevailing water mass properties, such as the sea-surface temperature (Bé, 1977). Recent studies also related the occurrence, or absence, of species to upwelling (Guptha et al. 1994), chlorophyll-*a* concentrations, (Fairbanks and Wiebe, 1980; Schiebel et al., 2001; Kuroyanagi and Kawahata, 2004; Retailleau et al., 2011) or seasonality (Schmuker, 2000b; Jonkers and Kučera, 2015). It is important to note that plankton tows depict only snapshots of the faunal distribution at the moment of sampling. Seasonality or interannual variability (Thunell and Reynolds, 1984; Jonkers and Kučera, 2015) cannot be recorded. Plankton is also highly influenced by patchiness (Siccha et al., 2012) and by external short-term forcing (e.g. storms or hurricanes, Schiebel et al., 1995; Chapter 4). Furthermore, if the distribution pattern of living planktonic foraminifera is determined, the reproduction cycle of single populations needs to be considered. These ontogenetic dynamics influence the habitat depth of the specimens during their individual life cycle (e.g. Erez et al., 1991; Schiebel and Hemleben, 2005) and have been related, for example, to the lunar cycle (Spindler et al., 1979; Erez et al., 1991). Nonetheless, plankton tow samples are essential to constrain the preferred habitats and life cycles of living planktonic foraminifera in the ocean. We investigated plankton net, plankton filter and sediment samples from the Caribbean Sea, eastern Gulf of Mexico, Florida Straits and Santaren Channel to gain new insights into the distribution pattern of subtropical and tropical planktonic foraminifera in relation to the prevailing hydrographical conditions. The living community in the water column was compared to the accumulated average of

foraminiferal tests in surface sediments to determine seasonal variability or changes over decades. Test-sizes were documented to assess the ontogenetic structure of the populations. This study aims to provide new observations and to verify previous findings on the habitat pattern of foraminiferal populations, for a better and more reliable application of planktonic foraminifera in paleo-studies.

# 2.2 Hydrography

The major surface water mass in the Caribbean Sea is the Caribbean Water (CW), indicated by a low salinity of <35.5 psu. It is a mixture of local precipitation with Atlantic surface water and Orinoco and Amazon river water that is transported into the Caribbean through the Lesser Antilles (Wüst, 1964; Gordon, 1967). The freshwater input of the rivers is highly seasonal and sustains a transient surface water layer in the southeastern Caribbean with low salinities and high chlorophyll concentrations (Froelich et al., 1978; Corredor and Morell, 2001). The maximum Amazon River runoff is in summer (May-June), and the highest river discharge for the Orinoco is in autumn (August) (Müller-Karger et al., 1989). Below the CW, the Subtropical Under Water (SUW) prevails between 50 to 250 m water depth and shows a higher salinity of up to 37 psu and decreasing temperatures with depth (Gallegos, 1996). The 18°C Sargasso Sea Water (Eighteen Degree Water=EDW) is present between 200 and 400 m water depth, and the influence of the Tropical Atlantic Central Water (TACW) is recorded between ~400 and 700 m water depth (Morrison and Nowlin, 1982).

The Caribbean Current brings modified CW through the Yucatan Strait into the Gulf of Mexico and continues as the Loop Current towards the Florida Straits (Vukovich, 2007). Furthermore, the Gulf Common Water (GCW) characterizes the water masses in the Gulf of Mexico in the upper 200 m water depth, with temperature and salinity of ~23°C and 36.4 psu (Vidal et al., 1994). Strong seasonal surface water temperature variations are recorded in the Gulf of Mexico, with low winter values of less than 20°C, which are linked to the southward migration of the Intertropical Convergence Zone (ITCZ) (Philander and Pacanowski, 1986; Locarnini et al., 2010).

# 2.3 Material and Methods

The investigated area comprises the Caribbean Sea, eastern Gulf of Mexico, Florida Straits and Santaren Channel (Fig. 2.1; Appendix A). All samples were collected during RV Sonne cruise SO164 in May/June 2002 and RV Meteor cruises M78/1 in February/March 2009 and M94 and M95 in March/April 2013 (Nürnberg et al., 2003; Schönfeld et al., 2011; Betzler et al., 2014; Hübscher et al., 2014).

The population structure of living planktonic foraminifera in the water column was assessed using a Hydrobios Midi multiple opening-closing plankton net (MSN). The MSN had an aperture of 50 x 50 cm and was equipped with five net bags with a mesh size of 100 µm. This device was deployed at five stations and the samples were taken in five different depth intervals between the surface and a maximum of 400 m. Net haul intervals were chosen according to the water mass boundaries obtained from previous hydrocasts during cruise M78/1. Additional samples were taken in the Yucatan Straits and Santaren Channel using an Apstein-Net (AN) with a 17 cm aperture diameter and a net mesh size of 100 µm, to gain a better resolution of the habitat depth in the first 100 m of the water column. In total four stations with intervals of 0–20, 20–40, 40–60 and 60–100 m water depth were sampled with the AN. A KC-Denmark plankton pump (PP) was deployed at a fixed depth ranging from 40 to 160 m at three stations, to obtain foraminifera from a specific depth. The pump filtered seawater through a 60 µm mesh, and the volume was measured with a digital flow meter. The ship´s pump was used to determine the regional distribution of foraminiferal populations in surface waters. The pump collected seawater from 3.5 m water depth, which was filtered through a sieve with a net mesh size of 63 µm. An average 2 m$^3$ of seawater was pumped for each filtered sample (PF). In total 45 PF samples from cruise M78/1 and 43 PF samples from cruise M94/M95 were analysed for faunal distribution patterns. The PF samples of cruise M78/1 were split on board with a Motodo plankton splitter and half was available for the present study. Each plankton sample was preserved immediately after sampling with a 1:1 mixture of ethanol and seawater. Additionally, the MSN samples of cruise M78/1 were stained with Rose Bengal (2 g/l) in order to distinguish between living specimens and empty tests. However, this step was later found to be unnecessary for plankton samples, as the cytoplasm in living planktonic foraminifera was recognizable without staining. Furthermore, stained samples impeded the discrimination between reddish and white foraminiferal tests. In the laboratory, the samples were rinsed with tap water and all foraminifera were wet picked with a glass pipette.
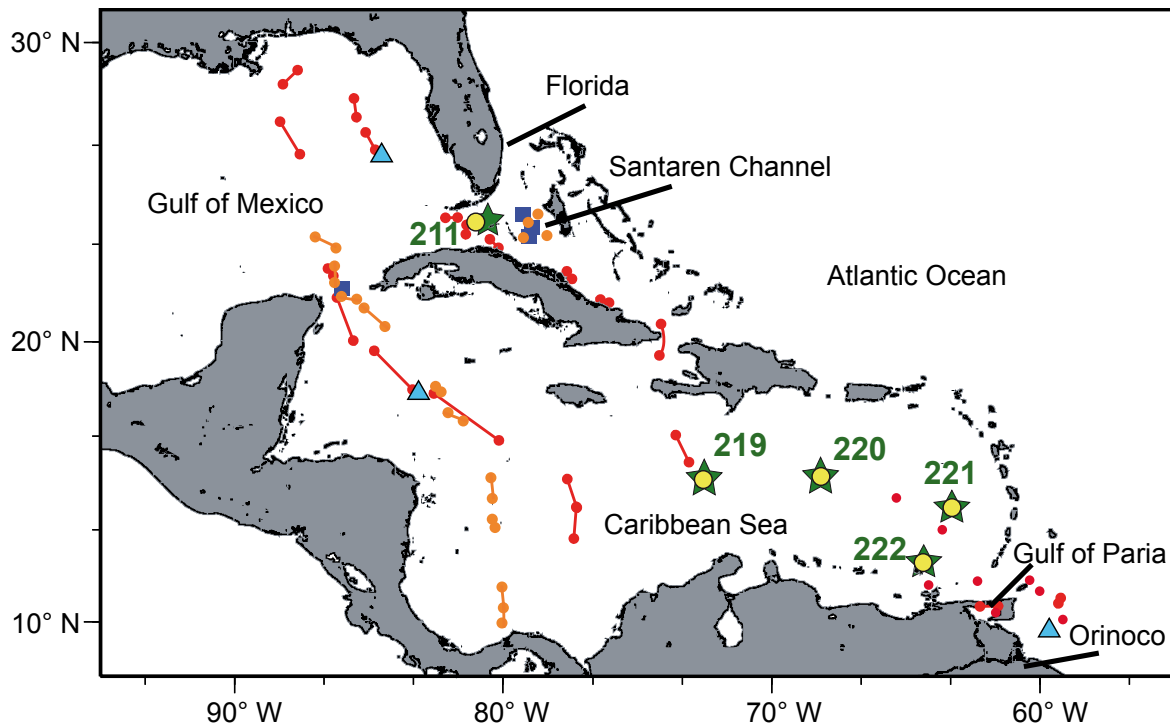
**Figure 2.1:** Location map: Plankton filter samples (PF) follow the ship tracks (red lines and dots cruise M78/1, orange lines and dots cruises M94 and M95). Apstein net samples (AN) (blue squares) taken during cruises M94 and M95. Plankton pump samples (PP) (light blue triangles), stations of multi-closure net samples (MSN) and CTD (green stars) taken during cruise M78/1. Sediment samples (yellow dots) obtained during cruises SO164 and M78/1 respectively.

Some foraminifera were tangled with organic flocs or other planktonic organisms (e.g. Chaetognatha) and therefore carefully removed using a fine brush and needle. The samples were dried on filter paper at room temperature.

In order to ensure compatibility with all plankton net samples, the dried foraminifera were sieved using a mesh size of 100 μm. Additionally, the MSN and PP samples were fractionated into 100–125, 125–150, 150–250, 250–300, 300–400, 400–500 and >500 μm using stacked sieves. Living (cytoplasm-bearing) and dead (empty) tests were differentiated. The specimens were collected in Plummer or Fema cells, counted and identified at species-level following the taxonomy of Bé (1967) and Hemleben et al. (1989). Additionally, we followed the new concepts of molecular phylogenetic analyses, which showed the relationship within morphotypes and genotypes of different species (e.g. Darling et al., 2006; Darling et al., 2009; Aurahs et al., 2011; André et al., 2013). We separated *Globigerinoides ruber* (white), *G. ruber* (pink) and *G. elongatus* following Aurahs et al. (2011). Species of the family *Globigerinella* were distinguished according to Weiner (2014). Furthermore, we distinguished between two different morphotypes of

*Globigerinoides sacculifer (= Trilobatus sacculifer)*: The *trilobus*-morphotype (Plate 1-f; 3-f) with a regular and spherical last chamber and the *sacculifer*-morphotype (referred in this study as *G. sacculifer* ws, Plate 1-e) with a sac-like last chamber. The two morphotypes are one genotype (André et al., 2013) and the sac-like morphological feature indicates that the specimens would undergo gametogenesis within the next 24 to 48 hours (Bé, 1980). We also noted the different ontogenetic stages of *Orbulina universa*, the juvenile multi-chambered trochospiral stage (Plate 1-m) and the single chamber spherical stage (Plate 1-o; 3-i) as described by Bé et al. (1973).

Meroplanktonic species such as *Tretomphalus bulloides* were very frequent in some PF samples. This group of foraminifera has a benthic and also a planktonic stage in their life cycle (Rückert-Hilbig, 1983; Darling et al., 2009). The number of meroplanktonics in the PF samples was recorded, but they were not distinguished at the species-level because it is beyond the scope of the present study.

Surface sediment samples were obtained during cruises SO164 and M78/1 using a multicorer or an USNEL giant box corer (Nürnberg et al., 2003; Schönfeld et al., 2011). The sediment samples have been taken at approximately the same position as the MSN samples (Fig. 2.1; Appendix A). Only the uppermost centimetre of the surface sediment was sampled for faunal analysis. The samples were freeze-dried, washed through a 63 μm screen, and dried at 40°C. The dry samples were split using an Otto microsplitter to obtain an aliquot with at least 300 planktonic specimens per sample. The splits were fractionated using the same sieve mesh sizes as for the MSN samples (100–125, 125–150, 150–250, 250–300, 300–400, 400–500 and >500 μm). The planktonic foraminifera were identified in these fractions and counted in the same way as for the plankton samples.

The salinity and temperature of the sea surface water was recorded by the shipboard thermosalinograph of RV Meteor during almost every PF sampling period. At the MSN stations, a RBR XR-420 Conductivity-Temperature-Depth (CTD) profiler recorded salinity and temperature. The chlorophyll-*a* concentrations in the water column were measured with a bbe Moldaenke FluoroProbe.

The population density, based on the MSN, AN and PF samples, is given as individuals per cubic meter seawater (ind. $m^{-3}$). For each species found in MSN and AN samples, the weighted average of the living depth (m), temperature (°C) and salinity (psu) during the time of sampling was calculated. Statistical analyses were performed in order to compare the regional surface distribution pattern between different species (paired sample t-test for PF samples). Additionally, the relationship between environmental factors

(temperature and salinity) and the living population was determined (multivariate multiple regression analysis for MSN and PF samples). For the MSN samples, only species with abundances more than 4% of the total assemblage, in at least 3 samples, were taken for the latter analysis. A hierarchical cluster analysis using the Unweighted Pair Group Method with Arithmetic mean (UPGMA) was performed with the software PAST (Hammer et al., 2001) to compare the similarity between MSN and sediment samples. For the cluster analysis the Bray-Curtis similarity index (values from 0 to 1) was applied, where 1 indicates that the two samples have the same faunal composition (highest similarity between two populations).

# 2.4 Results

## 2.4.1 Hydrographical conditions during the sampling campaign

The CTD-data showed a deepening of the CW from the east to the west (26.1–26.5°C; 35.5–35.9 psu), reaching a depth of ~100 m in the western Caribbean Sea (Fig. 2.2B; Schönfeld et al., 2011). High salinity (>37 psu) indicated the presence of the SUW between 80 and 160 m water depth, below the CW. Between the lower boundary of the surface mixed layer and the lower part of the SUW (~20°C), the upper thermocline is defined. A lower salinity (36.5 psu) indicated the probable influence of the GCW in the Florida Straits between 100 and 150 m water depth. The deep chlorophyll maxima was present above the thermocline (SUW) at every station, with the highest values of ~0.9 μg/l at station 222 (Fig. 2.2B). Surface water measurements (3.5 m water depth; Appendix A) during March 2009 showed low salinity (~32 psu) close to the Gulf of Paria and the Orinoco River (Fig. 2.2A), likely due to continental river runoff. A slightly higher salinity (>36 psu) was recorded in the Gulf of Mexico as compared to the surface of the Caribbean Sea. There was a large range of sea surface temperatures in the sampling area. The warmest surface waters were found in the western Caribbean Sea with values of up to 27°C, compared to much lower surface water temperatures of ~20°C in the Gulf of Mexico, indicating winter conditions during sampling time (Locarnini et al., 2010).
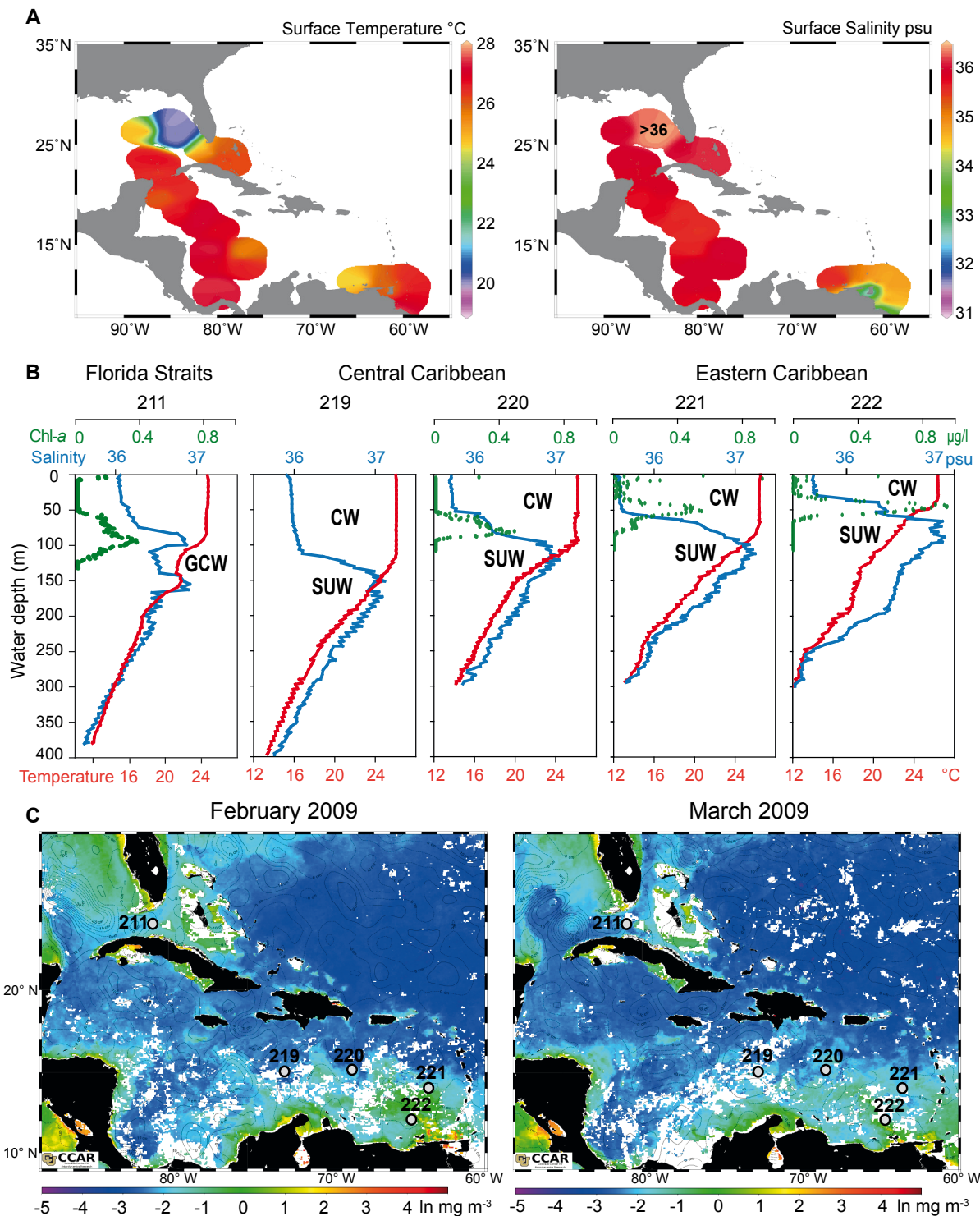
**Figure 2.2:** Hydrographical data during the sampling campaigns. **A:** Overview of salinity (psu) and temperature (°C) at 3.5 m water depth (data recorded with the shipboard thermosalinograph of RV Meteor during cruises M78/1 (Schönfeld et al., 2011), M94 (Hübscher et al., 2014) and M95 (Betzler et al., 2014)). The data are illustrated with the ODV program (Schlitzer, 2009). **B:** CTD profiles (recorded during cruise M78/1), chlorophyll-*a* concentration (µg/l), salinity (psu) and temperature (°C) (Schönfeld et al., 2011). The water mass is marked as CW (Caribbean Water), SUW (Subtropical Under Water) and GCW (Gulf Common Water). Note the deepening of the thermocline from east to west in the Caribbean Sea. **C:** Satellite images of the chlorophyll distribution in February and March 2009. Maps are derived from CCAR (Colorado Center for Astrodynamics Research; http://eddy.colorado.edu/ccar/ssh/hist_global_grid_viewer). Grey dots illustrate the MSN stations of RV Meteor cruise M78/1.

## 2.4.2 Plankton faunal analysis

In total, 33 different living species were identified from all plankton samples together (Tab. 2.1; Appendix A). The species characterized a typical tropical and subtropical fauna (Bé, 1977). The results of a multivariate multiple regression analysis indicated that the vertical distribution of the foraminiferal species composition in the water column was significantly related to temperature ($r^2 = 0.81$, $p<0.05$). Distribution patterns in the surface waters were even more strongly related to temperature ($r^2 = 0.91$, $p<0.05$). Salinity showed no significant ($p>0.05$) relationship to the distribution patterns of the foraminiferal population (Appendix A). Based on these findings and according to their weighted average living depth, we grouped the main habitats of the species into either the surface mixed layer, the SUW, or below the upper thermocline. However, some species did not show a distinct depth preference (Tab. 2.1; Tab. 2.2; Fig. 2.7). *Globigerinoides sacculifer* (average percentage 25.4%) and *Globigerinita glutinata* (24.0%) showed the highest abundance of the total living fauna, followed by *Globigerinoides ruber* (14.9%), *Neogloboquadrina dutertrei* (6.9%), *Globigerinella calida* (6.2%) and *Globorotalia ungulata* (4.9%). These species were also reported as common foraminifera in the planktonic assemblage around the Caribbean Sea in earlier publications (Jones, 1968; Schmuker and Schiebel 2002; Spear et al., 2011). The highest population density was recorded in the eastern Caribbean Sea. Up to 250 living specimens per cubic metre seawater were present in the surface waters (3.5 m water depth) and 160 ind. m$^{-3}$ in the entire mixed layer (at station 221 in 0–40 m water depth). The highest standing stocks were mainly found in the first sampling interval above the thermocline. However, some species (*G. glutinata, Turborotalita quinqueloba, Pulleniatina obliquiloculata, G. sacculifer* with sac-like chamber*, Hastigerina pelagica* and *Neogloboquadrina incompta*) showed an abundance maximum in the deep chlorophyll maximum at station 221 in the southeastern Caribbean Sea.

Meroplanktonic species were particularly frequent in the surface waters of the Santaren Channel (after 10th of April, 2013). They accounted for up to 80% of the total foraminiferal population with *Tretomphalus bulloides* as the dominant species.

## 2.4.2.1 Distribution of dominant planktonic species

The spinose species *G. sacculifer* had the highest standing stock in the eastern Caribbean Sea and close to Tobago (43 ind. m$^{-3}$ at station 221; Fig. 2.3). The highest density of this species in the water column was always found above the chlorophyll maximum. In the Caribbean Sea, the population density of *G. sacculifer* showed a deepening from the east

to the west in parallel to the deepening of the thermocline (Fig. 2.2B). The *sacculifer*-morphotype had a larger mean living depth ($66\pm25$ m) than the *trilobus*-morphotype ($41\pm9$ m).

The highest density of the small, non-spinose species *G. glutinata* was found in the upper water column at station 221 (73 ind. m$^{-3}$, Fig. 2.3B). Their distribution in surface waters showed a similar pattern to that of *G. sacculifer*. There were no significant differences between the species (paired samples t-test, $p<0.05$), with the highest abundance of both in the southeastern part of the study area (Fig. 2.3A).

The maximum abundance of *G. ruber* was recorded in the upper water column of the Florida Straits (26 ind. m$^{-3}$, station 211) and eastern Caribbean Sea (23 ind. m$^{-3}$, station 221) (Fig. 2.3). The proportion of *G. ruber* decreased from the eastern to the central Caribbean Sea and the highest percentage was found in the Florida Straits (27%, Fig. 2.4). The two species, *G. ruber* pink and white, showed highly similar distributions in the surface water (no significant differences, paired samples t-test, $p<0.05$). Nonetheless, the white variety had a slightly deeper living habitat than the pink variety (Tab. 2.1). The pink variety was more frequent in the Caribbean Sea close to Tobago (up to 50 ind. m$^{-3}$), whereas the white variety had a higher proportion in the Santaren Channel.

The distribution of *N. dutertrei* indicated a habitat in the mixed layer, with the highest abundance in the eastern Caribbean Sea (12 ind. m$^{-3}$, station 221). The MSN samples recorded the highest abundance of *G. calida* in the upper water column of the Florida Straits (9 ind. m$^{-3}$), although the species was abundant in surface waters of the eastern Caribbean Sea as well. The species *G. ungulata* was only present in large numbers in the Florida Straits (6.7 ind. m$^{-3}$, in the first sampling interval), in surface waters of the Gulf of Mexico (Fig. 2.3A), and in PP samples of the western Caribbean Sea. At all other stations, the species was rare or even absent.

## 2.4.2.2 Distribution of common planktonic species

*Globorotalia menardii*, *Pulleniatina obliquiloculata* and *Globoturborotalita rubescens* showed a very similar distribution in surface waters. There was no significant difference between the species as indicated by paired samples t-test ($p<0.05$). The depth habitat structure of *G. menardii* varied between the stations. In the Florida Straits, the species was most abundant below the SUW, whereas in the Caribbean Sea, the highest abundance was found at station 221 in 0–40 m water depth. The highest density of *P. obliquiloculata* was recognized at station 221 (3.2 ind. m$^{-3}$) in the chlorophyll maximum. In general, the

habitat of *G. rubescens* was confined to the surface water, but many empty tests were caught with the plankton net in the central Caribbean Sea and Florida Straits. Indeed, at station 220 the highest abundance of empty tests (3.4 ind. m$^{-3}$) in MSN samples was observed in the depth interval of 110–150 m and amounted to a higher density than for the living specimens (Fig. 2.3B). In the Gulf of Mexico, *Globorotalia truncatulinoides* (dextral), *Hastigerina pelagica*, *Orbulina universa* and *Globigerinella siphonifera* had their highest standing stock in the surface water and they showed a similar distribution pattern (paired samples t-test, p<0.05). The habitat structure of *G. truncatulinoides* (dextral) revealed a habitat depth close to the upper thermocline (176±18 m water depth), even though small specimens were found in MSN samples from the upper water column and in PF samples (Fig. 2.3A; Fig. 2.6). The fragile species *H. pelagica* was most abundant in the Florida Straits and eastern Caribbean (station 221), and generally showed a bimodal depth distribution. However, at stations 219, 220 and 221 the highest population density of *H. pelagica* was found in the SUW. At station 221, *O. universa* was most common (2.4 ind. m$^{-3}$) in MSN samples. Juvenile specimens without the spherical chamber were exclusively observed in the upper sampling intervals. A deep habitat (201±42 m water depth) was calculated for the species *Globorotalia crassaformis*. This species showed a strong increase in the standing stock with depth at station 222, where it was most abundant. Single small specimens of *G. crassaformis* were also recorded in surface water samples (PF) (Fig. 2.3A). *Sphaeroidinella dehiscens* was only found within and below the upper thermocline and had an average living depth of 201±6 m, with the highest standing stock in the Florida Straits (1 ind. m$^{-3}$). In the eastern Caribbean, this species was absent. However, it has to be emphasized that juvenile *S. dehiscens* are difficult to distinguish from *G. sacculifer*. As long as the smooth crust of *S. dehiscens* has not developed (Plate 1-l), the specimens still carry spines (Plate 1 j-k) and look similar to *G. sacculifer*. Bé (1967) even described *S. dehiscens* as a terminal morphotype of *G. sacculifer*.
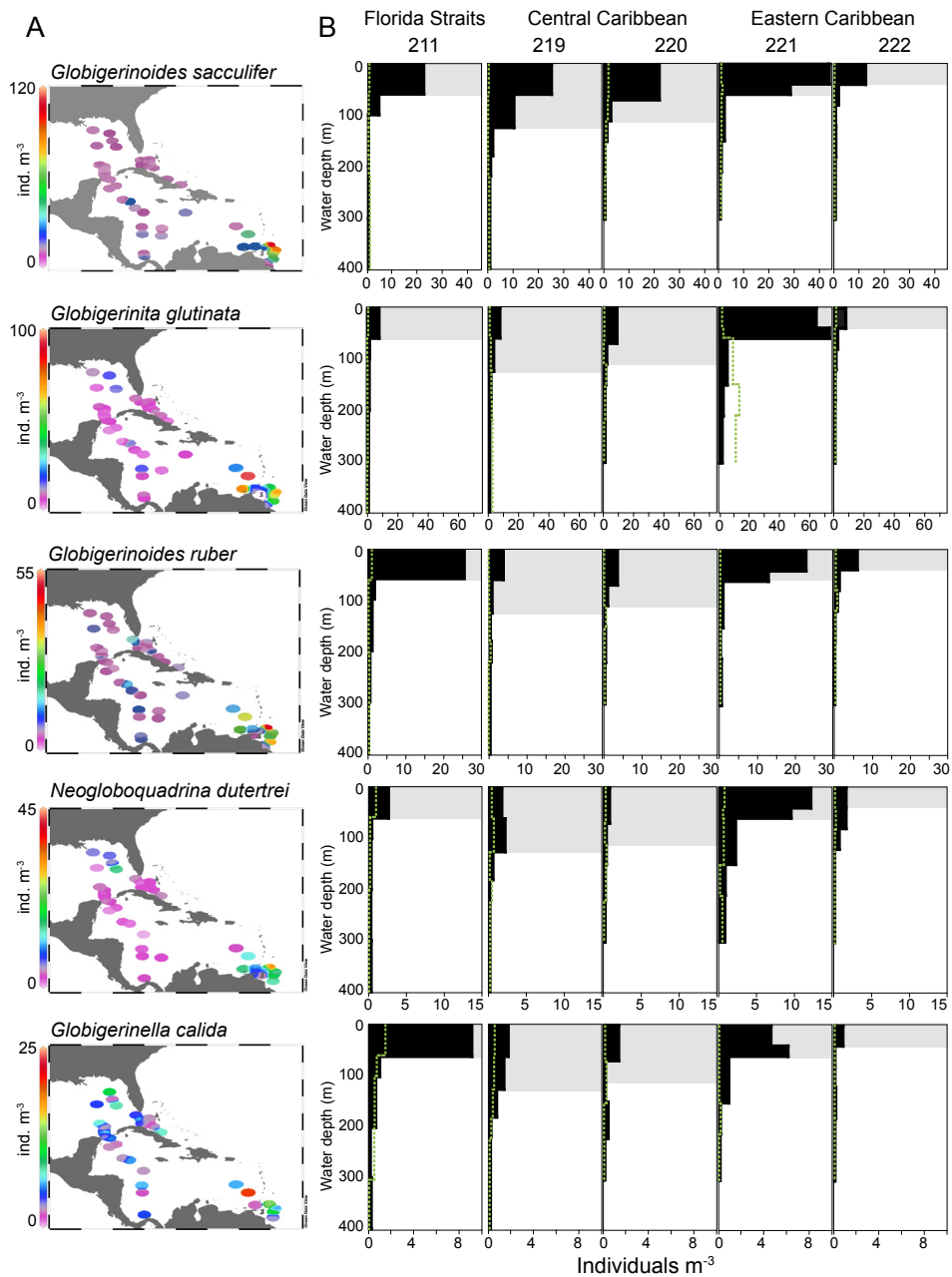
**Figure 2.3:** Surface **(A)** and depth **(B)** distribution of *Globigerinoides sacculifer* (both morphotypes), *Globigerinita glutinata*, *Globigerinoides ruber* (pink and white variety), *Neogloboquadrina dutertrei*, *Globigerinella calida*, *Globorotalia ungulata*, *Globoturborotalita rubescens*, *Globorotalia menardii*, *Pulleniatina obliquiloculata*, *Globorotalia crassaformis*, *Orbulina universa*, *Globigerinella siphonifera*, *Globorotalia truncatulinoides* dextral, *Sphaeroidinella dehiscens*, *Hastigerina pelagica* **A:** The surface distribution shows the standing stock of living foraminifera (ind. m$^{-3}$) in 3.5 m water depth (data of PF samples). The foraminiferal distribution is illustrated with the ODV program (Schlitzer, 2009). **B:** The depth profiles show the standing stock of living foraminifera (ind. m$^{-3}$) marked as black bars and the abundance of empty tests (ind. m$^{-3}$) marked as dashed green lines (data of MSN samples). The grey bars indicate the surface mixed layer.
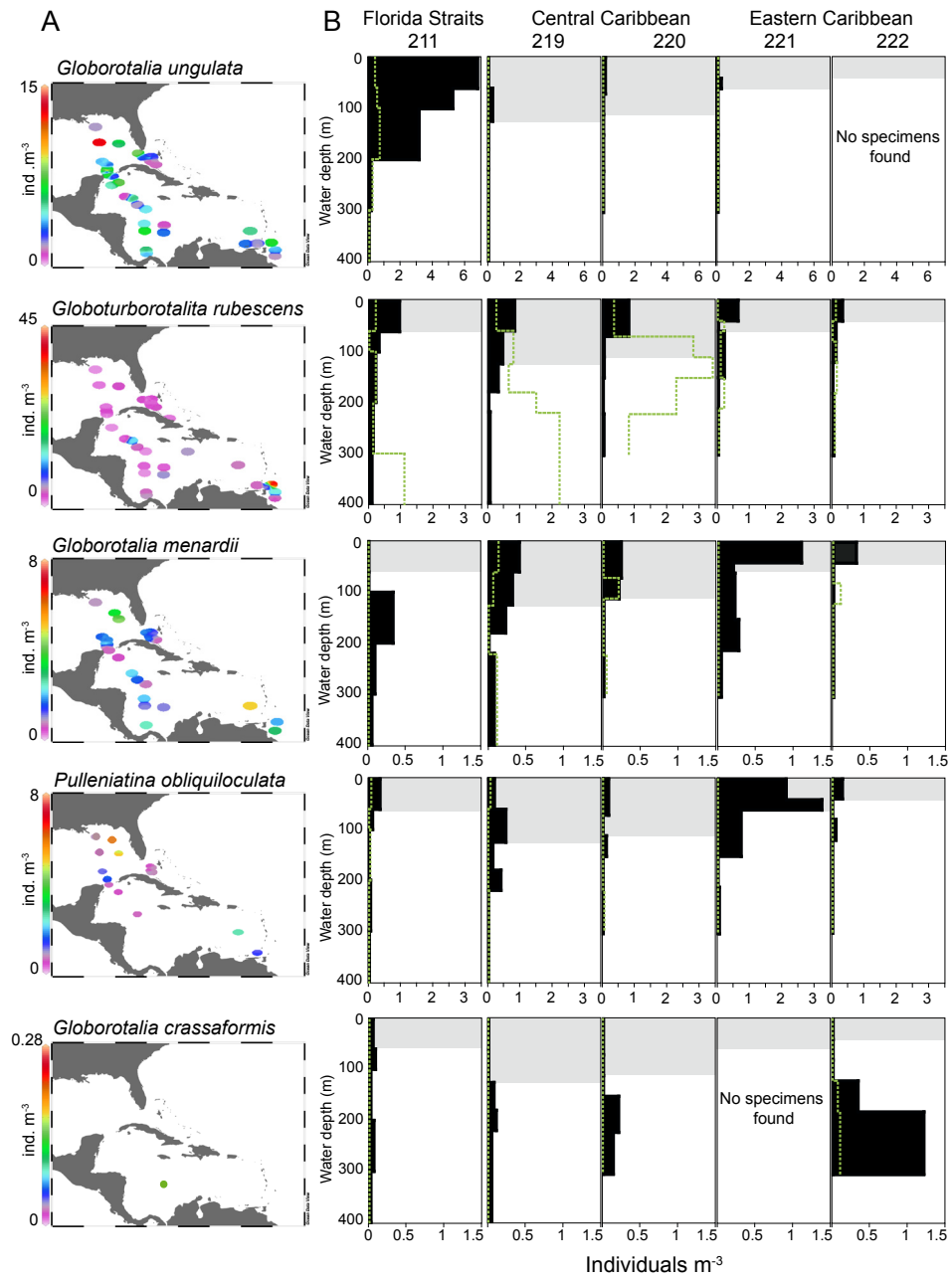
**Figure 2.3:** Continued.
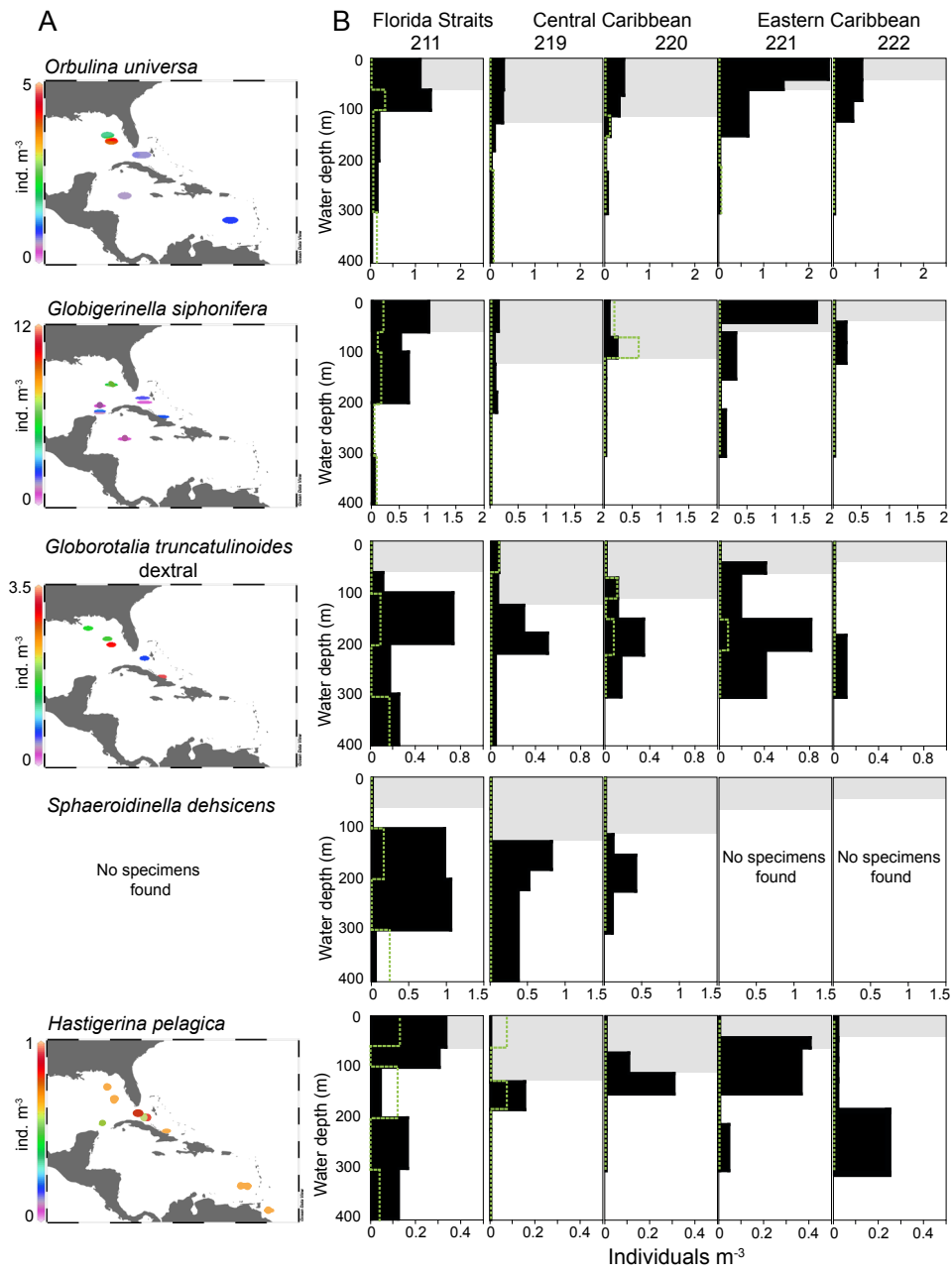
**Figure 2.3:** Continued.

## 2.4.2.3 Sediment faunal analysis

Overall, the species composition of the surface sediment assemblages showed a similar fauna compared to the plankton tows (Fig. 2.4, Fig. 2.5, Appendix A). Only *Globorotalia inflata* was found in the dead assemblage of the sediment surface and not in the plankton samples. Six rare species (*Globorotalia hirsuta*, *Globigerinita minuta*, *Globigerinita uvula*, *Tenuitella iota*, *Tenuitella parkerae* and *Turborotalita humilis*) were found only in the plankton samples and not in the sediment. Moreover, the tests of the *sacculifer*-morphotype constituted a higher proportion of the total planktonic fauna in the sediment (20%) than in the plankton tows (2%). In the Florida Straits in particular, *G. glutinata*, *G. ruber* and *G. sacculifer* had the same proportion in the plankton and sediment assemblages and the two populations showed a Bray-Curtis similarity index of 0.66 (Fig. 2.5). However, *G. ungulata* was common with up to 13% in the plankton net tows, but was rare with 0.8% in the sediment, and with a smaller test-size on average (Fig. 2.6). In contrast to this, the species *N. dutertrei* and *G. elongatus* had a higher proportion in the sediment (6.8% and 8.6%) than in the plankton net (2.5% and 0.3%). In the central Caribbean Sea, at stations 219 and 220, *G. sacculifer* was the dominant species in the water column with up to 50%. The
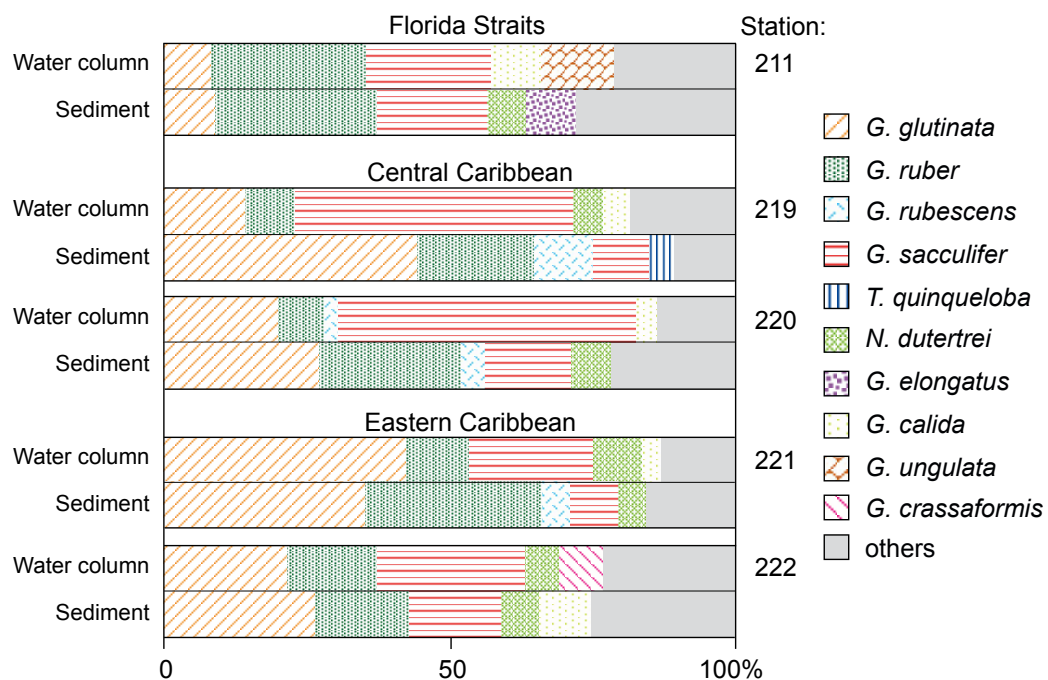


**Figure 2.4:** Planktonic foraminiferal composition (%) of MSN samples (living foraminifera in the water column from surface to max. 400 m water depth) compared to the corresponding surface sediment samples. Only the five most dominant species are depicted for each assemblage.
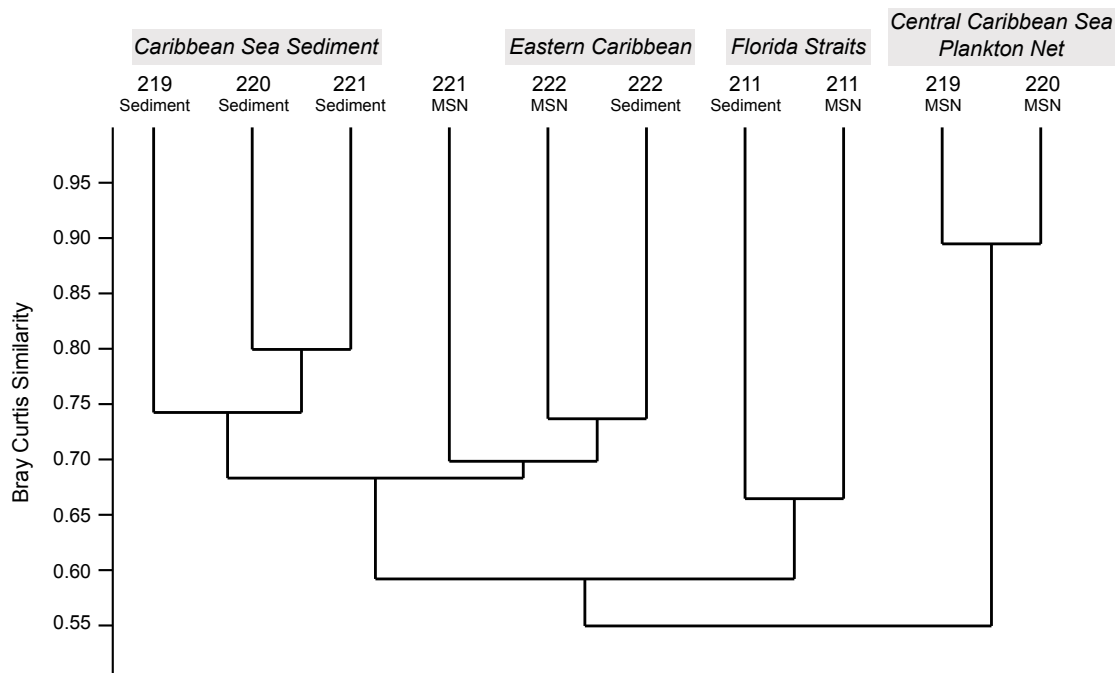
**Figure 2.5:** Dendrogram resulting from a hierarchical cluster analysis showing the similarity of plankton (MSN) and sediment samples nearby the MSN stations (cf. Fig. 2.1). Cluster analysis was performed using the Unweighted Pair Group Method with Arithmetic mean (UPGMA) based on the Bray-Curtis similarity index (values from 0 to 1). 1 indicates the highest similarity between two populations.

plankton samples of the two stations showed a high similarity index of 0.89 (Fig. 2.5). The surface sediment at those locations showed a lower similarity to the plankton net samples (0.41 at station 219 and 0.58 at station 220) and the assemblage was composed primarily of *G. ruber* and *G. glutinata*. The species *G. rubescens* was frequent in the sediments, even though their standing stock was low at the respective locations. Nonetheless, a high number of empty tests of *G. rubescens* were collected in the water column (Fig. 2.3B). At station 219 the small species *T. quinqueloba* was more abundant in the sediment (4.5%) than in the plankton net (0.3%) and *G. calida* showed a slightly higher proportion in the plankton samples of station 219, 220 and 221 (4.7%, 3.6%, 3.3%) compared to the sediment (1.8%, 3.4%, 2.4%). However, the sediment samples of station 219, 220 and 221 showed a high similarity between each other (Fig. 2.5). In the eastern Caribbean Sea, at station 222, a similar proportion of *G. ruber*, *G. glutinata, G. sacculifer* and *N. dutertrei* was observed in MSN and surface sediment samples and the two populations indicated a high similarity (Fig. 2.5). However, there was a lower abundance of *G. calida* in the plankton net (1.5%) than in the sediment (9%). Furthermore the species *G. crassaformis* showed a higher proportion in the plankton net (7.6%) as compared to the underlying surface sediment (4.5%) at station 222, although the specimens were larger in the sediment (Fig. 2.6).
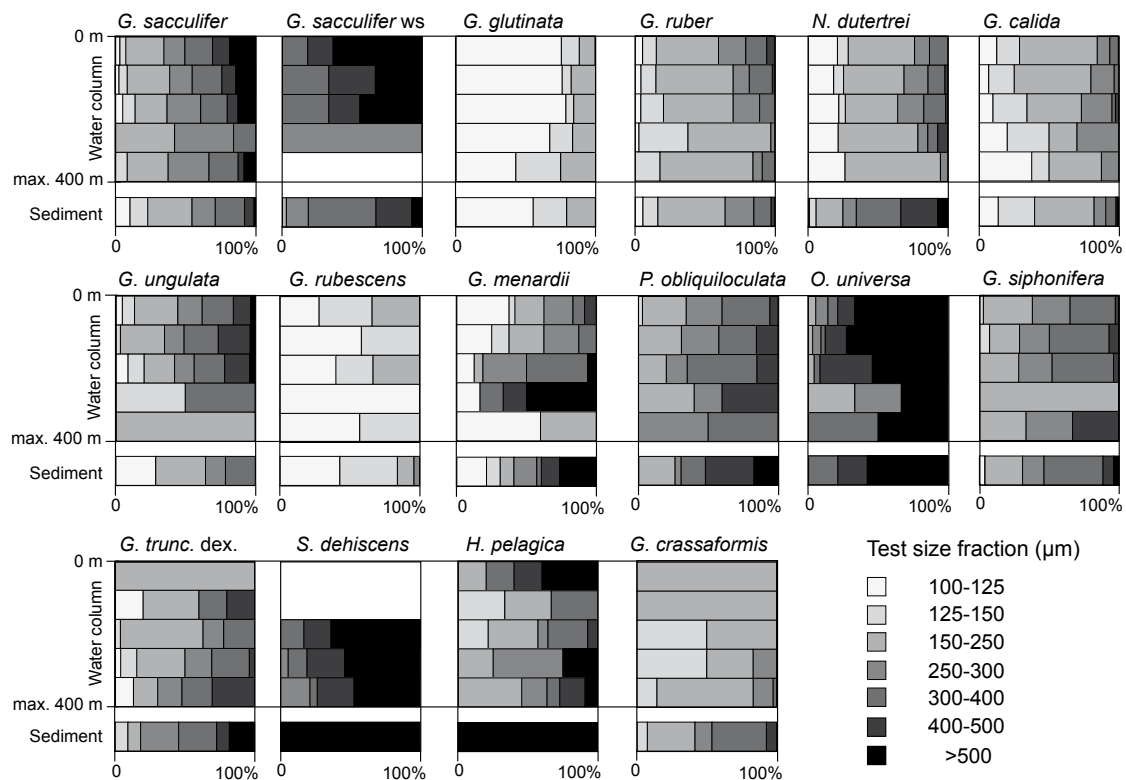
**Figure 2.6:** Distribution of different test-size fractions (100–125, 125–150, 150–250, 250–300, 300–400, 400–500 and >500 µm) of common species. The data are averages of the living specimens from all MSN stations. Five different depth intervals from surface to max. 400 m water depth are shown, according to the sampling. Additionally, the distribution of the test-size fractions in the sediment samples is given.

# 2.5 Discussion

## 2.5.1 Distribution pattern of planktonic foraminifera in relationship to environmental parameters

Overall, we observed a similar faunal composition as described in previous studies of the investigated area, with *G. sacculifer, G. glutinata* and *G. ruber* the dominant species of the planktonic foraminiferal assemblage (e.g. Jones, 1968; Miró, 1971; Schmuker and Schiebel, 2002; Spear et al., 2011). Our plankton net samples had a very similar species composition than the surface sediment samples (Fig. 2.4, Fig. 2.5). Regenberg et al. (2006) determined an age range of ~2 to 3 kyrs for the surface sediments in the Caribbean Sea. This may be evidence that the planktonic foraminiferal faunas have not experienced a substantial change during the past millennia. The different proportions of single species of the total floating assemblage can be related to variable seasonal occurrences in response to different water mass properties throughout the year (e.g. Schmuker, 2000b; Tedesco et al., 2007).

*Chlorophyll concentration*

The dominant species in the Caribbean Sea are typical for oceans with oligotrophic and mesotrophic conditions (Žarić et al., 2005; Morel et al., 2010). Under oligotrophic conditions, the light intensity is high and this favours photosynthetic symbionts. Most foraminifera, found in this study host photosynthetic symbionts (Gastrich, 1987; Hemleben et al., 1989). These symbionts restrict the habitat and influence the life span of single foraminifera (Bé et al., 1982; Bijma et al., 1992; Ortiz et al., 1995). The low turbidity that prevails offshore in the Caribbean Sea, favours the life conditions for species hosting algal symbionts (e.g. *G. sacculifer*). The species are rare in murky waters close to the Orinoco (Bahr et al., 2013).

The highest standing stock was recorded in the uppermost sampling intervals in the euphotic zone, probably related to the higher light and food availability (e.g. Berger, 1971a; Hemleben et al., 1989). At the MSN station 221 and in PF samples from the Atlantic, a distinct higher standing stock was recorded compared to the other stations (Fig. 2.3). Furthermore, some species (e.g. *G. glutinata*, *P. obliquiloculata*) showed a density peak in the deep chlorophyll maximum at station 221. During sample processing, these samples showed a high content of phyto- and small zooplankton such as diatoms, copepods, fishes, jellyfishes and algae. In this case we conclude that a higher nutrient input and food availability probably promoted foraminiferal reproduction and increased their standing stock at this location. A locally restricted and high standing stock was linked in a previous study to the occurrence of eddies, resulting in a high nutrient concentration (Schmuker and Schiebel, 2002). Images of satellite data of sea surface height anomaly (SSHA), generated by the CCAR (Colorado Center for Astrodynamics Research), give no evidence of an eddy passing the area at station 221 during or some days before the sampling time. However, satellite data of chlorophyll concentrations show that during February and March 2009, station 221 was adjacent to a high chlorophyll patch, that extended across the southeastern Caribbean Sea (Fig. 2.2C). The southern Caribbean Sea is generally affected by coastal upwelling and river plumes, which lead to higher chlorophyll concentrations (Corredor and Morell, 2001; Rueda-Roa and Müller-Karger, 2013). We speculate that this local hydrographical situation increased the food availability for the planktonic foraminifera, resulting in their higher density at station 221.

A very low standing stock (<5 ind. m$^{-3}$) was observed at single stations in the Santaren Channel, the Gulf of Paria and close to the Orinoco River plume. At the latter two locations, nutrient-rich waters fertilized by river runoff might cause a high turbidity, inhibit

the photosynthetic capabilities of the algal symbionts, and might influence also the food composition for the foraminiferal population. The stations in the Santaren Channel were close to the coast, and the high number of meroplanktonic foraminifera (up to thousand individuals per sample) might diminish the genuine planktonic population by competition for food at this site.

*Temperature and Salinity*

As described in previous studies, planktonic foraminifera are sensitive to temperature and salinity, but show a wide range for maximum growth and abundances (Tab. 2.2) (Bijma et al., 1990; Žarić et al. 2006; Lombard et al., 2009). Tropical areas generally have a low seasonal temperature and salinity variability, and thus these may not be the only controlling factors affecting the foraminiferal populations (Jonkers and Kučera, 2015). However, in our study, the faunal composition of the surface and vertical distribution in the water column showed a significant ($p<0.05$) relationship to temperature (Tab. 2.1; Fig. 2.7).



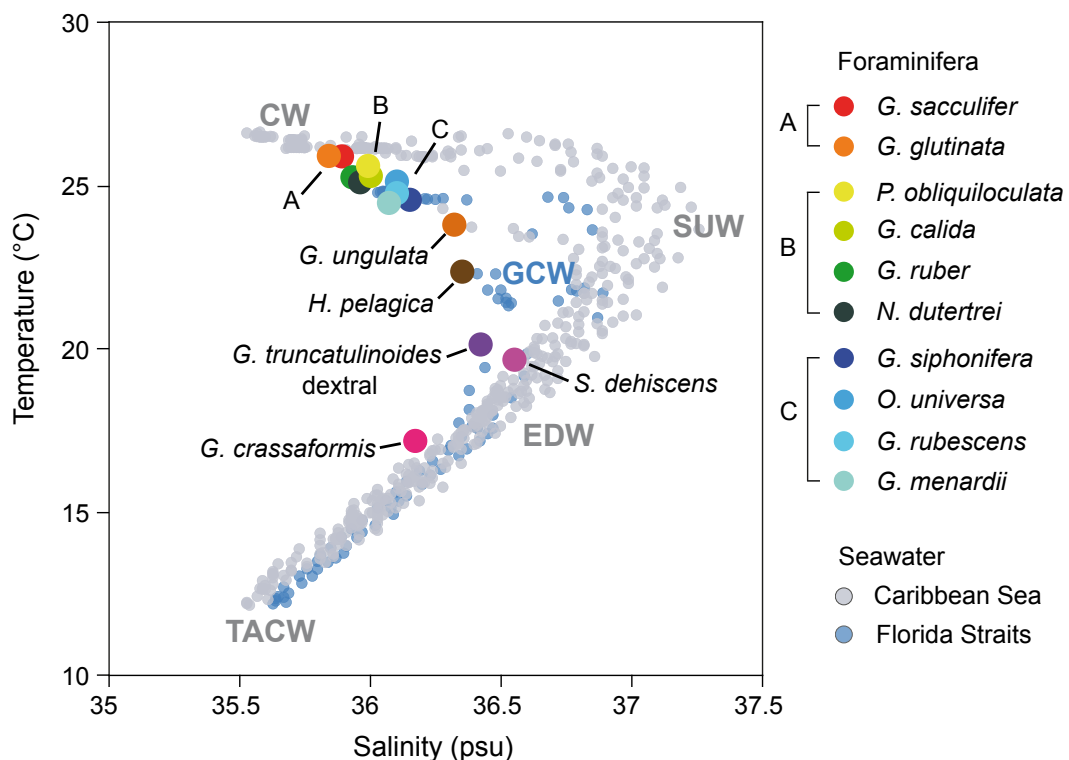**Figure 2.7:** Temperature *versus* salinity of the MSN/CTD stations compared to common species habitat. The species habitat indicates the weighted average of temperature and salinity (cf. Tab. 2.1). The data were measured during cruise M78/1 (Schönfeld et al., 2011). CW = Caribbean Water; SUW = Subtropical Under Water; GCW = Gulf Common Water; EDW = 18°C Sargasso Sea Water; TACW = Tropical Atlantic Central Water.

Vénec-Peyré et al. (1995) also concluded from sediment samples in the Somali Basin, that temperature and hydrographical structure of the upper water masses controlled the depth distribution of the foraminiferal fauna. Salinity by itself, on the other hand, showed no significant ($p>0.05$) relation to the faunal composition. Ufkes et al. (1998) similarly found no correlation between salinity and the geographical distribution of species in the eastern South Atlantic. However, low salinity lenses with high turbidity close to the coast restrict the occurrence of planktonic foraminifera (Schmuker and Schiebel, 2002; Retailleau et al., 2011; Bahr et al., 2013). Based on this observation, we speculate that, besides the high turbidity in the Gulf of Paria and in the vicinity of the Orinoco River debouchment, foraminifera were also influenced by low salinity (<35 psu) at these sites resulting in a lower standing stock.

## 2.5.2 Species specific habitat and life cycle
## 2.5.2.1 Surface dwellers (above the thermocline)

*Globigerinoides sacculifer*

The highest global abundance of the spinose species *G. sacculifer* was recorded between 20°N and 20°S and comprises over 20% of the total assemblage in surface sediments of the Atlantic and Caribbean Sea (Bé, 1977). Our plankton net stations in the central Caribbean Sea are characterized by a very high standing stock of this species, up to 50% of the foraminiferal assemblage in March 2009 (Fig. 2.4). Such high numbers were also observed in the western Caribbean Sea in May and June 1962 (Jones, 1968). Both the highest number and the largest specimens were caught in the uppermost sampling intervals (Fig. 2.6) from the euphotic zone with the highest light intensity. Nevertheless, the population density somewhat follows the deepening of the thermocline (Fig. 2.2B) and a higher standing stock was found in deeper zones of the mixed layer in the central Caribbean Sea compared to the eastern Caribbean Sea (Fig. 2.3B). The symbionts of *G. sacculifer* (e.g. dinoflagellates) and their favoured prey of calanoid copepods might particularly control this preferred depth habitat (Bé et al., 1982; Spindler et al. 1984). However, we also recognized a difference in the habitat depth of the two morphotypes of *G. sacculifer*. Even though the *sacculifer*-morphotype (Plate 1-e) was rare in plankton tows, it dwelled deeper on average (~66 m) than the *trilobus*-morphotype (~41 m) (Tab. 2.1; e.g. Jones, 1968). This distribution pattern corroborates the ontogenetic model, that *G. sacculifer* descend at a late stage of their life

cycle into deeper waters to release their gametes (Erez et al., 1991). The proportion of *G. sacculifer* was lower in surface sediments of the Caribbean Sea than in plankton tows, and the specimens were smaller (Fig. 2.4; Fig. 2.6). The size difference can also be effected by the spines on specimens collected alive in the water. In contrast, Schmuker and Schiebel (2002) reported a higher proportion of *G. sacculifer* in sediment samples than in plankton tows during their sampling campaign in April and May 1996. They concluded that seasonal variability was the main cause for these differences. Additionally, surface sediment and sediment-trap studies from the Gulf of Mexico associated a high abundance of *G. sacculifer* with a stronger Loop Current bringing warm Caribbean water into the Gulf (Brunner, 1979; Poore et al., 2013). High fluxes of *G. sacculifer* in the Gulf of Mexico were recorded during spring 2008 and 2009 (Poore et al., 2013), the same time as our sampling campaign took place. Combining the evidence from the Gulf of Mexico and eastern Caribbean, we conclude that the abundance of *G. sacculifer* is subject to seasonal variations and that during early spring large numbers of specimens thrive in the open waters of the Caribbean Sea.

*Globigerinita glutinata*

This species is ubiquitous and occurs in several different water masses (Bé and Tolderlund, 1971; Bé, 1977). Numerous studies link *G. glutinata* to phytoplankton blooms, high chlorophyll concentrations, and thus the abundance of diatoms in the water column, which is a favoured food source (Schiebel and Hemleben, 2000; Schiebel et al., 2001; Storz et al., 2009; Chapman, 2010). In our plankton samples, this species showed a distinctively high standing stock at station 221 (Fig. 2.3), which was presumably more fertile than other sites in the southern Caribbean during our sampling campaign (as discussed in Chapter 2.5.1). In the northern Atlantic Ocean, seasonal variability in the abundance of *G. glutinata* was linked to the phytoplankton spring bloom (Schiebel and Hemleben, 2000). In the Caribbean Sea, however, Schmuker and Schiebel (2002) recorded a high population density of *G. glutinata* in relation to a high nutrient supply, probably triggered by cyclonic eddies. Even though we cannot link the high abundance of *G. glutinata* to the occurrence of an eddy, we assume a high phytoplankton concentration adjacent to the chlorophyll patch (Fig. 2.2C) as the probable reason for their high abundance during March 2009.

*Globigerinoides ruber*

The species *G. ruber* is a main component of the foraminiferal assemblage. It is a spinose-species dwelling in the upper water column and dominates the subtropical and tropical oceans (Bé et al., 1971; Schmuker and Schiebel, 2002). Based on molecular studies, this species has several cryptic genotypes associated with different habitats and preferred temperatures (Kučera and Darling, 2002; Aurahs et al., 2009; Aurahs et al., 2011), which makes a definite interpretation of the distribution difficult. Sediment-traps in the East China Sea, Pacific Ocean and Panama Basin linked the flux of *G. ruber* to seasonal changes (Thunell and Reynolds, 1984; Xu et al., 2005). Neritic conditions, close the shelf, are favoured habitats, as has been observed in plankton studies off Puerto Rico (Chapter 4; Schmuker, 2000a). In a laboratory study, Bijma et al. (1992) observed that *G. ruber* reached smaller test-size under typical open ocean light irradiation ("blue"), than in fertile regions ("yellow-green"). Furthermore, the species is associated with an enhanced food supply and showed a decreasing abundance from the east to the west of the Caribbean Sea (Schmuker and Schiebel, 2002). This longitudinal gradient was linked to the Orinoco and Amazon river plumes prevailing in autumn (Corredor and Morell, 2001). The distribution patterns in our plankton and sediment samples support these previous findings. First of all, our plankton samples showed a decreasing proportion from the eastern to the western Caribbean Sea (Fig. 2.4). The highest proportion of *G. ruber* was found at station 222 (15%) and in the Florida Straits at station 211 (27%). During our sampling period in March, a very low proportion of *G. ruber* was found in the plankton samples as compared to the surface sediments in the central Caribbean Sea. In April and May 1996, Schmuker and Schiebel (2002) found a high frequency of *G. ruber* along the Antilles in both sediment and plankton samples. Jones (1968) noted a high proportion of up to 47% between November and December 1960 in his plankton nets from the central Caribbean. Beside a seasonal effect, a general decline of the species *G. ruber* white in the Atlantic and Caribbean Sea (coast of Puerto Rico) has been observed during the last decades (Chapter 4; Harbers, 2011), which may partly explain the lower population density in our plankton samples.

*Neogloboquadrina dutertrei*

Variable habitats have been reported for the non-spinose species *N. dutertrei* (Tab. 2.2) and no distinctive distribution pattern has been documented to date in the Caribbean Sea and southern California (Jones, 1968; Field, 2004). Around the Sea of Japan (Kuroyanagi and Kawahata, 2004), and in a study of the Indian Ocean and North Atlantic (Hilbrecht,

1997), it was suggested that two different populations exist for the same morphotype. One population is related to warmer temperatures, and the other population is associated with colder temperatures. Moreover, three genotypes of *N. dutertrei* have been distinguished and related to different faunal provinces (Caribbean, Coral Sea and Santa Barbara Channel) (Darling et al., 2003). Very often *N. dutertrei* has been linked to high chlorophyll concentrations and was considered to live in the thermocline (Fairbanks et al., 1982; Curry et al., 1983; Watkins et al., 1996; Steph et al., 2009). The inferred habitat depth is not only based on plankton tow observations, but also on geochemical studies (Mg/Ca and stable oxygen isotope signature) of specimens from surface sediments. For example, based on oxygen isotope data, Tedesco et al. (2007) concluded that the species adjusts its living depth to the thermocline and chlorophyll maximum, which vary during the year. The study of Steph et al. (2009) assumed a calcification depth between 140 and 160 m in the Caribbean Sea. Our plankton tow observations (and others Tab. 2.2), however, located the main habitat of *N. dutertrei* higher in the water column (~50 m). We assume, based on these observations and the fact that *N. dutertrei* hosts facultative symbionts requiring light (Gastrich, 1987), that the main habitat must be in the upper water column. However, our test-size distribution showed a slight increase in the proportion of large specimens in deeper water masses or even in the surface sediment (Fig. 2.6). We consider this trend as evidence that large specimens tend to descend and calcify deeper in the water column. Our surface catch may therefore contain juvenile specimens that did not yet reach the adult stage and test-size. Furthermore, *N. dutertrei* was grouped in the autumn-winter assemblage in the Gulf of Mexico (Spear et al., 2011) and in the Caribbean Sea (Schmuker, 2000b; Schmuker and Schiebel, 2002). The latter studies linked the species to a higher nutrient supply caused by enhanced Orinoco River outflow in autumn. In the Cariaco Basin and Panama Basin, however, an increased flux of *N. dutertrei* was recorded during spring and related to higher primary productivity triggered by upwelling (Thunell and Reynolds, 1984; Tedesco and Thunell, 2003). The species has also been associated to upwelling conditions in the Indian Ocean (Duplessy et al., 1981a). Our data, with the exception of station 221, showed that the sediment samples had a slight higher abundance of *N. dutertrei* than the respective plankton net samples (Fig. 2.4). This probably indicates seasonal variability with a lower productivity during spring. At station 221, where the highest standing stock in the water column was observed, a high chlorophyll patch (Fig. 2.2C) affected the population during the sampling time resulting in a high reproduction of specimens, which in turn created an overestimate of their abundance in early spring.

*Globorotalia ungulata and Globorotalia menardii*

A distinctive distribution pattern was discovered for the group of *G. ungulata* and *G. menardii*. In the Florida Straits, *G. ungulata* showed a prominent high standing stock in the upper water column, and was a major component of the living fauna. In contrast to this, the species was rare or even absent at the other stations (Fig. 2.3B) and in the surface sediment (Fig. 2.4). With reference to all available information, such a high number and such large specimens have not been previously reported in plankton studies. The species was only mentioned as a minor component (<1%) of the total assemblage in the Caribbean Sea (e.g. Schmuker, 2000b). The species *G. menardii* was recorded more sporadically in the Caribbean Sea, with the highest density at station 221, close to the sea-surface. In the literature however, specimens of *G. ungulata*, *G. menardii* and *Globorotalia tumida* were often pooled together as one taxon, and as a consequence different habitat patterns were not further explored (e.g. Schmuker, 2000b; Poore et al., 2013). Even though the species *G. ungulata* and *G. menardii* are close morphotypes, and juvenile forms are difficult to distinguish, they are in fact different genotypes (Seears et al., 2012). Furthermore, Brown (2007) assumed that *G. ungulata* is probably an ecophenotype of the species *G. tumida* (Plate 2-k). In general, and based on isotopic measurements, *G. tumida* develop a secondary crystalline crust and therefore geochemically represents deeper water masses (Brown, 2007; Steph et al., 2009). On the other hand, *G. ungulata* has a smooth hyaline test and dwells in shallow water depths (Brown, 2007). Indeed, our plankton samples support the hypothesis of different habitats. The living depth of *G. tumida* was deeper (~185 m) than that of *G. ungulata* (~75 m). We cannot estimate a persistent living depth for *G. menardii*, but we recorded the highest standing stock in the mixed layer, which is not surprising, as the species hosts facultative symbionts (e.g. zoochlorellae or chrysophycophytes, Gastrich, 1987; Hemleben et al., 1989). However, large specimens (>500 μm) were only found below the mixed layer and in the surface sediments (Fig. 2.6). Furthermore, geochemical studies categorize *G. menardii* as a deep dwelling, thermocline species (Steph et al., 2009; Tedesco et al., 2007). Different morphotypes were also discussed for *G. menardii* and associated with different habitats resulting in variable geochemical signals (Brown, 2007; Regenberg et al., 2010). When the species (*G. menardii, G. ungulata* and *G. tumida*) were grouped together, the highest abundance of this group in our plankton samples was recorded in the Florida Straits and Gulf of Mexico and is caused by the high population density of *G. ungulata*. Because the species were rare in surface sediment samples, we conclude a variable seasonal distribution with a maximum in colder months. This is supported by

sediment-trap studies (Thunell and Reynolds, 1984; Poore et al., 2013) and observations in plankton net samples taken in January (Jones, 1971). Even though, a seasonal effect is likely in the Florida Straits, the distinct high abundance of *G. ungulata* in the plankton nets leads us to speculate that this is either a unique observation, or that the species has had a distinct increase in its abundance over the past decades.

*Globoturborotalita rubescens*

A high abundance of empty tests of *G. rubescens* was found in the plankton tows from the central Caribbean Sea (Fig. 2.3B). We infer that the plankton tow contained a whole population after reproduction at station 220. This is only possible when the sinking speed is slow and the reproduction cycle is synchronised. *Globoturborotalita rubescens* has a small and light test, which is comparable to *G. glutinata* and therefore probably has an identical settling velocity of ~330 m day^{-1} in the water column (Berger and Piper, 1972; Takahashi and Bé 1984). High abundances of *G. rubescens* in the surface sediment from stations of the central Caribbean Sea (Fig. 2.4) indicates a high turnover and a high production rate of empty tests in this region. In the northeastern Atlantic, Storz et al. (2009) associated *G. rubescens* with warm oligotrophic environmental conditions, and as such condition also prevail in the central Caribbean Sea, this seems to be a preferred habitat.

## 2.5.2.2 Deep dwellers (below the mixed layer)

*Hastigerina pelagica*

In previous studies, *H. pelagica* was rare in the Caribbean (Jones, 1968; Schmuker, 2000b), but Bé and Hamlin (1967) and Bé and Tolderlund (1971) found high abundances of the species in the western Sargasso Sea and the Gulf Stream. In our plankton tows, the highest population density was observed in the Florida Straits (Fig. 2.3A/B). Specimens of *H. pelagica* are very fragile, have a slow settling velocity, and are sensitive to dissolution (Parker and Berger, 1971; Berger and Piper, 1972). Consequently, only one single specimen was found in our surface sediment samples. The molecular study of Weiner et al. (2012) discovered two different genotypes of *H. pelagica* (Type IIb and Type IIa) in the Caribbean Sea. Type IIb was associated with shallow water masses, above 200 m water depth. Type IIa was only found below 100 m water depth. In the Florida Straits and at station 221, the distribution pattern showed a shallow and a deep living depth (Fig. 2.3B) and probably

indicated the habitat of the two different genotypes.

*Globorotalia crassaformis*

Only low standing stocks have been described in the study area (Jones, 1968; Schmuker and Schiebel, 2002), though *G. crassaformis* comprised 7.6% of the total living fauna at station 222 (Fig. 2.4). This species is very important for paleo-studies and often taken to reconstruct deep-water properties. Geochemical studies in the Caribbean Sea proposed a calcification depth to ~500 m water depth (Steph et al., 2009). Indeed, previous plankton tows and our data recorded the highest population density in the deepest sampling intervals, and classified the species as a deep dweller (Fig. 2.3B, Tab. 2.2) (Jones, 1971; Ravelo and Fairbanks, 1992; Schmuker and Schiebel, 2002). Single juvenile specimens were found close to the sea surface above the thermocline (Fig. 2.3, e.g. Jones, 1968; Bé, 1977). Based on oxygen isotopes, Tedesco et al. (2007) linked the living depth of *G. crassaformis* in the Cariaco Basin to upwelling conditions. The authors assumed a deeper living habitat during non-upwelling periods. We see an increase in test-size from the surface water to the bottom sediment in our data (Fig. 2.6). The largest specimens in plankton nets were found in the size fraction of 300–400 μm, while the mode test size fraction was 150–250 μm. In contrast, the largest specimens in the sediment were in the 400–500 μm size fraction and the mode test-size fraction was 300–400 μm. These results confirm that *G. crassaformis* lives as small juvenile specimens in near surface waters and descends to deeper water masses as an adult to complete its life cycle.

*Globorotalia truncatulinoides*

In our samples both right-coiling (dextral) and left-coiling (sinistral) specimens of *G. truncatulinoides* were present in the foraminiferal assemblage. However, the right-coiling variety dominated the total *G. truncatulinoides* population (96%). Bé et al. (1971) found that left-coiling specimens dominated the northern Sargasso Sea and right-coiling specimens occurred mainly in the southern part of the Sargasso Sea and the Caribbean Sea. High abundances have been recorded in sediment samples of the Gulf of Mexico and Florida Straits (Jones, 1968). Quilléveré et al. (2013) identified different genotypes of *G. truncatulinoides* with distinguishable test morphology and related them to distinct water masses in the world ocean. The maximum occurrence of *G. truncatulinoides* (dextral) in different oceans of the Northern Hemisphere has been linked to the coldest months during winter and spring (December to March) (Brunner, 1979; Deuser et al., 1981; Williams et

al., 1981; Storz et al., 2009; Spear et al., 2011; Poore et al., 2013; Jonkers and Kučera, 2015). Furthermore, the specimens migrate vertically in the water column during ontogeny and therefore deep mixing of the water column (down to 600 m) enhances reproduction (Hemleben et al., 1985; Lohmann and Schweitzer, 1990). Based on test-sizes and oxygen isotopes, Birch et al. (2013) inferred that the specimens migrate in the water column and the largest individuals live below the thermocline. Another stable oxygen isotope study (Cléroux et al., 2007) suggested that *G. truncatulinoides* lives at the base of the seasonal thermocline and an increase of the temperature above 16°C causes a migration to deeper depths. Those previous studies offer an explanation for the population density of *G. truncatulinoides* close to the sea-surface in the Gulf of Mexico (Fig. 2.3A). Low temperature surface water prevailed (~20°C) when our samples were collected in early March 2009, which was the calculated main depth-habitat temperature for *G. truncatulinoides* (dextral) (Tab. 2.1). This cold winter temperature in the Gulf of Mexico probably caused an accumulation of specimens in surface waters. Although living specimens were found in the surface water, the vertical distribution pattern showed the maximum population density below the mixed layer, close to the upper thermocline (Fig. 2.3B). Schmuker and Schiebel (2002) suggested the species as a tracer for the SUW. They concluded that specimens of *G. truncatulinoides* (dextral) were transported from the Sargasso Sea into the Caribbean Sea and, as discussed by Lohmann and Schweitzer (1990), a strong thermocline inhibited their reproduction. In fact, we found small juvenile specimens (100–125 µm) and adults (400–500 µm) at the same stations. We regard these findings as a strong evidence that *G. truncatulinoides* (dextral) indeed reproduces in the Caribbean Sea, and juvenile specimens live near the sea-surface before they sink to deeper water masses to continue growing (Fig. 2.6). However, based on our data and previous studies, this species can be linked to colder temperatures (~20°C), for instance during the winter seasons, and to a main habitat close to the upper thermocline.

**Table 2.1:** Planktonic species recorded during the sampling. With maximal standing stock (ind. m$^{-3}$) in the surface water (3.5 m water depth) and water column (0–max. 400 m water depth), main regional distribution in the surface water, weighted average living depth (habitat) during sampling period (m), main living habitat above, in or below the upper thermocline, habitat temperature (°C) and salinity (psu) during sampling period, maximum and minimum test size fraction (μm), mode value of test size fraction (μm) in the water column and sediment.

| Species | Max st. stock in surface (1) | Regional distr. in surface (1) | Max st. stock in water column (2,3) | Avg. living depth (m) (2,3) | Main liv. habitat above/in/below thermocline (2,3) | Avg. Temp. (°C) (2, 4) | Avg. Salinity (psu) (2, 4) | Mode value test size fra. (2) | Max test size fra. (2) | Min test size fra. (2) | Mode value test size fra. in sediment (5) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Candeina nitida # | 0.57 | A | 0.12 | 135 ± 53 | below/above | 23.15 | 36.23 | 150–250 | 400–500 | 150–250 | 150–250 |
| Dentigloborotalia anfracta # | 3.16 | A | 1.55 | 73 ± 5 | above | 24.11 | 35.96 | 100–125 | 125–150 | 100–125 | 100–125 |
| Globigerina bulloides | 11.04 | A/B | 1.56 | 59 ± 46 | above/in/below | 25.28 | 35.93 | 150–250 | 250–300 | 150–250 | 150–250 |
| Globigerinella calida | 22.64 | B | 23.44 | 51 ± 14 | above | 25.30 | 36.00 | 150–250 | >500 | 100–125 | 150–250 |
| Globigerinoides conglobatus # | 0.84 | B | 0.10 | 150 ± 25 | below* | 20.80 | 36.76 | 300–500 | 400–500 | 300–400 | 400–500 |
| Globorotalia crassaformis | 0.24 | B | 1.20 | 201 ± 42 | below/above | 17.19 | 36.17 | 150–250 | 300–400 | 125–150 | 300–400 |
| Globigerinoides elongatus # | 0.48 | C | 0.90 | 83 ± 22 | above | 22.38 | 36.56 | 150–300 | 400–500 | 150–250 | 150–250 |
| Globigerina falconensis # | 3.15 | A | 1.56 | 85 ± 53 | above/below | 23.41 | 36.18 | 150–250 | 150–250 | 125–150 | 250–300 |
| Globigerinita glutinata | 95.00 | B | 73.01 | 46 ± 7 | above | 25.91 | 35.84 | 100–125 | 250–300 | 100–125 | 100–125 |
| Globorotalia hirsuta # | 0.43 | C | - | - | - | - | - | - | - | - | - |
| Globorotalia menardii | 7.77 | A/B | 2.34 | 81 ± 43 | above/in/below | 24.47 | 36.07 | 100–125 | >500 | 100–125 | >500 |
| Globigerinita minuta # | - | - | 0.40 | 48 ± 47 | above/below | 25.49 | 35.85 | 100–125 | 150–250 | 100–125 | - |
| Globigerinoides ruber (p/w) | - | - | 25.93 | 46 ± 15 | above | 25.26 | 35.93 | 150–250 | 400–500 | 100–125 | 150–250 |
| Globigerinoides ruber pink | 53.69 | B | 14.06 | 30 ± 8c | above | - | - | - | - | - | 150–250 |
| Globigerinoides ruber white | 21.74 | B | 7.03 | 32 ± 14c | above | - | - | - | - | - | 150–250 |
| Globoturborotalita rubescens | 40.27 | B | 8.59 | 67 ± 14 | above | 24.77 | 36.10 | 100–125 | 150–250 | 100–125 | 100–125 |
| Globigerinoides sacculifer | 114.09 | B | 42.90 | 41 ± 9 | above | 25.90 | 35.89 | 150–250 | >500 | 100–125 | 150–250 |
| Globigerinoides sacculifer ws # | - | - | 1.60 | 66 ± 25 | above | 25.28 | 36.10 | >500 | >500 | 250–300 | 300–400 |
| Globorotalia scitula # | 3.28 | A | 0.33 | 231 ± 15 | below* | 16.16 | 36.10 | 100–125 | 150–250 | 100–125 | 125–150 |
| Globigerinella siphonifera | 11.02 | A/C | 4.69 | 69 ± 22 | above/in/below | 24.49 | 36.15 | 300–400 | 400–500 | 125–150 | 300–400 |
| Globoturborotalita tenella # | - | - | 0.10 | 60 | above | 23.92 | 36.58 | 100–125 | 100–125 | 100–125 | 100–125 |
| Globorotalia tumida # | - | - | 0.20 | 185 ± 49 | above/in | 21.72 | 36.50 | 400–500 | >500 | 250–300 | 300–500 |
| Globorotalia truncatulinoides d. | 3.68 | A/C | 0.80 | 176 ± 18 | below/in* | 20.14 | 36.42 | 150–250 | 400–500 | 100–125 | 250–400 |
| Globorotalia truncatulinoides s. # | - | - | 0.07 | 135 ± 39 | below/in/above | 22.37 | 36.51 | 150–250 | 150–250 | 100–125 | 250–400 |
| Globorotalia ungulata | 13.08 | A | 11.72 | 75 ± 5 | above | 23.81 | 36.32 | 150–250 | >500 | 100–125 | 150–250 |
| Globigerina uvula # | 2.61 | B | - | - | - | - | - | - | - | - | - |
| Hastigerina pelagica | 3.28 | A/B | 0.78 | 125 ± 42 | below/in* | 22.37 | 36.35 | 150–250 | >500 | 125–150 | >500 |
| Neogloboquadrina dutertrei | 40.25 | A/B | 12.00 | 54 ± 10 | above | 25.11 | 35.96 | 150–250 | 400–500 | 100–125 | 300–400 |
| Neogloboquadrina incompta | 5.86 | A/B/C | 1.20 | 88 ± 44 | above/in/below | 24.12 | 35.99 | 125–150 | 300–400 | 100–125 | 150–250 |
| Orbulina universa | 4.93 | A/B | 2.40 | 58 ± 16 | above | 25.13 | 36.10 | >500 | >500 | 150–250 | >500 |
| Pulleniatina obliquiloculata | 7.89 | A | 3.20 | 61 ± 29 | above | 25.61 | 35.99 | 300–400 | 400–500 | 125–150 | 400–500 |
| Sphaeroidinella dehiscens | - | - | 1.04 | 201 ± 6 | below/in | 19.68 | 36.55 | >500 | >500 | 250–300 | >500 |
| Tenuitella iota # | 1.64 | C | - | - | - | - | - | - | - | - | - |
| Tenuitella parkerae # | - | - | 0.20 | 62 ± 91 | below/above | 22.28 | 36.47 | 100–125 | 100–125 | 100–125 | - |
| Turborotalita humilis # | 7.49 | C | - | - | - | - | - | - | - | - | - |
| Turborotalita quinqueloba | 20.13 | B | 6.25 | 103 ± 74 | in/below/above | 23.23 | 35.95 | 100–125 | 150–250 | 100–125 | 100–125 |

1 = Plankton Filter (PF); 2 = Multi-closure net (MSN); 3 = Apstein net (AN); 4 = CTD; 5 = Surface sediment; A = Gulf of Mexico; B = East Caribbean; C = Santaren Channel and Coast of Cuba
ws = *G. sacculifer* with a sac-like last chamber; d. = dextral; s. =sinistral; * = single individuals also found in PF samples (3.5 m water depth); # = low abundance; only single individuals were found in the water column

**Table 2.2:** Living depth (m), salinity (psu) and temperature (°C) range of different species as noted in previous studies.

| Author | Area (data of plankton studies) | G. calida | G. crassaformis | G. glutinata | G. menardii | G. ruber* | G. rubescens | G. sacculifer | G. siphonifera | G. truncatulinoides | H. pelagica | N. dutertrei |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bé et al. (1985) | Panama Basin | 50–200 m | | 0–25 m | 25–50 m | 0–25 m | | 0–50 m | 25–50 m | | 25–50 m | 25–50 m |
| Bé and Tolderlund (1971) | Atlantic, Indian ocean | | 16–27°C | 24–27°C[a] | 20–25°C[a] | 21–29°C[a] | | 24–30°C[a] | 19–28°C[a] | 17–22°C[a] | 20–26°C[a] | 16–24°C[a] |
| Bijma et al. (1990) | Experimental data[b] | | | | <16 – <31°C <27 – <44 psu | 14–32°C 22–49 psu | | 14–32°C 24–47 psu | 11–30°C 27–45 psu | | | 15–32°C 25–46 psu |
| Jones (1971) | Florida Straits | | 100–350 m 16–23°C 36.61 psu | 0–50 m 25–28°C 35.98 psu | 50–150 m 17.6–27.7°C 36.1–36.5 psu | 0–100 m 24–28.8°C 35.9–36.7 psu | | 0–100 m 24.6–28.8°C 35.9–36.4 psu | 75–200 m 19.5–26.0°C 36.1–36.6 psu | 175–225 m 18.8–21.5°C 36.5–36–8 psu | 50–150 m 25.2–27.5°C 36.1–36.4 psu | 50–100 m 19.1–24.8°C 36.1–36.5 psu |
| Jones (1968) | Western Caribbean, Gulf of Mexico | | Surface to below 300 m | | 0–100 m | 0–50 m | | 0–75 m | 0–100 m | 0–150 m | 0–100 m | surface |
| Ravelo and Fairbanks (1992) | Tropical Atlantic | | 80–100 m | | 30–60 m | 0–20 m | | 0–30 m | 30–60 m | 80–100 m | | 30–60 m |
| Retailleau et al. (2011) | Atlantic | 40 m 13.1°C 35.5 psu | | 37 m 13°C 35.7 psu | | | | | | | | |
| Schmuker and Schiebel (2002) | Antilles arc | 58 m 26.36°C 36.34 psu | 230 m 17.58°C 36.26 psu | 39 m 26.47°C 36.17 psu | 52 m 26.32°C 36.13 psu | 34[1]; 37[2] m 26.5[1,2]°C 36.1[1]; 36.2[2] psu | 54 m 25.96°C 36.42 psu | 40 m 26.26°C 36.24 psu | 51 m 26.46°C 36.30 psu | 161 m 21.47°C 36.75 psu | 108 m 24.85°C 36.42 psu | 39 m 26.27°C 36.12 psu |
| Žarić et al. (2006) | Global model range of SST[#] | 9.3–31°C | | 1.9–31°C | 13.3–30.5°C | 16.4–29.6°C[1] 9.8–31°C[2] | 16.3–29.8°C | 9.7–31°C | 11.9–31°C | 3.5–29.8°C | | 2.6–31°C |

a = max peak in surface distribution; b = upper and lower optimum limit; 1 = pink variety; 2 = white variety
*average of pink and white variety; # = data of foraminiferal fluxes and actual sea-surface-temperature (SST)

# 2.6 Summary and conclusion

Our census of plankton and sediment samples has significantly added to the pre-existing database of the spatial distribution of subtropical and tropical planktonic foraminifera in the Caribbean. The results verify previous observations and reduce uncertainties when using planktonic foraminifera for paleoenvironmental reconstructions.

The vertical and spatial distribution of the planktonic foraminiferal composition showed a significant relationship to seawater temperature. Moreover, enhanced reproduction of the foraminiferal population in the eastern Caribbean Sea can be linked to high food availability (e.g. diatoms and copepods) sustained by a patch with high chlorophyll concentrations adjacent to station 221. On the other hand, high turbidity, and presumably low salinity, expelled planktonic foraminifera from the Orinoco River plume and from the Gulf of Paria. In the Santaren Channel, high frequencies of meroplanktonic specimens in the surface water indicate additional food competitors that probably reduced the number of planktonic foraminifera.

As previously documented in the literature (e.g. Jones, 1968; Schmuker and Schiebel, 2002) *G. sacculifer*, *G. glutinata* and *G. ruber* characterize the Caribbean fauna in the upper water column during spring and also represent the dominant species in surface sediments. Therefore no major change took place in the foraminiferal composition during the last decades and two millennia. However, differences between the living and the fossil assemblages point to a large seasonal variable abundance of some species. Large specimens and a high frequency of *G. sacculifer* can be associated with oligotrophic offshore conditions in the Caribbean Sea during early spring. *Globigerinoides ruber*, however, showed a lower abundance during spring than in other seasons and probably favours neritic conditions with an elevated nutrient supply from riverine plumes. A high population density of *G. glutinata* was found in near-surface waters in the southeastern Caribbean Sea adjacent to a high chlorophyll patch. The species can be linked to a high phytoplankton concentration, as reported from other areas (Schiebel et al., 2001; Storz et al., 2009).

Juvenile specimens of *N. dutertrei* live in surface waters and a high population density at station 221 is likely related to high food supply. However, an overall lower proportion in the water column during spring indicates that *N. dutertrei* is more abundant in other seasons. For the first time, a high population density of large specimens of *G. ungulata* (>400 μm) was observed in the uppermost water column in the Florida Straits.

The low abundance in the sediment probably indicates a seasonal effect, but an increased occurrence of *G. ungulata* over the past decades in this area might also be possible. *Globoturborotalita rubescens* prefers the oligotrophic conditions of the offshore Caribbean Sea and there was evidence for a synchronised reproduction. Small and juvenile specimens of *G. crassaformis* were found in the deepest sampling interval of the water column and large specimens were only observed in surface sediments. Thus large adult specimens are rather useful to reconstruct properties of deep-water masses below 400 m. The main habitat of *G. truncatulinoides* (dextral) is close to the upper thermocline and can be associated with colder temperatures (~20°C) during winter seasons. There is evidence that the species reproduces in the Caribbean Sea, even though a strong thermocline inhibits deep mixing of the water column.

## Acknowledgements

**Plate 1**

**Scanning electron micrographs (SEM)**

| Species | Sample<br>Cruise: Station (Water depth) |
|---|---|
| **a–b:** *Globigerinella calida* | M78/1: 211-6 (100–200 m) |
| **c–d:** *Globigerinella siphonifera* | M78/1: 211-6 (100–200 m)<br>M78/1: 211-5 (200–300 m) |
| **e:** *Globigerinoides sacculifer* – with sac-like chamber | M78/1: 211-5 (60–100 m) |
| **f:** *Globigerinoides sacculifer* | M78/1: 211-6 (0–60 m) |
| **g:** *Globigerinoides ruber* | M78/1: 221-8 (0–40 m) |
| **h–i:** *Hastigerina pelagica* | M78/1: 222-6 (180–300 m) |
| **j-l:** *Sphaeroidinella dehiscens* – open (j) | M78/1: 211-5 (200–300 m)<br>M78/1: 219-7 (125–180 m)<br>M78/1: 220-9 (150–220 m) |
| **m:** *Orbulina universa* – juvenile stage | M78/1: 211-5 (0–60 m) |
| **n:** *Orbulina universa* – open | M78/1: 220-8 (0–70 m) |
| **o:** *Orbulina universa* | M95: 531 (60–100 m) |

**Plate 1**



a

b

c

d

e

f

g

h

j

k

i

m

n

o

l

— 100 µm
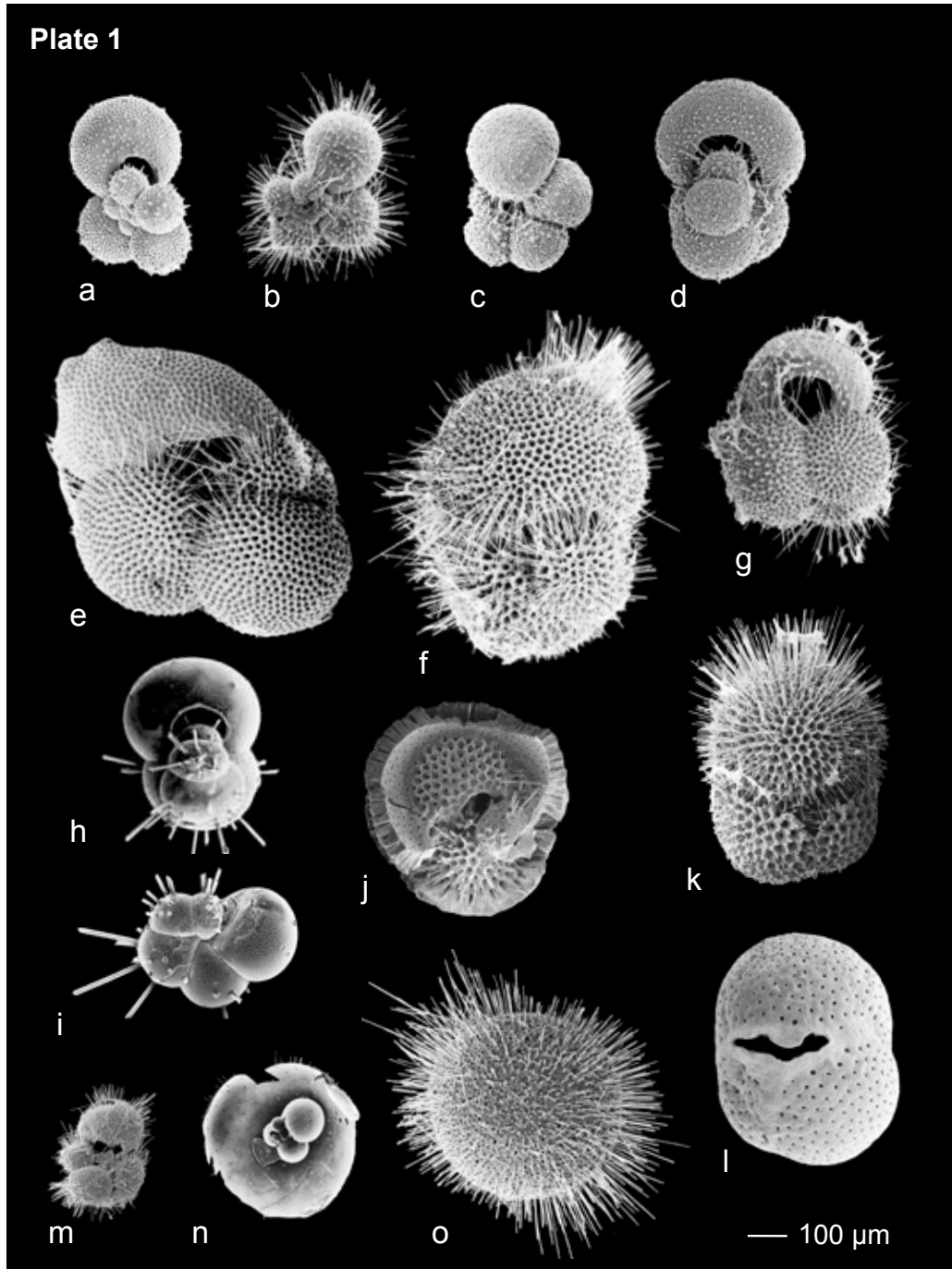
## Plate 2

### Scanning electron micrographs (SEM)

| Species | Sample<br>Cruise: Station (Water depth) |
|---|---|
| **a–b:** *Globorotalia crassaformis* | M78/1: 222-6 (180-300 m)<br>M78/1: 222-7 (180-300 m) |
| **c–d:** *Globorotalia truncatulinoides* dextral | M78/1: 221-7 (210-300 m)<br>M78/1: 221-7 (150-210 m) |
| **e–f:** *Pulleniatina obliquiloculata* | M78/1: 219-7 (0-60 m)<br>M78/1: 219-8 (180-220 m) |
| **g–h:** *Globorotalia menardii* | M78/1: 221-7 (150-210 m)<br>M78/1: 220-8 (0-70 m) |
| **i–j:** *Globorotalia ungulata* | M78/1: 211-6 (0-60 m)<br>M78/1: 211-6 (60-100 m) |
| **k:** *Globorotalia tumida* | M78/1: 219-8 (220-400 m) |
| **l:** *Neogloboquadrina dutertrei* | M78/1: 221-7 (60-150 m) |
| **m:** *Globigerinita glutinata* | M78/1: 221-7 (0-40 m) |
| **n:** *Globoturborotalita rubescens* | M78/1: 219-8 (220-400 m) |
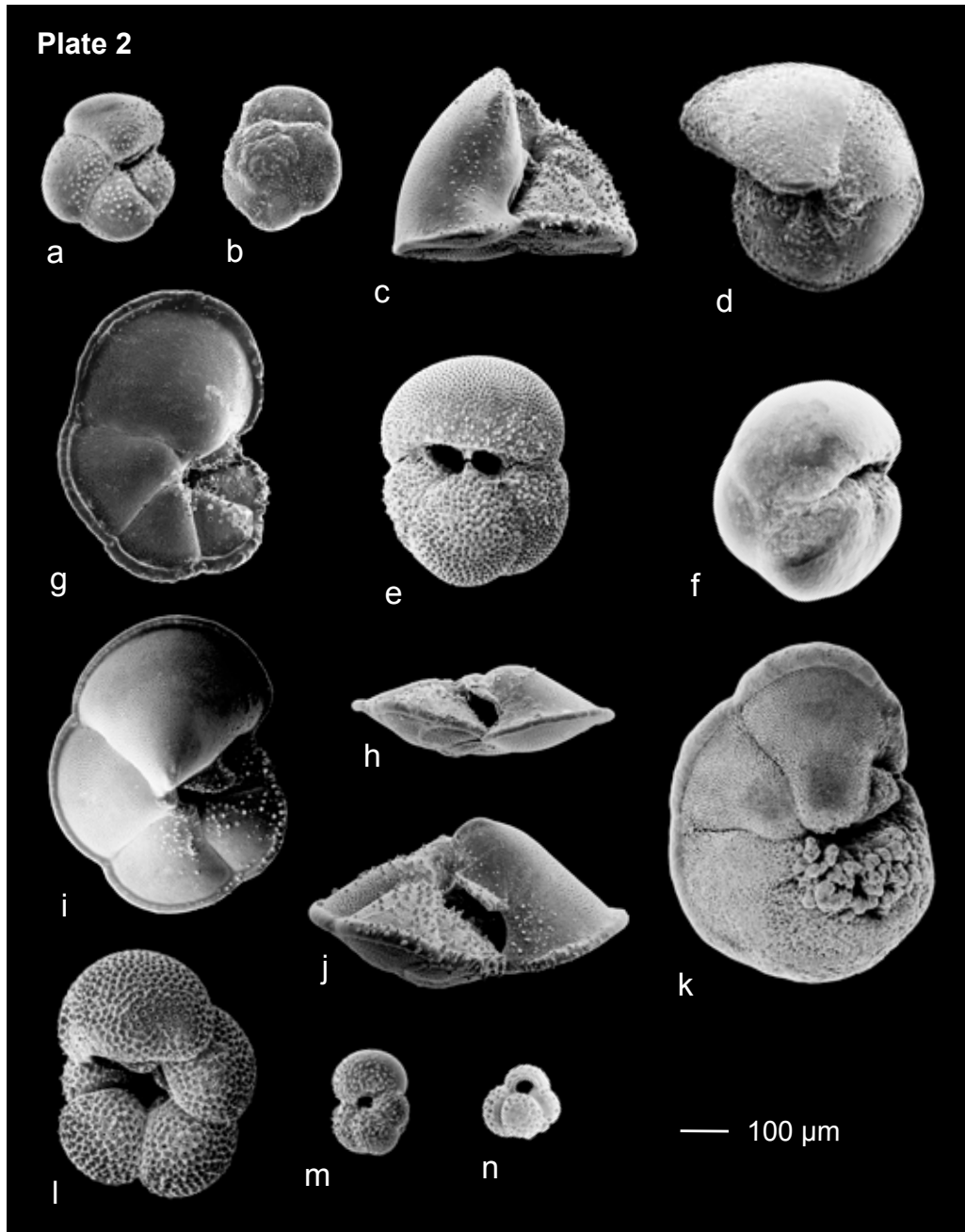
**Plate 2**

## Plate 3

### Optical microscope images

| Species | Sample<br>Cruise: Station (Water depth) |
|---|---|
| **a:** *Globorotalia menardii* | M95: 531 (60-100 m) |
| **b–c:** *Globorotalia ungulata* | M94: 474 (0-20 m) |
| **d:** *Globorotalia truncatulinoides* dextral | M78/1: PF 12 (3.5 m) |
| **e:** *Pulleniatina obliquiloculata* | M94: 474 (60-100 m) |
| **f:** *Globigerinoides sacculifer* | M94: 474 (0-20 m) |
| **g:** *Globigerinoides ruber* white | M95: 487 (20-40 m) |
| **h:** *Globigerinoides ruber* pink | M95: 487 (0-20 m) |
| **i:** *Orbulina universa* | M95: 531 (60-100 m) |
| **j:** *Hastigerina pelagica* | M95: 531 (60-100 m) |
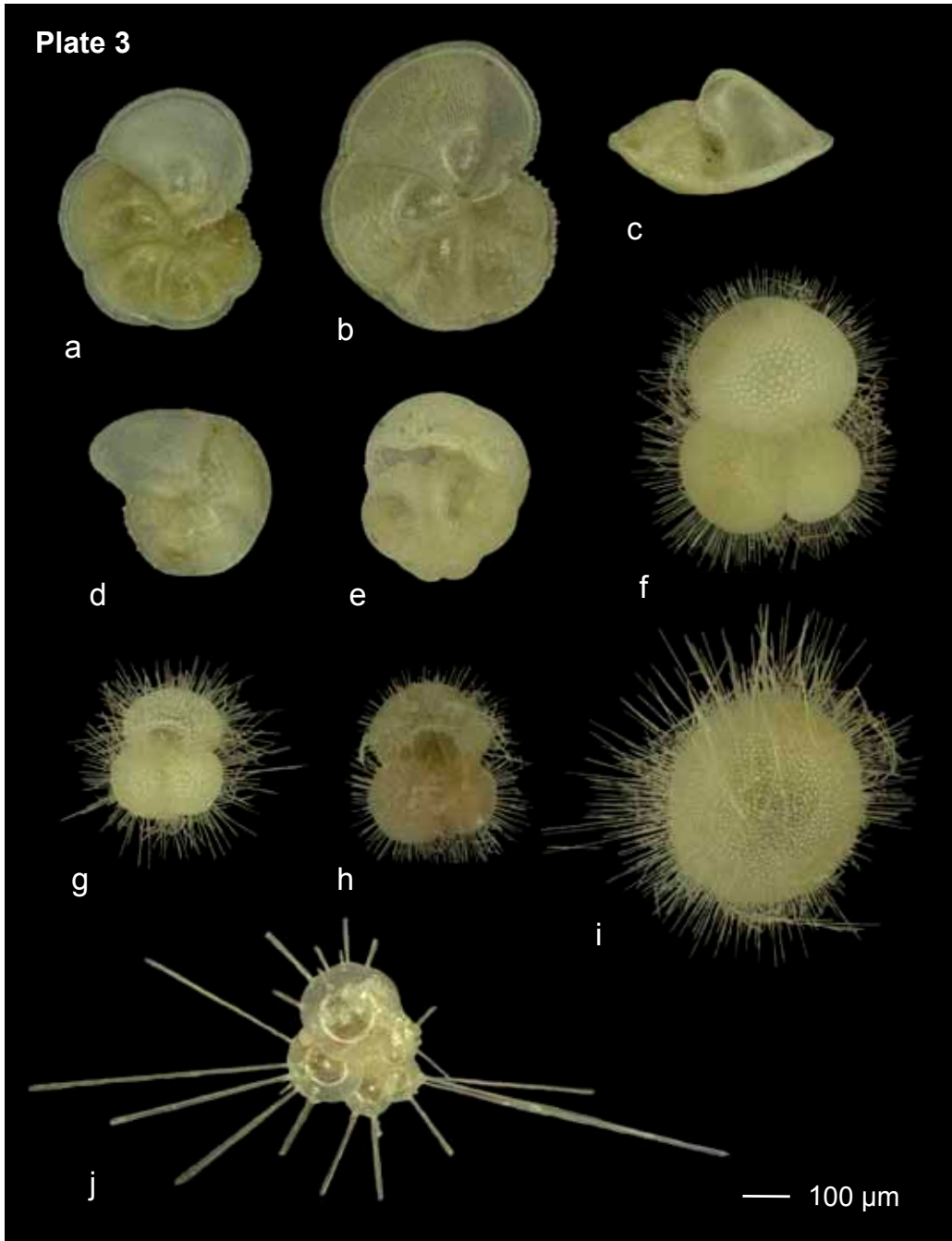
**Plate 3**

# CHAPTER 3

# Mg/Ca and $\delta^{18}$O in living planktonic foraminifera from the Caribbean, Gulf of Mexico and Florida Straits

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*This chapter is in preparation for submission*

## Abstract

Past ocean temperatures and salinities are successfully approximated from combined stable oxygen isotopes ($\delta^{18}$O) and Mg/Ca measurements in fossil foraminifera. To further support this approach, we collected living planktonic foraminifera by net sampling and pumping of sea surface waters from the Caribbean Sea, the eastern Gulf of Mexico, and Florida Straits. Analyses of $\delta^{18}$O and Mg/Ca in eight living planktonic species (*Globigerinoides sacculifer*, *Orbulina universa*, *Neogloboquadrina dutertrei*, *Pulleniatina obliquiloculata*, *Globorotalia menardii*, *Globorotalia ungulata*, *Globorotalia truncatulinoides* and *Globorotalia tumida*) were compared to measured *in-situ* properties of the ambient seawater (temperature, salinity and $\delta^{18}$O$_{seawater}$) and fossil tests of underlying surface sediments. "Vital effects" such as symbiont activity and test-growth cause $\delta^{18}$O disequilibria to the ambient seawater and a large scatter in foraminiferal Mg/Ca. Overall, ocean temperature excites the most prominent environmental influence on $\delta^{18}$O$_{calcite}$ and Mg/Ca. Enrichment of the heavier $^{18}$O isotope in living specimens below the mixed layer and in fossil tests are clearly related to lowered *in-situ* temperatures and gametogenic calcification. Mg/Ca-based temperature estimates of *G. sacculifer* indicate seasonal maximum accumulation rates on the seafloor in early spring (March) at stations of the Caribbean Sea and later in the year (May) in Florida Straits, related to the respective mixed layer temperatures of ~26°C. Notably, *G. sacculifer* reveals a positive linear relationship between foraminiferal derived $\delta^{18}$O$_{seawater}$ estimates and both measured *in-situ* $\delta^{18}$O$_{seawater}$ and salinity. Our results affirm the applicability of

existing $\delta^{18}O$ and Mg/Ca calibrations for the reconstruction of past ocean temperatures and $\delta^{18}O_{seawater}$ reflecting salinity due to the convincing accordance of proxy data in both living and fossil foraminifera, and *in-situ* environmental parameters. Large "vital effects" and seasonally varying proxy signals, however, need to be taken into account.


# 3.1 Introduction

Calcite tests of planktonic foraminifera are precipitated from the surrounding seawater and their stable oxygen isotope compositions ($\delta^{18}O_{calcite}$) and Mg/Ca ratios are established proxies to reconstruct past ocean conditions (e.g. Erez and Luz, 1983; Nürnberg et al., 2000). The $\delta^{18}O_{calcite}$ signature depends on the ambient seawater temperatures and oxygen isotopic compositions ($\delta^{18}O_{seawater}$) the planktonic organism is thriving in. Their relationship was defined in several $\delta^{18}O$-paleotemperature equations (e.g. Erez and Luz, 1983; Bouvier-Soumagnac and Duplessy, 1985; Bemis et al., 1998). Earlier studies showed that $\delta^{18}O_{calcite}$ reveals an offset to the equilibrium of the seawater, caused by environmental factors (e.g. salinity, carbonate ion concentration [$CO_3^{2-}$], ocean pH) and/or biological controlled processes, so-called "vital-effects" (Weiner and Dove, 2003) (e.g. symbiont photosynthesis, respiration) as influencing factors (Spero and Lea, 1993; Spero et al., 1997; Bemis et al., 1998; Bijma et al., 1999).

Mg/Ca ratios in foraminiferal tests are predominantly controlled by ocean temperature. Meanwhile, robust benthic and planktonic species-specific calibrations exist (e.g. Nürnberg, 1995; Nürnberg et al., 1996; Lea et al., 1999; Anand et al., 2003; Regenberg et al., 2009), which allow to reconstruct the thermal structure of the entire water column, even on timescales of million of years. The incorporation of magnesium during calcification is largely driven by physiological processes (e.g. $Mg^{2+}$ uptake by mitochondria, Spero et al. 2015), which may cause Mg/Ca heterogeneity in single tests with diurnal bandings in some species (e.g. *Orbulina universa*) (Erez, 2003; Sadekov et al., 2005; Bentov and Erez, 2006; Spero et al., 2015). Further, environmental parameters (e.g. salinity, [$CO_3^{2-}$], ocean pH) may affect foraminiferal Mg/Ca (Nürnberg et al., 1996; Lea et al., 1999; Russel et al., 2004; Kisakürek et al., 2008). Most critical are carbonate dissolution processes that considerably lower Mg/Ca in foraminiferal tests (Brown and Elderfield, 1996; Rosenthal et al., 2000; Regenberg et al., 2006).

Only few (isotope) geochemical studies were accomplished on recent/living planktonic foraminifera, either collected from the water column or cultured under controlled laboratory conditions. These studies are an important addition to a multitude of core-top and downcore studies, allowing us to assess the different steering factors on $\delta^{18}O_{calcite}$ and Mg/Ca during biomineralization (e.g. Kahn, 1979; Erez and Honjo, 1981; Nürnberg et al., 1996; Lea et al., 1999; Russel et al., 2004; Kisakürek et al., 2008; Spero et al., 2015).

We here systematically sampled the upper water column of the Caribbean, the eastern Gulf of Mexico, and Florida Straits for living tropical and subtropical planktonic foraminifera using plankton nets and on board pumping devices. $\delta^{18}O_{calcite}$ and Mg/Ca analyses within bulk calcite and single chambers of living specimens collected from different depth-intervals were i) related to ocean parameters (temperature, salinity, $\delta^{18}O_{seawater}$) measured in water samples from CTD sampling stations nearby, and ii) compared to fossil counterparts from underlying or nearby surface sediments. Our integrated approach aims to evaluate (i) "vital-effects" under natural conditions, (ii) the ontogenetic development in particular test growth and (iii) the impact of environmental conditions on foraminiferal $\delta^{18}O_{calcite}$ and Mg/Ca to further substantiate their potential as paleoceanographic proxies.

# 3.2 Material and Methods

## 3.2.1 Sampling and preparation of planktonic foraminifera

Light stable isotope and geochemical analyses were performed on living and fossil foraminiferal tests sampled from plankton nets, pumping from below the ship, and surface sediments obtained during cruises SO164 (RV Sonne) in May/June 2002 (Nürnberg et al., 2003) and M78/1 (RV Meteor) in February/March 2009 (Schönfeld et al., 2011) (Fig. 3.1; Tab. 3.1). To collect living planktonic foraminifera, the Hydrobios Midi multiple opening-closing plankton net (MSN) with a mesh size of 100 μm was deployed at five stations in different water depth intervals (surface to max. 400 m) (Tab. 3.1). Further sampling of living specimens was accomplished by pumping seawater from 3.5 m water depth during ship´s transit and subsequent filtering over a 63 μm sieve (PF samples). Immediately after sampling, the plankton samples (MSN and PF) were preserved in a mix of 50% ethanol and seawater. The MSN samples were stained with Rose Bengal (2 g/l). Surface sediment samples were recovered by Multicorer and USNEL giant box corer at positions close to the

MSN stations (Tab. 3.1). During cruise M78/1, salinity and temperature were recorded by the RBR XR-420 Conductivity-Temperature-Depth (CTD) profiler and by the shipboard thermosalinograph. For stable isotope analyses in seawater ($\delta^{18}O_{seawater}$), water samples were collected at different water depths (Tab. 3.1) with the shipboard rosette Niskin bottle system connected to the CTD profiler, filled in glass bottles (100 ml) and poisoned with 0.2 ml $HgCl_2$ to prevent biological activity.

In the home laboratory, the plankton net samples were rinsed with tap water and all foraminifera were picked wet with a glass pipette. The picked foraminifera were dried on a filter paper at room temperature, fractionated into different mesh-sizes (100–125, 125–150, 150–250, 250–300, 300–400, 400–500 and >500 μm) and identified on species level after Bé (1967) and Hemleben et al. (1989). For (isotope) geochemical analyses, individual tests from eight different species were selected including: *Globigerinoides sacculifer* "without sac" (spherical last chamber; recently termed *Trilobatus sacculifer*; Spezzaferri et al., 2015)*, Orbulina universa, Neogloboquadrina dutertrei, Pulleniatina obliquiloculata, Globorotalia menardii, Globorotalia ungulata, Globorotalia truncatulinoides* (dextral), and *Globorotalia tumida* (Appendix B). Only cytoplasm-bearing specimens with an intact calcite test were considered for analyses, indicating that the foraminifera were still alive when collected. For all species, the weighted average living depth (m) and habitat (=living) temperature (°C) (temperature at the weighted average living depth) was calculated based on standing stocks (individual $m^{-3}$) in the water column (Tab. 3.3; cf. Chapter 2).

Surface sediment samples were freeze-dried, wet sieved using tap water over a 63 μm sieve, and dried at 40°C. Single intact foraminiferal tests were picked from the 355–400 μm size fraction, in order to stay compatible with published data from similar Caribbean station sites (existing $\delta^{18}O_{calcite}$ data from Steph et al., 2009 and Mg/Ca data from Regenberg et al., 2006).
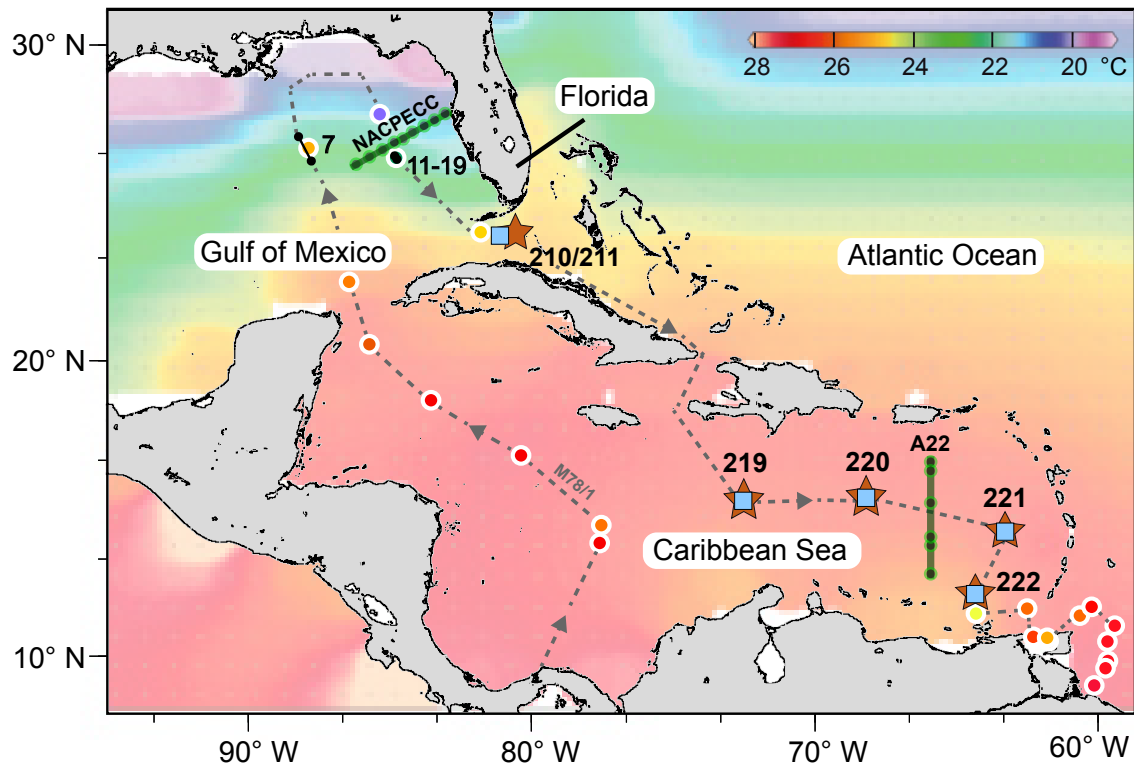
**Figure 3.1:** Sea surface temperature chart (SST) of the Caribbean Sea, Gulf of Mexico and Florida Straits showing sampling locations (Tab. 3.1). Brown stars: Multiclosure net samples (MSN) and CTD stations (RV Meteor cruise M78/1). Black dots and lines: Plankton filter samples (PF, M78/1). Blue squares: Surface sediment samples (M78/1 and RV Sonne cruise SO164, cf. Regenberg et al., 2006; Steph et al., 2009). Green lines and grey dots: World Ocean Circulation Experiment (WOCE) transect line A22 (stations 10–15) and North American Carbon Program (NACP) line NACPECC (stations 20-28) (cchdo.ucsd.edu). Coloured shading: SST illustrated with ODV (Schlitzer, 2009) using World Ocean Atlas 2013 (WOA13) data from January-March (Locarnini et al., 2013). Coloured dots with white outline: SST (3.5 m water depth) recorded during cruise M78/1 with the shipboard thermosalinograph (Schönfeld et al., 2011; Appendix A). Grey dashed line: Cruise track of RV Meteor cruise M78/1 in February and March 2009.

**Table 3.1:** Station list of sediment, water and plankton samples obtained during cruises SO164 and M78/1 (Nürnberg et al., 2003; Schönfeld et al., 2011). MUC: Multicorer; GKG: Giant box corer; CTD: Conductivity Temperature Depth profiler; MSN: Hydrobios Midi multiple opening-closing plankton net; PF: Plankton filter. *indicates surface sediment sites close to MSN station (1) 219, (2) 220, (3) 221 and (4) 211 (Fig. 3.1).

| Cruise | Date | Device | Station No. | Latitude N (Start-End) | Longitude W (Start-End) | Water depth (m) | Sampling intervals/depth |
|---|---|---|---|---|---|---|---|
| SO164 | 27.05.2002 | MUC | 02-3 *(1) | 15°18.29 | 72°47.06 | 2977 | 0–1 cm |
| SO164 | 07.06.2002 | MUC | 22-2 *(2) | 15°24.00 | 68°12 | 4506 | 0–1 cm |
| SO164 | 09.06.2002 | MUC | 24-3 *(3) | 14°11.89 | 63°25.43 | 1545 | 0–1 cm |
| M78/1 | 10.03.2009 | MUC | 212-1 *(4) | 24°11.10 | 81°15.74 | 723 | 0–1 cm |
| M78/1 | 19.03.2009 | GKG | 222-8 | 12°1.48 | 64°28.50 | 1019 | surface |
| M78/1 | 10.03.2009 | CTD | 210-13 | 24°14.88 | 80°55.10 | 452 | 40, 85, 100, 150, 190, 275, 400 m |
| M78/1 | 10.03.2009 | CTD | 211 | 24°15.50 | 80°54.81 | 456 | – |
| M78/1 | 15.03.2009 | CTD | 219-1 | 15°18.27 | 72°47.08 | 2956 | 50, 100, 220, 600 m |
| M78/1 | 16.03.2009 | CTD | 220-1 220-2 | 15°23.99 15°23.99 | 68°12.01 68°11.99 | 4480 4480 | 10, 61, 91, 136, 196, 485 m |
| M78/1 | 18.03.2009 | CTD | 221-1 221-2 | 14°11.89 14°11.98 | 63°25.45 63°25.41 | 1534 1534 | 10, 30, 60, 100, 150, 200, 500 m |
| M78/1 | 19.03.2009 | CTD | 222-1 | 12°1.49 | 64°28.55 | 1023 | 10, 30, 55, 75, 140, 229 m |
| M78/1 | 10.03.2009 | MSN | 211-5 211-6 | 24°15.50 24°15.30 | 80°54.81 80°54.69 | 456 453 | 0–60, 60–100, 100–200, 200–300, 300–400 m |
| M78/1 | 15.03.2009 | MSN | 219-7 219-8 | 15°18.30 15°18.30 | 72°47.06 72°47.06 | 2960 2960 | 0–60, 60–125, 125–180, 180–220, 220–400 m |
| M78/1 | 17.03.2009 | MSN | 220-8 220-9 | 15°23.99 15°23.99 | 68°12.00 68°12.00 | 4481 4482 | 0–70, 70–110, 110–150, 150–220, 220–300 m |
| M78/1 | 18.03.2009 | MSN | 221-7 221-8 | 14°11.89 14°11.89 | 63°25.43 63°25.43 | 1533 1535 | 0–40, 40–60, 60–150, 150–210, 210–300 m |
| M78/1 | 19.03.2009 | MSN | 222-6 222-7 | 12°1.57 12°1.55 | 64°28.80 64°28.80 | 1031 1028 | 0–40, 40–80, 80–120, 120–180, 180–300 m |
| M78/1 | 03.03.2009 | PF | 7 | 26°31.38– 27°39.86 | 87°5.32– 88°16.23 | – | 3.5 m |
| M78/1 | 06.03.2009 | PF | 11 | 26°18.35– 26°12.21 | 84°44.97– 84°41.92 | – | 3.5 m |
| M78/1 | 06.03.2009 | PF | 12 | 26°10.7– 26°12.48 | 84°44.08– 84°43.40 | – | 3.5 m |
| M78/1 | 07.03.2009 | PF | 19 | 26°12.18– 26°12.18 | 84°43.87– 84°43.87 | – | 3.5 m |
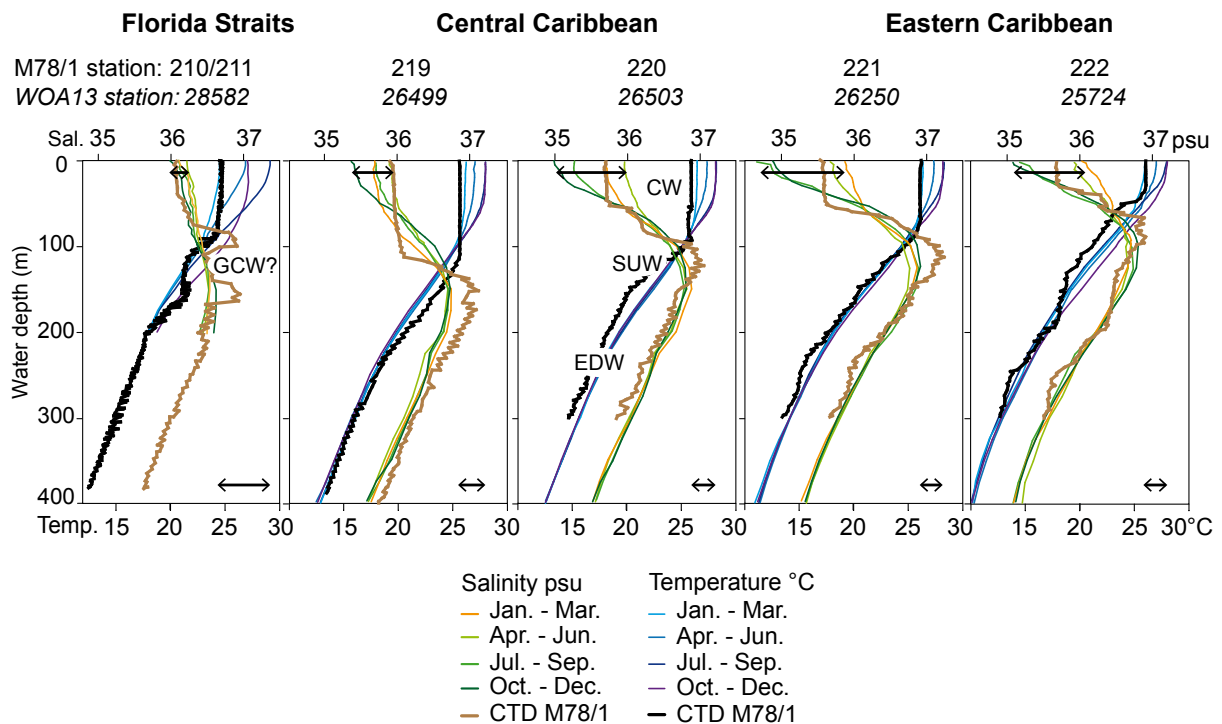
**Figure 3.2:** Temperature (°C) and salinity (psu) depth profiles in the working area. *In-situ* CTD-data measured during cruise M78/1 (March 2009, thick brown and black lines) are presented in comparison to the seasonally differentiated World Ocean Atlas 2013 (WOA13) data (Locarnini et al., 2013; Zweng et al., 2013; coloured thin lines). GCW: Gulf Common Water; CW: Caribbean Water; SUW: Subtropical Under Water; EDW: 18°C Sargasso Sea Water. Black double arrows indicate the seasonal ranges of temperature (bottom) and salinity (top) in the uppermost water column (0–10 m water depth).

## 3.2.2 Stable isotope analyses

Depending on the selected species and size fraction, a varying number of specimens were analysed for stable isotopes ($\delta^{18}O_{calcite}$) (Appendix B). Prior to the measurements, the foraminiferal tests were cracked and the remaining cytoplasm was removed with a needle. The measurements were run on a ThermoScientific MAT 253 mass spectrometer connected to an automatic carbonate preparation device Kiel CARBO IV at GEOMAR. The stable isotope results are reported relative to the Vienna Pee Dee Belemnite (VPDB) in per mil (‰) and calibrated *versus* the National Bureau of Standards (NBS) 19. The *in-house* standard (Solnhofen limestone) indicate a long-term analytic precision of <0.06‰ (±1σ).

Stable oxygen isotopes in seawater ($\delta^{18}O_{seawater}$) were analysed by the Isotope Ratio Infrared Spectroscopy (IRIS) analyser (Model L1102-i CRDS) at the laboratory of GeoZentrum Nordbayern (Erlangen). The measurements are expressed in per mil (‰) *versus* the Vienna Standard Mean Ocean Water (VSMOW). The analytical precision is better than 0.05‰ (±1σ) (Appendix B).

The difference between the predicted inorganic calcite $\delta^{18}O$ signal of the seawater (calcite formed in thermodynamic equilibrium, $\delta^{18}O_{equilibrium}$) and the $\delta^{18}O_{calcite}$ value of the foraminiferal test is commonly termed as "vital effect" ($\delta^{18}O_{disequilibrium}$) (Tab. 3.3).

$$\delta^{18}O_{disequilibrium} = \delta^{18}O_{calcite} - \delta^{18}O_{equilibrium} \tag{3.1}$$

To determine $\delta^{18}O_{equilibrium}$ (Fig. 3.3A), the temperature equation of Kim and O´Neil (1997) for inorganic precipitation was applied:

$$\delta^{18}O_{equilibrium} = 25.778 - 3.333 * \sqrt{43.704 + T} + \delta^{18}O_{seawater} \tag{3.2}$$

with *in-situ* temperatures (°C) measured during cruise M78/1 by CTD and measured seawater ($\delta^{18}O_{seawater}$) values (Schönfeld et al., 2011; Appendix B). $\delta^{18}O_{seawater}$ was corrected to the PDB scale by subtracting 0.27‰ after Hut (1987).
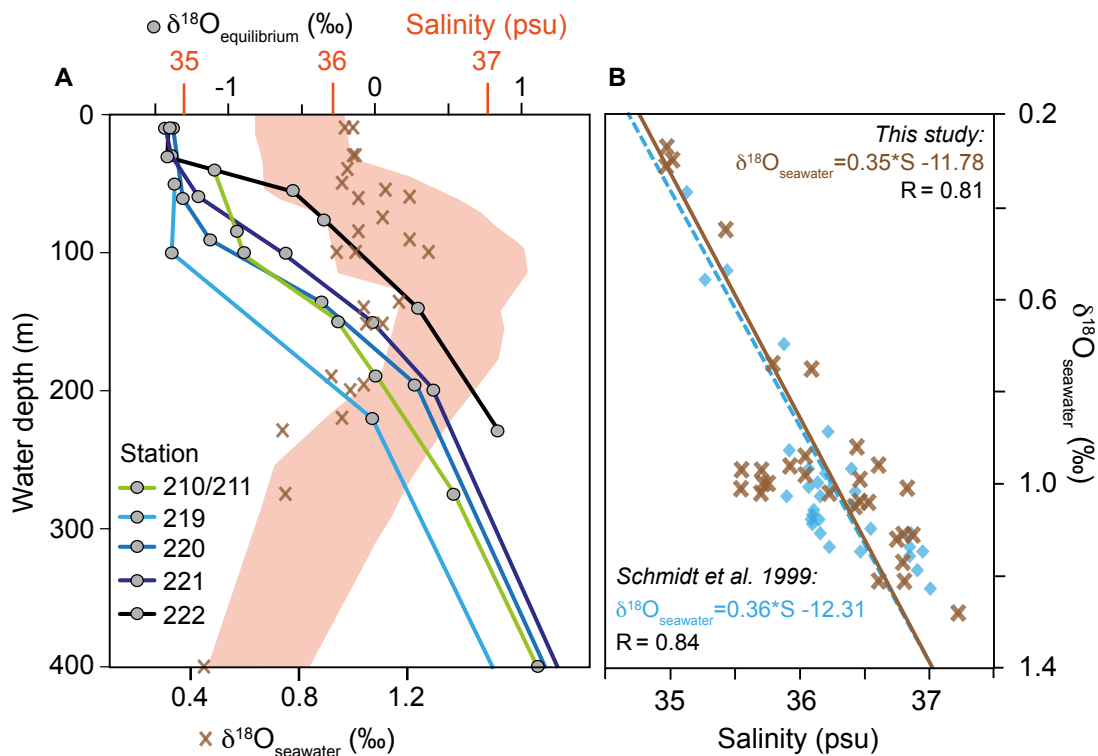


**Figure 3.3: A)** $\delta^{18}O_{seawater}$ (‰ VSMOW) and colour-coded $\delta^{18}O_{equilibrium}$ (‰ PDB) depth profiles at the CTD stations 210/211, 219, 220, 221, and 222 (see Fig. 3.1). Red shading: Salinity envelope (psu) of the ambient seawater from Florida Straits and Caribbean Sea measured during cruise M78/1 matching $\delta^{18}O_{seawater}$. **B)** Brown crosses: Measured *in-situ* salinity vs. $\delta^{18}O_{seawater}$ in the Caribbean Sea and Florida Straits in the upper 600 meter of the water column (cf. Appendix B for data); blue squares: Salinity vs. $\delta^{18}O_{seawater}$ from Schmidt et al. (1999; Global Seawater Oxygen-18 Database) in the upper 600 meter of the water column in the Caribbean Sea.

In addition to equation (3.2), we further elaborated other $\delta^{18}O$-paleotemperature equations to test which one is consistent with our *in-situ* data, and can be used for further calculations considering the species-specific "vital effect" (Erez and Luz, 1983; Bouvier-Soumagnac and Duplessy, 1985; Bemis et al., 1998; Mulitza et al., 2003; Spero et al., 2003; Farmer et al., 2007; Tab. 3.2; Fig. 3.5). We applied different conversion factors correcting SMOW to PDB for the different $\delta^{18}O$-paleotemperature equations according to the corresponding studies (Tab. 3.2) to estimate $\delta^{18}O_{seawater}$ from foraminiferal $\delta^{18}O_{calcite}$.
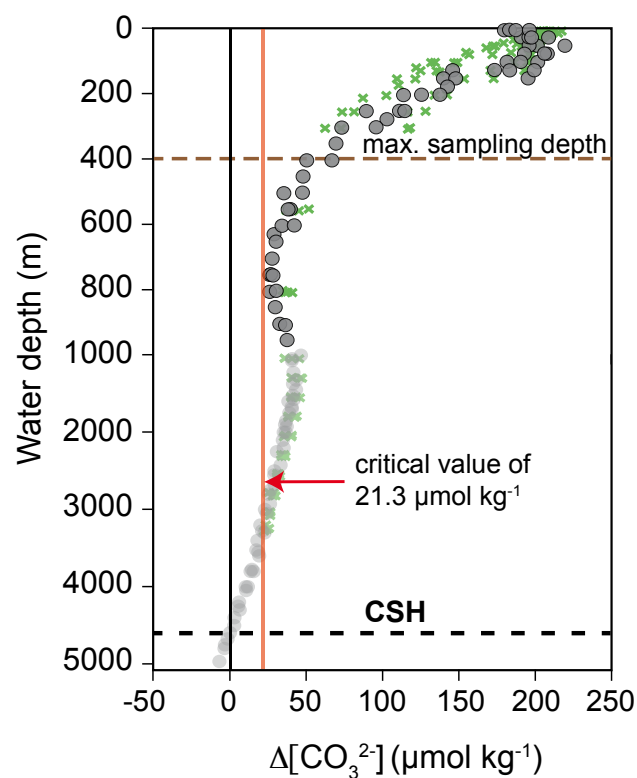


**Figure 3.4:** Calcite saturation state indicated by $\Delta[CO_3^{2-}]$ depth profiles of the Caribbean Sea and Gulf of Mexico. Grey dots and green crosses: Transect A22 (station 10-15) and NACPECC (station 20-28) (Fig. 3.1) with $\Delta[CO_3^{2-}]$ being the difference between $[CO_3^{2-}]_{in-situ}$ and $[CO_3^{2-}]_{saturation}$. Alkalinity and $TCO_2$ was taken from WOCE and NACP (cchdo.ucsd.edu; cruise RV Knorr in 1997, EXPOCODE: 316N151_4 and cruise RV Ronald H. Brown in 2007, EXPOCODE: 33RO20070710) to calculate $[CO_3^{2-}]_{in-situ}$ using the program CO2SYS (Pierrot et al., 2006; taking the constants ($K_1$ and $K_2$) of Mehrbach et al. (1973) refitted by Dickson and Millero (1987) and ($K_{SO4}$) from Dickson (1990)). $[CO_3^{2-}]_{saturation}$ was calculated after Jansen et al. (2002). Red vertical line indicates the critical $\Delta[CO_3^{2-}]$ value of 21.3 µmol kg⁻¹ below which selective $Mg^{2+}$-ion removal starts (Regenberg et al., 2014); black dashed line marks the calcite saturation horizon (CSH), which is defined to 0 µmol kg⁻¹ and represents the top of the lysocline at ~4600 m water depth; brown dashed line indicates the maximum plankton-tow sampling depth.

**Table 3.2:** Temperature: $\delta^{18}$O relationship from different studies including different conversion factors (SMOW to PDB; cf. Bemis et al., 1998). A = species-specific equation used to estimate $\delta^{18}$O$_{seawater}$ for *G. sacculifer* (Fig. 3.10).

| T= **a** + **b**\*($\delta^{18}$O$_{calcite}$– $\delta^{18}$O$_{seawater}$) + **c**\*($\delta^{18}$O$_{calcite}$– $\delta^{18}$O$_{seawater}$)$^2$ | | | | | | | |
|---|---|---|---|---|---|---|---|
| Nr. | Reference | Species | | Material | **a** | **b** | **c** | SMOW to PDB conversion |
| 1 | Kim and O´Neil 1997 | *Inorganic* | | Experiment | 16.1 | -4.64 | 0.09 | -0.27 |
| 2 | Shackleton 1974 | *Uvigerina* | | Sediment | 16.9 | -4.38 | 0.1 | -0.20 |
| 3 | Erez and Luz 1983 | *G. sacculifer* | | Culture experiment | 17.0 | -4.52 | 0.03 | -0.22 |
| 4 | Bouvier-Soumagnac and Duplessy 1985 | *O. universa* | | Culture experiment | 16.4 | -4.67 | | -0.20 |
| 5 | Bouvier-Soumagnac and Duplessy 1985 | *O. universa* | | Plankton tow | 15.4 | -4.81 | | -0.20 |
| 6 | Bouvier-Soumagnac and Duplessy 1985 | *G. menardii* | | Plankton tow | 14.6 | -5.03 | | -0.20 |
| 7 | Bouvier-Soumagnac and Duplessy 1985 | *N. dutertrei* | | Plankton tow | 10.5 | -6.58 | | -0.20 |
| 8 | Bemis et al. 1998 | *O. universa* | | Culture experiment, high-light conditions | 14.9 | -4.8 | | -0.27 |
| 9 | Bemis et al. 1998 | *O. universa* | | Culture experiment, low-light conditions | 16.5 | -4.8 | | -0.27 |
| 10 | Mulitza et al. 2003 | *G. sacculifer* | | Surface pump samples | 14.91 | -4.35 | | -0.27 |
| 11 | Spero et al. 2003 | *G. sacculifer* | A | Culture experiment, high-light conditions | 12.0 | -5.67 | | -0.27 |
| 12 | Farmer et al. 2007 | *G. sacculifer* | | Surface sediment | 16.2 | -4.94 | | -0.27 |
| 13 | Farmer et al. 2007 | *O. universa* | | Surface sediment | 16.5 | -5.11 | | -0.27 |
| 14 | Farmer et al. 2007 | *N. dutertrei* | | Surface sediment | 14.6 | -5.09 | | -0.27 |
| 15 | Farmer et al. 2007 | *G. menardii* | | Surface sediment | 16.6 | -5.20 | | -0.27 |
| 16 | Farmer et al. 2007 | *P. obliquiloculata* | | Surface sediment | 16.8 | -5.22 | | -0.27 |
| 17 | Farmer et al. 2007 | *G. tumida* | | Surface sediment | 13.1 | -4.95 | | -0.27 |
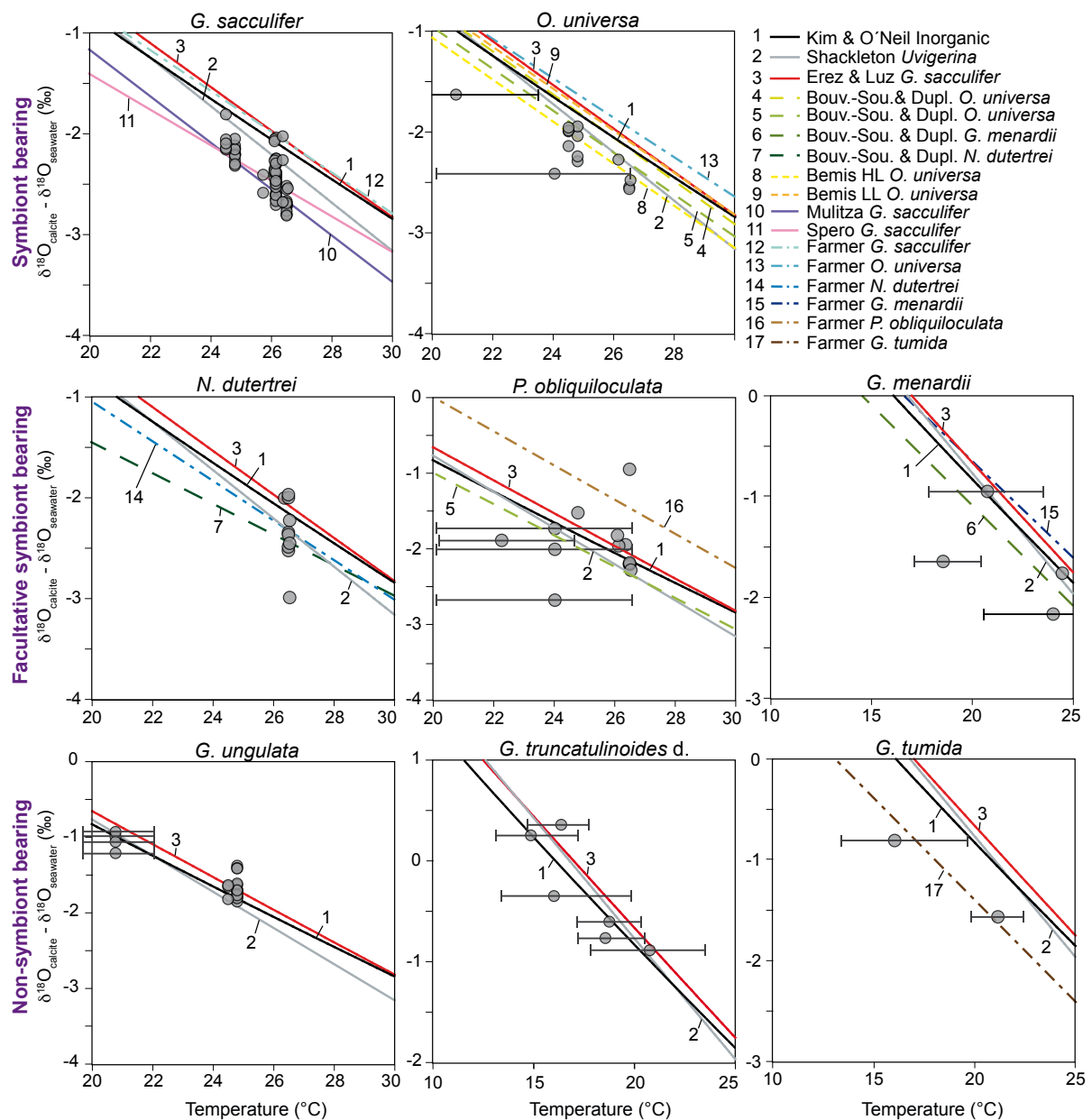
**Figure 3.5:** Assessment of existing $\delta^{18}O$-paleotemperature relationships. Grey dots: Difference between the measured $\delta^{18}O_{calcite}$ and the measured $\delta^{18}O_{seawater}$, depicted at the average *in-situ* temperature of the plankton net intervals measured during cruise M78/1. Black error bars denote the temperature ranges of the sampling intervals. Coloured-coded lines labelled by numbers are published $\delta^{18}O$-paleotemperature equations (cf. Tab. 3.2).

## 3.2.3 Mg/Ca analyses

Mg/Ca ratios in foraminiferal calcite were analysed from both bulk samples comprising numerous of tests of a single species, and single specimens, depending on their abundances (Appendix B). Prior to analyses, the samples were cleaned with a hydrogen peroxide-cleaning step (following Barker et al., 2003), which is suggested to be an efficient method to remove the high amount of cytoplasm in live foraminifera (Pak et al., 2004). We omitted a reductive hydrazine cleaning step. This step is unnecessary for plankton samples and we avoid further chemical treatment, which preferential dissolution of foraminiferal calcite (e.g. Rosenthal et al., 2004; Yu et al., 2007). Furthermore, employing only the oxidative cleaning step allows for direct comparison to foraminiferal Mg/Ca from surface sediments, which are treated similarly (Regenberg et al., 2006). For each bulk sample (plankton net and sediment), ~400-800 μg of *G. sacculifer*, *N. dutertrei* and *G. ungulata* from different size fractions were used for analyses (Appendix B). The tests were gently crushed between two glass plates, in order to open the chambers, and transferred into a vial. The samples were first rinsed with ultrapure water (18.2 MΩ/cm) and ethanol. Then, 250 μl of a NaOH/$H_2O_2$ solution (100 μl 30% $H_2O_2$ and 10 ml NaOH) were added to each vial and placed for 20 minutes in a hot water bath (92°C). For the plankton samples these steps were repeated 1–2 times in order to completely remove the cytoplasm. The samples were subsequently rinsed with ultrapure water. Finally, the tests were leached with 250 μl of $HNO_3$ (0.001 M). Prior to the element analyses, the samples were dissolved in $HNO_3$ (0.075 M). The measurements were performed with an axial-viewing VARIAN 720 Inductively Coupled Plasma-Optical Emission Spectrometer (ICP-OES) at GEOMAR. The data of the measurements were normalized and trend-corrected using the ECRM 752-1 standard (3.761 mmol mol$^{-1}$ Mg/Ca; Greaves et al., 2008). The analytic precision is 0.1 mmol mol$^{-1}$ (±2σ).

Single chambers of living foraminifera were analysed with an Excimer ArF 193 nm laser ablation system, coupled to an Inductively Coupled Plasma-Mass Spectrometer (ICP-MS Agilent 7500cx) at GEOMAR. The single foraminiferal tests were cleaned with a buffered hydrogen peroxide solution, in a similar way as the bulk samples. Only one specimen was put into a vial to avoid crashing and breaking the test during the cleaning process. Each foraminiferal test was rinsed with ultrapure water and ethanol before adding 250 μl of NaOH/$H_2O_2$ solution. The samples were then placed in a hot water tub (92°C) for 20 minutes and rinsed with ultrapure water and ethanol afterwards. Subsequently, the samples were dried at room temperature. The laser ablation technique allowed us to ablate through the test wall from the outer test surface towards the inner side. Its spot-

size diameter was focused to 50 and 75 μm. Ablation profiles were carried out on the final four chambers (F to F-3) (Appendix B). The energy density of the laser was 0.9–2.6 $J/cm^2$ and a laser repetition rate of 5 and 7 Hz was selected. The following isotopes were measured: $^7Li$, $^{11}B$, $^{23}Na$, $^{24}Mg$, $^{26}Mg$, $^{27}Al$, $^{39}K$, $^{43}Ca$, $^{44}Ca$, $^{55}Mn$, $^{66}Zn$, $^{88}Sr$, $^{111}Cd$, $^{137}Ba$, $^{139}La$, $^{232}Th$ and $^{238}U$. The ablation was stopped when the test wall was penetrated. Analyses were calibrated using standard glasses 610 and 612 of National Institute of Standards and Technology (NIST) and normalized to reported values of Jochum et al. (2011). The NIST 610 and NIST 612 were ablated with an energy density of 2–3 $J/cm^2$ after every ten measurements of foraminiferal tests. Raw counts of elements were processed offline and $^{43}Ca$ was used as internal standard to determine the element/Ca ratios. Outliers ($\pm 2\sigma$) were rejected from the results. A powder pellet of JCt-1 (giant clam shell) was used as internal reference and repeatedly analysed (n=15) during the ablation sessions revealing an average Mg/Ca ratio of $1.21 \pm 0.13$ mmol $mol^{-1}$ (standard deviation of 10.6%, $1\sigma$) being consistent with Hathorne et al. (2013) (Mg/Ca = 1.289 mmol $mol^{-1}$).

*In-situ* temperature (°C) measured during cruise M78/1 (Schönfeld et al., 2011) were compared to derived Mg/Ca-temperature estimates. We applied different calibrations for each species to account for species-specific variabilities (e.g. Russel et al., 2004; Cléroux et al., 2008; Regenberg et al., 2009; Tab. 3.4; Fig. 3.8).

### 3.2.4 Calculation of δ¹⁸O$_{seawater}$

The combination of δ¹⁸O$_{calcite}$ and Mg/Ca in foraminiferal tests allows us to estimate δ¹⁸O signals of the ambient seawater, which is used as a proxy for surface seawater salinity (Craig and Gordon, 1965; Schmidt, 1999; Fig. 3.3B). We compared our measured *in-situ* δ¹⁸O$_{seawater}$ to δ¹⁸O$_{seawater}$ estimates derived from combined foraminiferal δ¹⁸O$_{calcite}$ and Mg/Ca-temperatures of *G. sacculifer*. For the calculation we used the species-specific δ¹⁸O-paleotemperature equation for *G. sacculifer* of Spero et al. (2003) (Tab. 3.2) with the species-specific Mg/Ca-temperature calibration for *G. sacculifer* of Regenberg et al. (2009) (Tab. 3.4). Both calibrations are broadly consistent with the analysed calcite and the measured *in-situ* seawater properties (Fig. 3.5; Fig. 3.8A).

### 3.2.5 Calcite dissolution

Calcite dissolutions strongly affect foraminiferal Mg/Ca, which are mainly a function of the regionally different calcite saturation state in the oceans and the sensitivity of the species-specific foraminiferal test structure (Brown and Elderfield, 1996; Regenberg et al., 2006; 2014). The calcite saturation state $\Delta[CO_3^{2-}]$ is defined as:

$$\Delta[CO_3^{2-}] = [CO_3^{2-}]_{in\text{-}situ} - [CO_3^{2-}]_{saturation} \qquad (3.3)$$

and decreases from the surface (~150–200 µmol kg$^{-1}$) to ~5000 m water depth (<0 µmol kg$^{-1}$) in the eastern Caribbean Sea and Gulf of Mexico (Fig. 3.4). $\Delta[CO_3^{2-}]$ of ~21 µmol kg$^{-1}$, which is a critical threshold for the onset of selective $Mg^{2+}$ ion removal from planktonic foraminiferal calcite, is at ~2500–3000 m water depth in the study area. Below, the undersaturated waters will lower foraminiferal Mg/Ca substantially (Regenberg et al., 2006; 2014). As all plankton net samples of this study were taken from shallower than 400 m water depth, we assume that the studied foraminiferal tests originate from supersaturated seawater with respect to calcite ($\Delta[CO_3^{2-}]$ >50 µmol kg$^{-1}$) and that substantial $Mg^{2+}$-ion removal is not to be expected.

## 3.3 Results and Discussion

### 3.3.1 Hydrographical setting during sampling

In order to be able to directly relate our results on vertical foraminiferal distribution patterns and species-specific (isotope) geochemical signatures to the modern hydrographical conditions in the study area, we systematically accomplished temperature, salinity and $\delta^{18}O_{seawater}$ measurements. The CTD and thermosalinograph data gathered during cruise M78/1 (February–March 2009) low sea surface temperatures (SST) in the Gulf of Mexico (~20°C) and Florida Straits (~24°C) (Fig. 3.1; Fig. 3.2) comparable to the boreal winter situation, as reflected in the WOA2013 data (Fig. 3.2; Locarnini et al., 2013). Hydrographical conditions in the Caribbean vary seasonally with a large range of SSTs (range in the Florida Straits up to 5°C) and salinities (SSS; range in the Caribbean Sea up to 1 (psu)) (Fig. 3.2) and are closely linked to the migrating Intertropical Convergence Zone (ITCZ), which is at its northernmost position (6-10°N) during summer (Locarnini

et al., 2013; Zweng et al., 2013). The surface mixed layer extends to max. 100 m water depth in the Caribbean, and it is characterized by the relatively fresh Caribbean Water (CW; <36 psu). The lowest salinity is recorded in the southeastern Caribbean during summer and autumn when the Amazon and Orinoco river discharges are most intense and freshwater plumes arrive the Caribbean Sea (Wüst, 1964; Müller-Karger et al., 1989; Chérubin and Richardson, 2007). Modified CW is transported via anticyclonic eddies (Loop Current) towards the Gulf of Mexico and Florida Straits (Vukovich, 2007). In the upper thermocline, the highly saline Subtropical Under Water (SUW; >37 (psu)) prevails. This water mass originates in tropical and subtropical regions (Gallegos, 1996; Blanke et al., 2002) and resides in ~80–160 m water depth. The 18°C Sargasso Sea Water (Eighteen Degree Water = EDW) prevails in ~200–400 m water depth entering the Caribbean Sea via the passages of the Greater Antilles (Morrison and Nowlin, 1982). The Gulf Common Water (~23°C and ~36.4 (psu); Vidal et al., 1994) possibly influences the Florida Straits hydrography (Station 210/211) in the upper thermocline at 100–150 m, characterized by low salinity (36.5 (psu)).

*In-situ* $\delta^{18}O_{seawater}$ averages to ~0.9‰ (VSMOW) in the uppermost 400 m water depth (Fig. 3.3A). Highest $\delta^{18}O_{seawater}$ values can be found in the salinity maximum at ~60–150 m water depth, whereas the lowest value is measured in the deepest sampling interval at the lowest salinity. Additionally, the *in-situ* $\delta^{18}O_{seawater}$ and salinity recorded during M78/1 show a positive correlation (linear regression, r=0.81) and yield similar values as earlier data sets from the Caribbean Sea (Schmidt et al., 1999) (Fig. 3.3B). The $\delta^{18}O_{equilibrium}$ increases with depth from ~-1.5 to 1‰ in dependence of the decreasing ocean temperature (Fig. 3.2; Fig. 3.3A).

## 3.3.2 Vital effects on foraminiferal $\delta^{18}O_{calcite}$

In order to address the effects of symbiont activity and life cycle on foraminiferal oxygen isotopes, $\delta^{18}O_{calcite}$ values of living foraminifera were compared to the calculated $\delta^{18}O_{equilibrium}$ of the ambient seawater and $\delta^{18}O_{calcite}$ estimates of fossil tests from underlying surface sediments (Fig. 3.7).

## 3.3.2.1 Symbionts and life cycle effect on foraminiferal $\delta^{18}O$

Specimens of *G. sacculifer* and *O. universa* from the mixed layer are characterized by large negative $\delta^{18}O_{disequilibrium}$ values of -0.35‰ and -0.32‰, (=vital effects), respectively (Tab. 3.3; Fig. 3.7). These two species host dinoflagellates as symbionts (Gastrich, 1987) and similarly negative $\delta^{18}O_{disequilibrium}$ values were reported in spinose, symbiont-bearing species caught in plankton tows from various ocean areas (Tab. 3.3 and references therein). Laboratory experiments (Spero, 1992; Spero and Lea, 1993; Bemis et al., 1998) revealed a depletion of 0.3 to 0.6‰ in $\delta^{18}O_{calcite}$ of *O. universa* and *G. sacculifer* under high irradiance levels related to algae photosymbiont activity. In particular, a high irradiance in the euphotic zone intensifies the photosynthetic rate in the Caribbean Sea under its prevailing oligotrophic conditions (Spero and Parker, 1985; Morel et al., 2010). Enhanced photosymbiont activity increases the $O_2$ concentration and fosters $CO_2$ fixation, resulting in an elevated pH within the microenvironment around the living foraminifera (Jørgensen et al., 1985; Rink et al., 1998). Both, increasing pH and increasing carbonate ion concentration $[CO_3^{2-}]$ apparently cause a depletion of $\delta^{18}O_{calcite}$ (Spero et al., 1997; Bijma et al., 1999).

Among all species studied, only *G. sacculifer* and *N. dutertrei* reveal a significant positive correlation (Spearman rank correlation, $p<0.05$) between test-size and $\delta^{18}O_{calcite}$ (Fig. 3.6, Appendix B), suggesting that ontogeny affects $\delta^{18}O_{calcite}$ fractionation processes. The species *G. ungulata* shows lower $\delta^{18}O_{calcite}$ values in the test-size fraction <300 μm and *G. menardii* indicate no significant ontogenetic effect ($p>0.5$; Fig. 3.6). It should be noted that for some species we did not have enough sample materials in all test-size classes. However, our results are consistent to Kahn (1979), Kahn and Williams (1981), Spero and Lea (1996) and Bemis et al. (1998), who postulated that juvenile foraminifera reveal a larger "vital-effect" than adult individuals, with their tests being depleted of the heavy $^{18}O$ isotope due to a higher metabolic rate (incorporation of respired $CO_2$) and/or rapid growth rate. Rapidly growing calcitic skeletons result in a stronger kinetic isotope fractionation and cause the enrichment of the lighter $^{16}O$ isotope (McConnaughey, 1989).

**Table 3.3:** Average weighted living depth (m), habitat temperature (°C), symbionts information and $\delta^{18}O_{disequilibrium}$ values of single species from this study and other authors (cf. Chapter 2 for living depth and habitat temperature calculations).

| Species | G. sacculifer | N. dutertrei | O. universa | P. obliquiloculata | G. ungulata | G. menardii | G. truncatulinoides | G. tumida |
|---|---|---|---|---|---|---|---|---|
| Avg. living depth (m)[×] | 41 ± 9 | 54 ± 10 | 58 ± 16 | 61 ± 29 | 75 ± 5 | 81 ± 43 | 176 ± 18[d] | 185 ± 49 |
| Avg. habitat temperature (°C)[×] | 25.9 | 25.11 | 25.13 | 25.61 | 23.81 | 24.47 | 20.14[d] | 21.72 |
| Symbionts | Dinoflagellates[1] | Chrysophycophyte[1F] | Dinoflagellates[1] | Chrysophycophyte[1F] | None?[2] | Chrysophycophyte[1F] | None[1] | None[3] |
| **Disequilibrium values $\delta^{18}O_{calcite} - \delta^{18}O_{equilibrium}$ (‰)** | | | | | | | | |
| Mixed layer* | -0.35 | -0.14 | -0.32 | +0.18 | +0.08 | -0.05 | +0.02[d] | -0.65 |
| Thermocline* | -0.98 | -0.79 | -0.72 | -0.54 | +0.01 | -0.54 | | |
| Bouvier-Soumagnac and Duplessy, 1985 | | -0.3 | -0.2 | | | -0.3 | | |
| Duplessy et al., 1981a | -0.6 | | | | | | | |
| Erez and Honjo, 1981# | -0.15 | -0.21 | -0.14 to -0.02 | -0.05 | | | -0.15 to +1.28 | |
| Vergnaud-Grazzini, 1976 | -0.6 | | -1.0 | | | | -0.4[+] to -0.6 | |
| Kahn, 1979 | -0.38 | -1.57 to -0.29[+] | -0.95 | | | -0.24 to 0[+] | | <0 |
| Lončarić et al., 2006 | -0.36 to -0.03 / -0.13 to -0.16[+] | | | | | | 0[d] / -0.1 to +0.16[d+] | |
| Shackleton et al., 1973 | -0.39 | -0.11 | | +0.06 | | | | |

* This study (average values); × Jentzen and Schönfeld *(in preparation)*; d= *G. truncatulinoides* dextral
1= Gastrich, 1987; 2= Bé, 1977; 3= Kučera, 2007
F= Facultative symbionts
+= large/thick specimens; # = seasonal variations

Vertical migration of planktonic species to deeper and colder water masses during their life cycle may additionally affect $\delta^{18}O_{calcite}$, leading to commonly higher values in adult specimens (Kroon and Darling, 1995; Lončarić et al., 2006; Birch et al., 2013). Samples from the same test-size fraction of all species exhibit the enrichment of heavier $^{18}O$ isotopes at deeper water levels (Fig. 3.7; Tab. 3.5). We speculate that the increasing $\delta^{18}O_{calcite}$ at deeper water levels is a function of increasing $\delta^{18}O_{equilibrium}$ of the ambient seawater, rather than ontogenetic effects itself. The surface dweller *G. sacculifer* reveals the largest $\delta^{18}O_{disequilibrium}$ value (~1‰) in the thermocline (Tab. 3.3). As a higher rate of photosynthetic processes in deeper water depths can be excluded and specimens were still alive when sampled, we suggest that *G. sacculifer* completed calcifying in the thermocline before reproduction. Our observation corroborates South Atlantic plankton net studies of Lončarić et al. (2006), who noted that *G. sacculifer* $\delta^{18}O_{calcite}$ increased with depth in the upper 60 m water depth and remained constant below the surface mixed layer, even though $\delta^{18}O_{equilibrium}$ increased continuously.
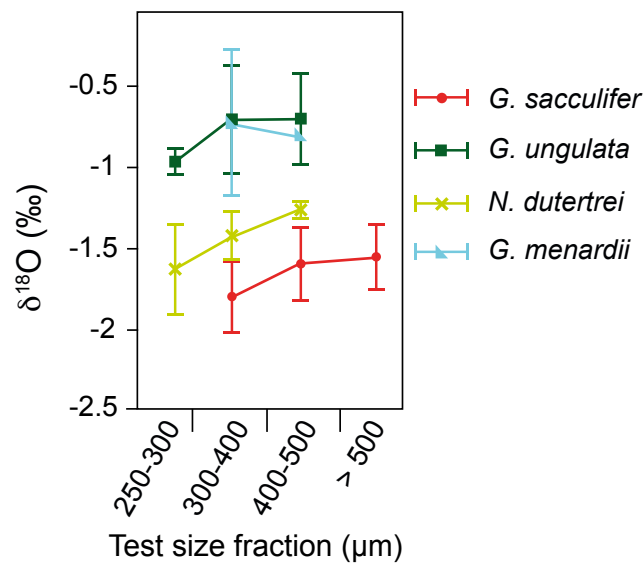


**Figure 3.6:** Stable oxygen isotopes (average $\delta^{18}O_{calcite}$ and ±standard deviations) compared to different test-size fractions of living planktonic foraminifera (only species with more than two analysed test-size fractions are depicted).

## 3.3.2.2 The $\delta^{18}O$ offset between living and fossil foraminiferal specimens

It becomes evident that almost all fossil tests from surface sediment samples, in particular *N. dutertrei*, *P. obliquiloculata*, *G. truncatulinoides* (dextral) and *G. tumida* are enriched in $\delta^{18}O_{calcite}$ (>0.5‰) compared to their living counterparts from the water column (Fig. 3.7; Tab. 3.5). $\delta^{18}O_{calcite}$ of fossil shallow-dweller *G. sacculifer* and *O. universa* are rather close to those values of specimens caught in the thermocline (average difference of 0.14‰ and 0.02‰ respectively) (Tab. 3.5). Yet, the overall discrepancy in $\delta^{18}O_{calcite}$ between fossil and living specimens may be best explained by gametogenetic calcification processes, which take place during the vertical migration through the water column. At the end of the life cycle and prior to gametogenesis, various planktonic foraminiferal species (e.g. *G. sacculifer*, *O. universa*, *P. obliquiloculata*, *G. truncatulinoides*, *G. tumida*) add a calcitic crust of variable thickness on the outer surface of the test. Based on calculations of Bouvier-Soumagnac and Duplessy (1985) and Hamilton et al. (2008) up to 25% (~4 µg) gametogenic calcite is added by *O. universa*, which is mainly secreted in colder waters prior to reproduction. The tests thereby lose their glassy and transparent look, grow thicker and become more opaque (Bé, 1980; Deuser et al., 1981; Duplessy et al., 1981b; Hemleben et al., 1985; Schweitzer and Lohmann, 1991). Specifically, spinose species resorb their spines before releasing their gametes (Bé and Anderson, 1976; Spero, 1988). These processes result in heavier $\delta^{18}O_{calcite}$ compositions of fossil tests from surface sediments (and even individual foraminifera from sediment traps) (Duplessy et al., 1981b; Bouvier-Soumagnac and Duplessy, 1985; Bouvier-Soumagnac et al., 1986; Lin et al., 2011). Consistently, the heavy $\delta^{18}O_{calcite}$ values in adult specimens of *G. truncatulinoides* (dextral) and *G. tumida* may be best explained by vertical migration into colder water masses at a late ontogenetic stage (Franco-Fraguas et al., 2011; Birch et al., 2013). Vergnaud-Grazzini (1976) recognized that living individuals of *G. truncatulinoides* (dextral) with a thick test and pustules on the test surface are more likely to be found in deeper water masses than non-ornamented, thin-shelled specimens. As expected, such tests had $\delta^{18}O_{calcite}$ values close to those observed in surface sediments. Overall, our proxy database supports the notion that specimens of *P. obliquiloculata*, *G. tumida* and *G. truncatulinoides* (dextral) add a thick opaque calcite layer or cortex at deeper water depths than 400 m. Hence, the fossil tests are enriched in $\delta^{18}O_{calcite}$ relative to the living foraminifera (up to 0.85‰) (Fig. 3.7; Tab. 3.5).

During the sampling campaign in February/March 2009, mainly juvenile specimens of *N. dutertrei* were found in plankton nets (mode test-size fraction 150–250 µm;

Chapter 2). This finding may additionally explain the large $\delta^{18}O_{calcite}$ offset between living foraminifera and fossil tests (~1‰) (Fig. 3.7; Tab. 3.5). Kroon and Darling (1995) recognized that small specimens of *N. dutertrei* have similar $\delta^{18}O_{calcite}$ values as surface dwellers and lower values than large specimens, supporting the notion on the ontogenetic-related migration to deeper waters. Fairbanks et al. (1982) and Bouvier-Soumagnac and Duplessy (1985) also noted increasing $\delta^{18}O_{calcite}$ values of *N. dutertrei* with increasing water depth in the Panama Basin and Indian Ocean, suggesting that this species secrete important proportions of their tests below the mixed layer. Furthermore, living *N. dutertrei* from the South China Sea were depleted in $\delta^{18}O_{calcite}$ compared to individuals from sediment traps (Lin et al., 2011). Our data confirm these assumptions as we recognized higher $\delta^{18}O_{calcite}$ values and larger individuals of *N. dutertrei* in surface sediments compared to the mixed layer (Fig. 3.7; Tab. 3.5; Chapter 2).

The species *G. menardii* shows increasing $\delta^{18}O_{calcite}$ values from the mixed layer to the thermocline (+0.3‰), and from the thermocline to the surface sediments (+0.2‰) pointing to decreasing ambient seawater temperatures at deeper water levels and migration within the water column (Fig. 3.2; Fig. 3.7; Tab. 3.5). Apparently, *G. ungulata* is an exception to the rule, as this species does not show the enrichment of $\delta^{18}O_{calcite}$ in fossil tests compared to living specimens (Fig. 3.7; Tab. 3.5). Yet, the species secreted their calcite tests close to the equilibrium with the ambient seawater (0.01–0.08‰) throughout the water column (Tab. 3.3). The average surface sediment $\delta^{18}O_{calcite}$ value corresponds well with the depth where the highest standing stock was observed during the sampling campaign in February/March 2009 (Fig. 3.7; cf. Chapter 2).
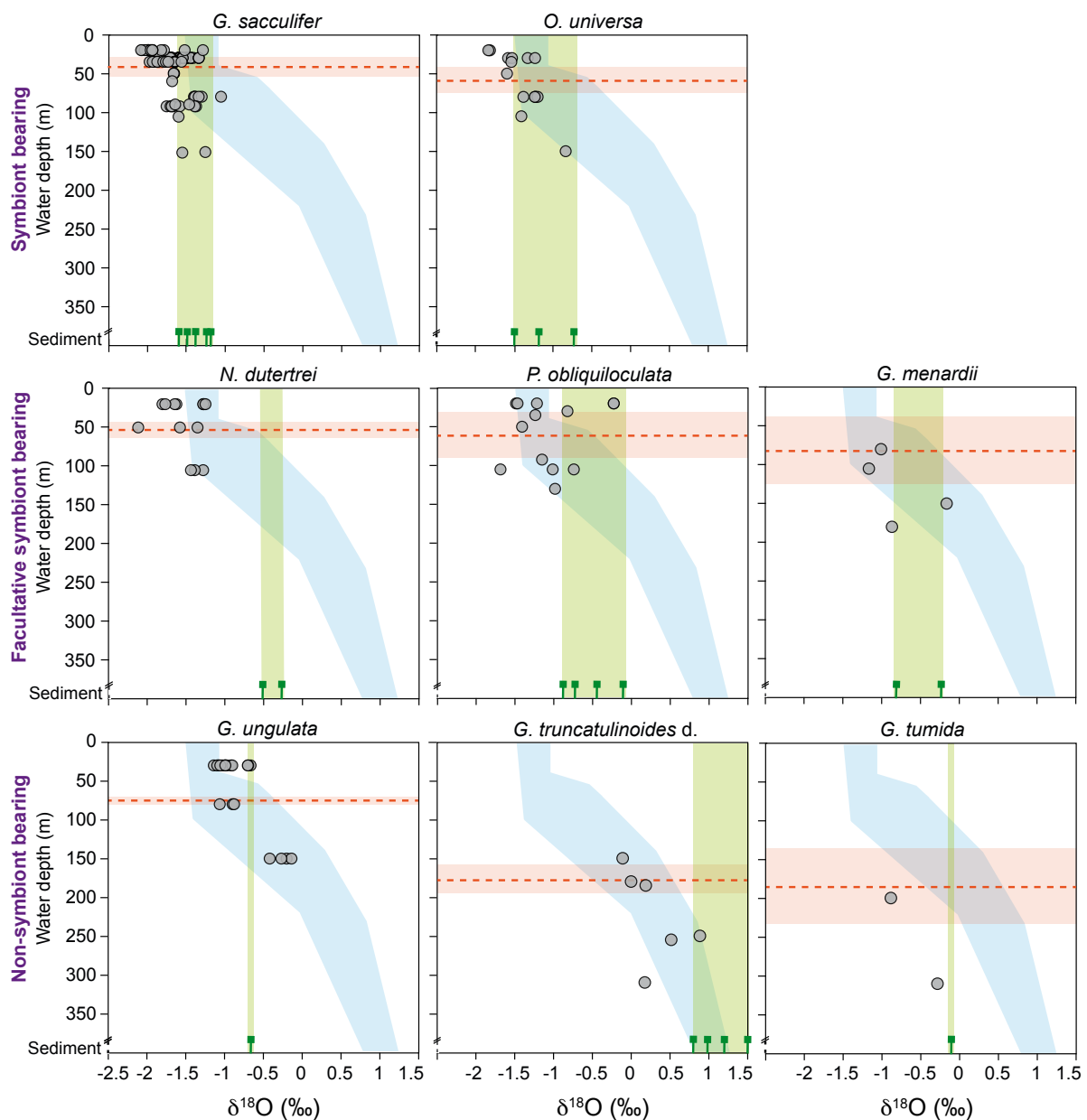
**Figure 3.7:** Stable oxygen isotopes of living planktonic foraminifers from Florida Straits and the Caribbean Sea plotted *versus* water depth (m) in comparison to calculated $\delta^{18}O_{equilibrium}$ and surface sediment data (illustrating the "vital effect"). The foraminiferal dataset was differentiated into symbiont-bearing, facultative symbiont-bearing, and non-symbiontic species from top to bottom (Tab. 3.3; see Appendix B for data). Grey dots: Foraminiferal $\delta^{18}O_{calcite}$ from MSN samples, plotted at the mean sampling depth intervals. Blue shading: $\delta^{18}O_{equilibrium}$ envelope of the ambient seawater from Florida Straits and the Caribbean Sea (cf. Fig. 3.3A). Green bars: Range of $\delta^{18}O_{calcite}$ of fossil tests from surface sediments (green signs = average values of single stations; cf. Appendix B). Red dashed lines: Average weighted living depths of single species during the sampling campaign in February/March 2009 (red shaded bars = the standard deviations; Tab. 3.3). Note, all test-size fractions are included.

## 3.3.3 Mg/Ca-based ocean temperature assessment from living foraminifera

In order to evaluate Mg/Ca as proxy for seawater temperature, we compared Mg/Ca-temperature estimates of living specimens to (i) measured *in-situ* temperatures and (ii) Mg/Ca-temperature estimates of fossil tests from surface sediments. Within this study, Mg/Ca analyses were performed on bulk foraminiferal samples measured by ICP-OES and single tests measured by LA-ICP-MS. ICP-OES samples of *G. sacculifer*, *N. dutertrei* and *G. ungulata* yield higher Mg/Ca ratios on average compared to LA-ICP-MS samples from the same MSN samples (Tab. 3.5; Appendix B). The data indicate a difference of $0.5 \pm 0.5$ mmol mol$^{-1}$ for *G. sacculifer* (average value of eight MSN sampling intervals), $1.2$ mmol mol$^{-1}$ for *N. dutertrei* (one MSN sampling interval) and $0.17 \pm 0.05$ mmol mol$^{-1}$ for *G. ungulata* (three MSN sampling intervals). We compare the results of both methods to each other (Fig. 3.9) having in mind the data discrepancy originating from the different analytical techniques.

Our Mg/Ca ratios of eight species collected at specific ocean temperature-ranges (corresponding to different water depth intervals) are in good agreement with established species-specific Mg/Ca-temperature calibrations (Fig. 3.8A/B), and further support the foraminiferal Mg/Ca-dependency on ambient water temperature. Hence, we estimate Mg/Ca-temperatures applying the best fitting calibration for each species (Tab. 3.4). Overall, all specimens collected in the surface waters of the eastern Gulf of Mexico (PF samples) yield low Mg/Ca-temperature estimates (averaged ~20.6°C) according to the low early spring temperatures of ~20°C prevailing during cruise M78/1 (Fig. 3.1; Fig. 3.9). Higher Mg/Ca-temperature estimates (~25°C) of shallow-dwellers (symbiont and facultative symbiont-bearing species) in the Florida Straits and Caribbean Sea (MSN samples) point to higher temperatures in the mixed layer (>24°C). Low Mg/Ca ratios of deep-dwellers (*G. truncatulinoides* dextral and *G. tumida*) in the thermocline follow the decreasing ambient seawater temperatures (Fig. 3.9).

**Table 3.4:** Relationship between temperature and Mg/Ca ratios from different authors, species and material. A–H indicate species-specific calibrations used to estimate calcification temperature from Mg/Ca for A=*G. sacculifer*; B=*O. universa*; C=*N. dutertrei*; D=*P. obliquiloculata*; E=*G. menardii*; F=*G. ungulata*; G=*G. truncatulinoides* dextral; H=*G. tumida* (Fig. 3.9).

| | | Mg/Ca = **b** * exp(**a** * T) | | | | |
|---|---|---|---|---|---|---|
| Nr. | Reference | Species | | Material/Method | **b** | **a** |
| 1 | Regenberg et al. 2009 | *G. sacculifer* | A | Surface sediment/ICP-OES | 0.596 | 0.075 |
| 2 | Nürnberg et al. 2000 | *G. sacculifer* | | ICP-OES | 0.491 | 0.076 |
| 3 | Regenberg et al. 2009 | *N. dutertrei* | C | Surface sediment/ICP-OES | 0.65 | 0.065 |
| 4 | Regenberg et al. 2009 | *G. tumida* | H | Surface sediment/ICP-OES | 1.23 | 0.041 |
| 5 | Regenberg et al. 2009 | *G. menardii* | E | Surface sediment/ICP-OES | 0.36 | 0.091 |
| 6 | Regenberg et al. 2009 | *G. truncatulinoides* d. | | Surface sediment/ICP-OES | 1.32 | 0.05 |
| 7 | Regenberg et al. 2009 | Shallow-Dweller | F | Surface sediment/ICP-OES | 0.29 | 0.101 |
| 8 | Regenberg et al. 2009 | Deep-Dweller | | Surface sediment/ICP-OES | 0.84 | 0.083 |
| 9 | Russel et al. 2004 | *O. universa* | B | Culture experiments/ICP-MS | 0.85 | 0.096 |
| 10 | Lea et al. 1999 | *O. universa* | | Culture experiments/ICP-MS | 1.36 | 0.085 |
| 11 | Anand et al. 2003 | *N. dutertrei* | | Sediment-Trap/ICP-OES | 0.342 | 0.09 |
| 12 | Anand et al. 2003 | *G. sacculifer* | | Sediment-Trap/ICP-OES | 1.06 | 0.048 |
| 13 | Anand et al. 2003 | *P. obliquiloculata* | | Sediment-Trap/ICP-OES | 0.18 | 0.12 |
| 14 | Anand et al. 2003 | *P. obliquiloculata* | | Sediment-Trap/ICP-OES | 0.328 | 0.09 |
| 15 | Anand et al. 2003 | *G. truncatulinoides* d. | | Sediment-Trap/ICP-OES | 0.359 | 0.09 |
| 16 | Anand et al. 2003 | *O. universa* | | Sediment-Trap/ICP-OES | 0.595 | 0.09 |
| 17 | Anand et al. 2003 | Multi-species | | Sediment-Trap/ICP-OES | 0.38 | 0.09 |
| 18 | Elderfield and Ganssen 2000 | Multi-species | | Surface sediment/ICP-OES | 0.52 | 0.1 |
| 19 | Nürnberg et al. 1996 | *G. sacculifer* | | Culture experiment/EPMA | 0.39 | 0.09 |
| 20 | Dekens et al. 2002 | *G. sacculifer* | | Surface sediment/ICP-MS | 0.37 | 0.09 |
| 21 | Cléroux et al. 2008 | *G. truncatulinoides* d. | G | Surface sediment/ICP-AES | 0.62 | 0.074 |
| 22 | Cléroux et al. 2008 | *P. obliquiloculata* | D | Surface sediment/ICP-AES | 1.02 | 0.039 |
| 23 | McKenna and Prell 2004 | *G. truncatulinoides* d. | | Surface sediment/EPMA | 0.355 | 0.098 |

**Table 3.5:** Average values of $\delta^{18}O_{calcite}$ and Mg/Ca (measured on ICP-OES* and LA-ICP-MS) from the mixed layer, thermocline and surface sediment (cf. Appendix B for data). PF samples are not included in the calculations.

| Species | $\delta^{18}O_{calcite}$ (‰) | | | Mg/Ca (mmol mol⁻¹) | | |
|---|---|---|---|---|---|---|
| | Mixed layer | Thermocline | Sediment | Mixed layer | Thermocline | Sediment |
| *G. sacculifer* | -1.62 | -1.52 | -1.38 | 3.87*/ 3.51 | 3.52 | 4.20* |
| *P. obliquiloculata* | -1.15 | -1.07 | -0.55 | 2.84 | 2.86 | |
| *O. universa* | -1.53 | -1.13 | -1.15 | 8.33 | 7.61 | |
| *N. dutertrei* | -1.51 | -1.37 | -0.40 | 3.59*/ 2.36 | | 2.88* |
| *G. ungulata* | -0.95 | -0.26 | -0.67 | 3.30*/ 3.20 | 3.32*/ 3.10 | |
| *G. menardii* | -1.01 | -0.73 | -0.54 | 3.10 | 3.19 | 3.27* |
| *G. tumida* | | -0.58 | -0.11 | 2.45 | 1.80 | 2.68* |
| *G. truncatulinoides* d. | | 0.28 | 1.13 | | 2.50 | 2.52* |
| *Bulk foraminiferal samples (measured on ICP-OES) | | | | | | |
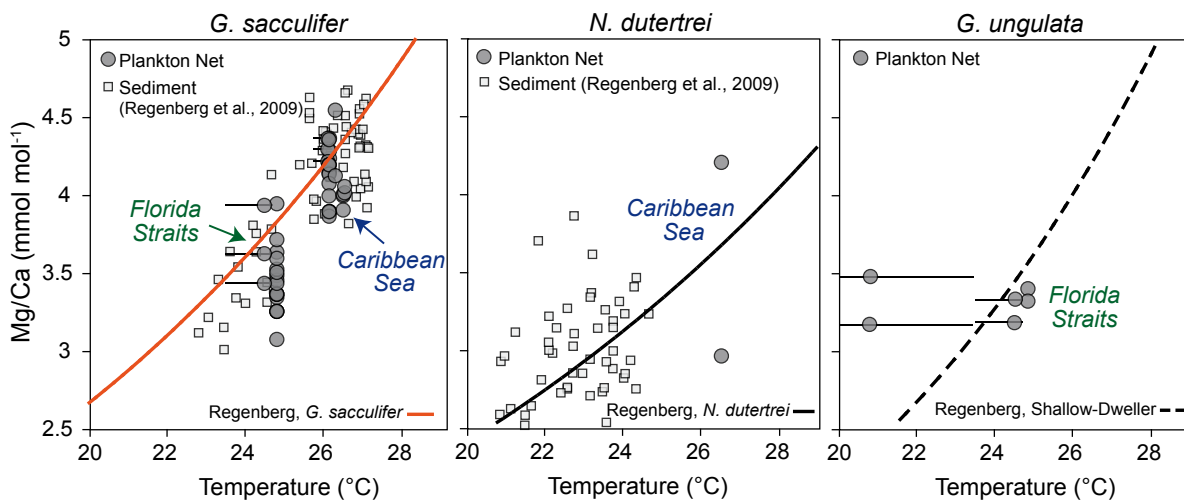


**Figure 3.8: A)** Mg/Ca values of ICP-OES bulk samples vs. temperature. Grey dots: Mg/Ca values of living specimens (*G. sacculifer*, *N. dutertrei* and *G. ungulata*), depicted at the average *in-situ* temperature of the plankton net intervals (MSN) in the Florida Straits and Caribbean Sea recorded during cruise M78/1. Black error bars: Modern temperature ranges of the sampling intervals. Grey squares: Mg/Ca ratios of fossil tests vs. δ¹⁸O calcification temperature from the Caribbean Sea and tropical Atlantic modified after Regenberg et al. (2009). Orange curve: Mg/Ca calibration of Regenberg et al. (2009) (surface sediments) for *G. sacculifer*. Black curve: Mg/Ca calibration of Regenberg et al. (2009) for *N. dutertrei*. Dashed black curve: Mg/Ca calibration of Regenberg et al. (2009) for shallow species.
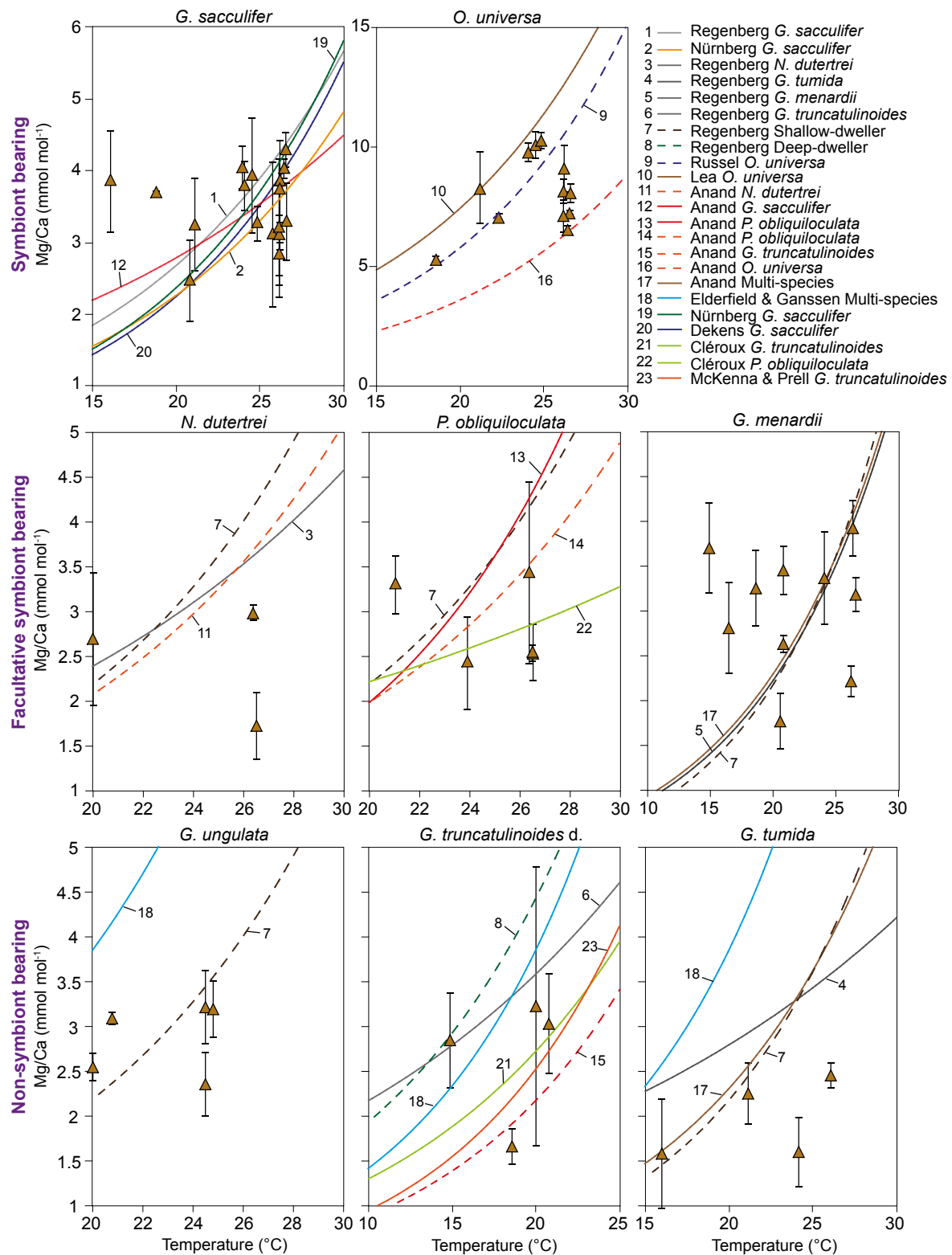
**Figure 3.8: B)** Average Mg/Ca values (± standard deviations) of LA-ICP-MS measurements of single tests vs. *in-situ* temperature (recorded during M78/1). Brown triangles: Mg/Ca values of living specimens depicted at the average *in-situ* temperature of the plankton net intervals (MSN and PF) during cruise M78/1. Black error bars indicate the standard deviations of single foraminiferal tests (Appendix B; Appendix C). The various published Mg/Ca calibration curves are colour-coded and labelled by numbers (cf. Tab. 3.4).

## 3.3.3.1 (Facultative) symbiont bearing species

Our dataset is most complete for *G. sacculifer*, allowing for a detailed comparison between Mg/Ca-based temperature estimates from plankton net and surface sediment samples. In the Caribbean Sea, the estimated Mg/Ca-temperatures for *G. sacculifer* (~26°C) are consistent with *in-situ* temperatures of the mixed layer (~26.2°C), the average habitat temperature (~26°C, derived from the standing stock, see Chapter 2) and Mg/Ca-temperatures derived from fossil tests (~26°C) (Fig. 3.8A; Fig. 3.9). Below 150 m water depth, the deviation between Mg/Ca-temperature and the ambient seawater temperature increases (Fig. 3.9), which support the former conclusion based on δ$^{18}$O$_{calcite}$ that *G. sacculifer* completed calcifying above or within the thermocline (Chapter 3.3.2.1). Lower temperature estimates of ~24°C in the Florida Straits (Station 211) (Fig. 3.8A) mirror the generally lower sea surface temperatures of ~24.6°C at this station during cruise M78/1 (Fig. 3.2). Here the fossil tests from surface sediments yield higher Mg/Ca ratios (+0.7 mmol mol$^{-1}$; Appendix B) than the living specimens. The Mg/Ca-temperature of fossil specimens indicates ~26.5°C, which is rather comparable to temperatures in the Florida Straits of the mixed layer in May (Locarnini et al., 2013, Fig. 3.2). Foraminiferal census data from the MSN samples (Chapter 2) suppose that the highest population density of *G. sacculifer*, therefore also the highest flux and accumulation rate of empty tests on the seafloor, appears during early spring in the Caribbean Sea, linking this species to the warm and oligotrophic Caribbean Water (CW) (~26°C). Furthermore, high frequencies of *G. sacculifer* are related with the strength of the Loop Current transporting warm Caribbean Water into the Gulf of Mexico (Poore et al., 2013). Therefore, we presume that a higher flux of *G. sacculifer* in Florida Straits is likely to occur later in the year, presumably in May, hence after our sampling, and the fossil tests of *G. sacculifer* from the Caribbean Sea and Florida Straits thereby reflect different seasonal signals.

Beside the seasonal effect, millennial-scale variabilities also affect the Mg/Ca-signal of fossil tests in surface sediments. Regenberg et al. (2006) assumed an age range of 2–3 kyrs in surface sediments (~0–1 cm) of the Caribbean Sea. As such, the surface sediments include the record of earlier climate variations, like the Little Ice Age, when sea surface temperatures were cooler by ~2°C (Watanabe et al., 2001). A large scatter of ~0.9 mmol mol$^{-1}$ Mg/Ca of fossil tests from surface sediments in the Caribbean Sea was therefore partly linked to past environmental variabilities (Regenberg et al., 2006). Our study, however, shows a similarly large Mg/Ca scatter in living specimens collected from the same plankton nets (MSN samples, Mg/Ca range up to ~0.87 mmol mol$^{-1}$; Fig. 3.8A;

Appendix B). Furthermore, LA-ICP-MS profiles across single chamber walls reveal a large Mg/Ca-variability (Fig. 3.8B), with decreasing Mg/Ca values towards the final chamber (F) (Appendix C) and is implying "vital-effects" driving $Mg^{2+}$ incorporation. Earlier studies on surface sediments and culture experiments indicate an ontogenetic effect on the incorporation of $Mg^{2+}$ during test growth of *G. sacculifer*, with lowest Mg/Ca ratios in the final, newly precipitated chambers (Sadekov et al., 2005; Dueñas-Bohórquez et al., 2011). Although lower average Mg/Ca ratios were measured in living planktonic specimens than in fossil test, the bulk foraminiferal samples of living *G. sacculifer* from the mixed layer show a significant positive correlation between Mg/Ca and *in-situ* temperatures (Pearson linear, r=0.8, p<0.05) (Fig. 3.8A), with an overall Mg/Ca scatter comparable to that of fossil specimens from surface sediments.

Our database for the other species is rather limited. Nonetheless, we can derive the following information. The symbiont-bearing species *O. universa* characteristically yields very high Mg/Ca ratios in single tests (up to ~10 mmol mol$^{-1}$ on average) (Fig. 3.8B) (cf. Lea et al., 1999; Russel et al., 2004). Mg/Ca-temperature estimates of *O. universa* are on average ~1°C lower than the measured *in-situ* temperature, but show decreasing values in larger depths according to lower *in-situ* temperatures (Tab.3.5; Fig. 3.2; Fig. 3.9). The offset between Mg/Ca-temperatures of *P. obliquiloculata* and *in-situ* temperatures vary from -3°C to 9°C. Both, *O. universa* and *P. obliquiloculata* show low and high $Mg^{2+}$ bands across single chambers of the tests (Appendix C). Those bands are likely caused by physiological processes (Eggins et al., 2004; Kunioka et al., 2006; Sadekov et al., 2009; Spero et al., 2015) and reveal a large Mg/Ca variability in single chambers. Single LA-ICP-MS measurements of *N. dutertrei* yield lower Mg/Ca ratios than the ICP-OES measurements (Tab. 3.5). Here, probably a high "vital-effect" may cause a large offset between the two measuring techniques. However, the average derived Mg/Ca-temperature of plankton bulk samples (~26.3°C) at station 221 is in good agreement with the *in-situ* temperature of the seawater at this station (~26.5°C) (Fig. 3.2; Fig. 3.9). The difference of 0.71 mmol mol$^{-1}$ Mg/Ca between the living and fossil bulk samples (Tab. 3.5) support the assumption that adult specimens of *N. dutertrei* dwell at larger depths continuing calcifying, as indicated by the lower δ¹⁸O$_{calcite}$ values and smaller specimens collected in the upper mixed layer (Chapter 3.3.2.2; Chapter 2). Living specimens of *G. menardii* yield a Mg/Ca-temperature range between ~18 and 26.5°C, which is larger but covering the temperature range of fossil tests (~23.2–25°C) and calculated average habitat temperature (~24.5°C; Tab. 3.3) in the Florida Straits and Caribbean Sea (Fig. 3.2; Fig. 3.9).
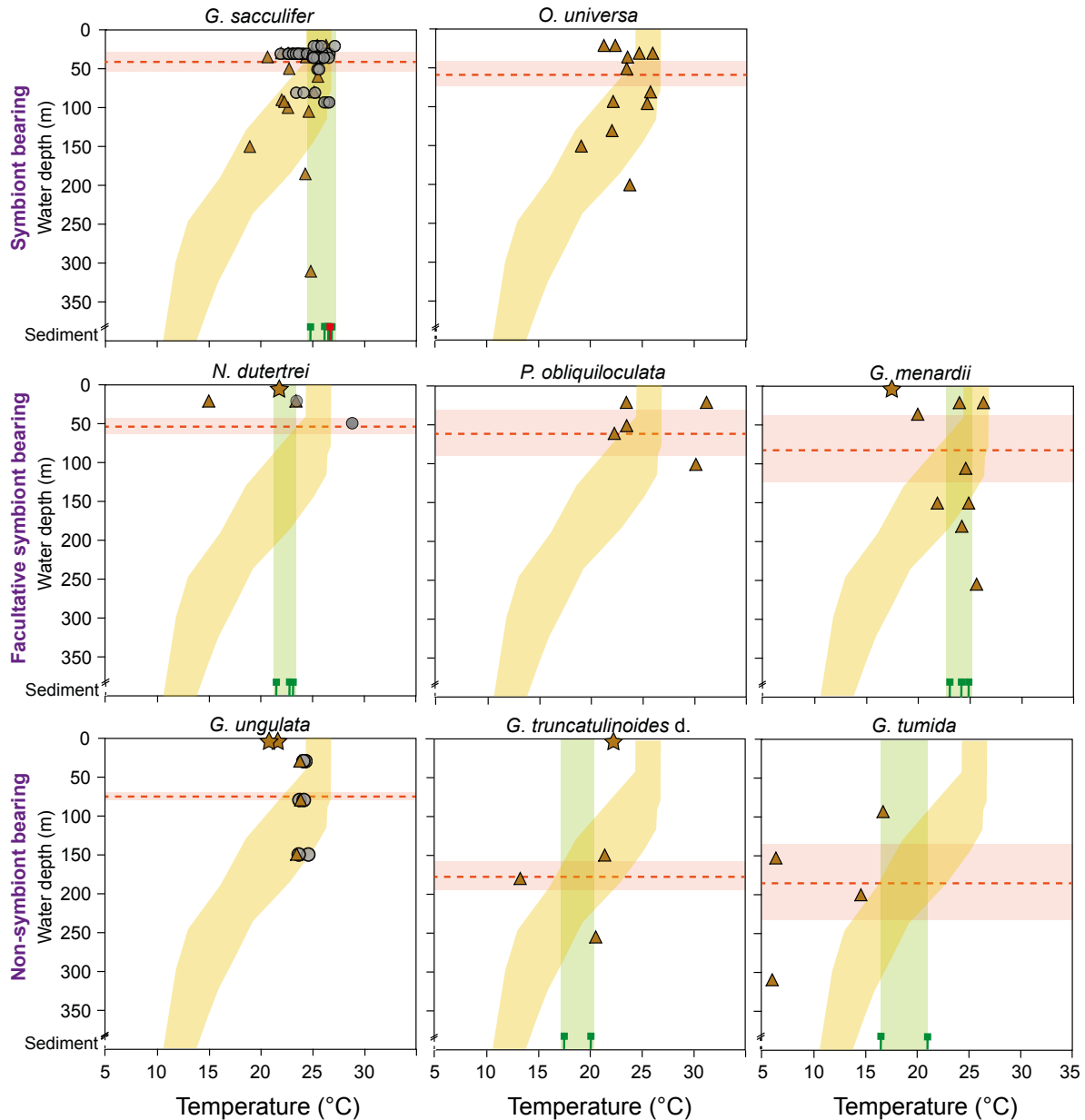
**Figure 3.9:** Mg/Ca-derived temperature estimates of living planktonic foraminifers combined from Florida Straits, the eastern Gulf of Mexico and the Caribbean Sea in comparison to the ambient seawater temperature. The foraminiferal dataset was differentiated into symbiont-bearing, facultative symbiont-bearing, and non-symbiontic species from top to bottom (Tab. 3.3; Tab. 3.4; cf. Appendix B for data). Grey dots: Mg/Ca-temperature estimates from bulk foraminiferal MSN samples measured by ICP-OES, depicted at the mean sampling depth intervals. Brown triangles and stars: Mg/Ca-temperature estimates derived from LA-ICP-MS measurements of single tests from MSN samples (Caribbean Sea and Florida Straits) and PF samples (Gulf of Mexico), respectively (average values, cf. Appendix B). Yellow shading: Temperature envelope (°C) of the ambient seawater from Florida Straits and the Caribbean Sea measured during cruise M78/1 (Fig. 3.2; Schönfeld et al., 2011). Note: PF samples (brown stars) were taken in 3.5 m water depth in the eastern Gulf of Mexico at SST of ~20°C during cruise M78/1 (Fig. 3.1). Green bars: Mg/Ca derived temperature range of fossil bulk foraminiferal samples from surface sediments closest to the MSN (Green sign: Average values of single stations in the Caribbean Sea; Red sign: average value of *G. sacculifer* in the Florida Straits, cf. Appendix B). Red dashed lines: Average weighted living depths of single species during the sampling campaign in February/March 2009 (red bars= standard deviation; Tab. 3.3). Note, all test-size fractions are included.

## 3.3.3.2 Non-symbiont bearing species

In the Florida Straits both, bulk and single Mg/Ca measurements of *G. ungulata* yield temperature estimates of ~24°C in the mixed layer and thermocline (Tab. 3.5; Fig. 3.9) being congruent to the average habitat temperature of 23.8°C during February/ March 2009 (Tab. 3.3). The average Mg/Ca-temperature estimates of living and fossil *G. truncatulinoides* (dextral) (~19°C) mirror the average habitat temperature of ~20°C during February/March 2009 (Fig. 3.9; Tab. 3.3). The deep-dweller *G. tumida* shows a decreasing Mg/Ca-temperature trend from the mixed layer to the thermocline following the decreasing *in-situ* temperature (Fig. 3.9; Tab. 3.5). The fossil tests of *G. tumida* show higher average Mg/Ca ratios than the living individuals (Tab. 3.5) and yield higher temperature estimates. However, the Mg/Ca-temperature of fossil tests (~19°C) represents the calculated average habitat temperature (~21.7°C) far better than the living foraminifera, which show an offset to the prevailing *in-situ* temperature of ~7°C to 17°C (Fig. 3.9).

## 3.3.4 δ¹⁸O$_{seawater}$ relationship

The combination of foraminiferal δ¹⁸O$_{calcite}$ and Mg/Ca-temperatures to estimate δ¹⁸O$_{seawater}$ approximating paleo-salinity is a commonly accepted approach in paleoceanography (e.g. Lea et al., 2000; Schmidt et al., 2004; Nürnberg et al., 2008). However, this approach reveals some imponderabilities (Arbuszewski et al., 2010). Support derived from living foraminifera collected under natural conditions is still sparse. Our unique dataset on living planktonic foraminifera in the mixed layer (>125 m water depth) at least allows us to test the abovementioned approach for the surface-dweller *G. sacculifer* from the Caribbean Sea and Florida Straits (Fig. 3.10). As the δ¹⁸O$_{seawater}$ estimates are strongly depending on both the applied δ¹⁸O-paleotemperature equation and empirical Mg/Ca-calibration (Tab. 3.2; Tab. 3.4; Fig. 3.5; Fig. 3.8), we decided to apply the δ¹⁸O-paleotemperature equation of Spero et al. (2003). This equation is based on *G. sacculifer* cultured in laboratory, which takes the large disequilibrium of δ¹⁸O$_{calcite}$ in living specimens to the ambient seawater into account (cf. Chapter 3.3.2.1). For the estimation of Mg/Ca-temperature, we applied the species-specific calibration of Regenberg et al. (2009) for *G. sacculifer* derived from fossil tests of surface sediments in the tropical Atlantic and Caribbean Sea. Our study shows that this calibration reflects our *in-situ* temperatures very close (cf. Chapter 3.3.3.1). δ¹⁸O$_{seawater}$ estimates of *G. sacculifer* show a positive linear relationship with *in-situ* δ¹⁸O$_{seawater}$ (r=0.78) as well as with salinity (r=0.77), and thus are indicating a good relationship in the mixed layer of this approach (Fig. 3.10). Our study on living foraminifera hence provides

compelling evidence that the combination of foraminiferal $\delta^{18}O_{calcite}$ and Mg/Ca-temperature reflecting ambient seawater properties reliably approximates the modern ocean salinity.
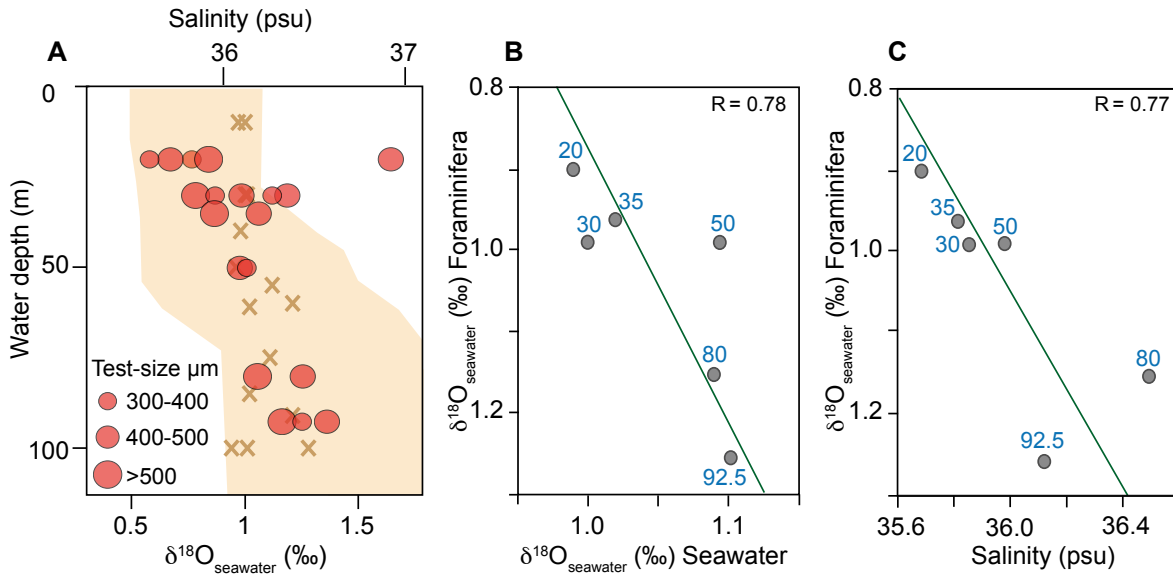


**Figure 3.10:** $\delta^{18}O_{seawater}$-estimates based on foraminiferal tests from living *G. sacculifer* compared to measured $\delta^{18}O_{seawater}$ and salinity recorded during cruise M78/1 in the Caribbean Sea and Florida Straits **A)** Red dots: Average $\delta^{18}O_{seawater}$-estimates of bulk samples from different test-size fractions; brown crosses: *in-situ* $\delta^{18}O_{seawater}$ (‰ VSMOW); orange envelop: Salinity **B)** Relationship between $\delta^{18}O_{seawater}$-estimates (foraminiferal test) and measured $\delta^{18}O_{seawater}$ (seawater). **C)** Relationship between $\delta^{18}O_{seawater}$-estimates (foraminiferal test) and measured *in-situ* salinity. Grey dots indicate average values at a specific water depth (blue numbers denote sampling water depth in m).

## 3.4 Conclusions

Our combined δ18O and Mg/Ca analyses on living planktonic foraminifera, collected by MSN and PF from surface to max. 400 m water depth of the Caribbean Sea, the eastern Gulf of Mexico and Florida Straits, allow for the following conclusions:

(1) The large negative disequilibrium (between $\delta^{18}O_{calcite}$ and $\delta^{18}O_{equilibrium}$) of up to -0.35‰ observed for *G. sacculifer* and *O. universa* point to a strong photosynthetic activity of the host symbionts (dinoflagellates).

(2) Ontogeny most likely controls $\delta^{18}O_{calcite}$ values. In this study *G. sacculifer* and *N. dutertrei* show a significant increase of $\delta^{18}O_{calcite}$ with increasing test-size.

(3) Vertical migration in the water column and additional secretion of gametogenic calcite (at the end of the foraminiferal life cycle) likely cause the increase of $\delta^{18}O_{calcite}$ with water depths and the enrichment of heavier 18O isotopes in fossil tests compared to living specimens.

(4) The large intraspecific scatter of Mg/Ca implies a strong "vital-effect". Nonetheless, it is evident that the ambient calcification temperature drives the Mg/Ca compositions in foraminiferal tests and causes lowered Mg/Ca-derived temperature estimates at lowered *in-situ* temperature. The various species-specific datasets agree well to published δ¹⁸O and Mg/Ca calibrations.

(5) Fossil tests of *G. sacculifer* from surface sediments in the Caribbean Sea and Florida Straits suggest that the regional Mg/Ca signatures may be seasonally biased. Mg/Ca values indicate that the highest flux/accumulation rate of *G. sacculifer* occurs during spring (March) in the Caribbean Sea and is delayed by a few months in the Florida Straits (most likely in May) linked to prevailing seawater temperatures of ~26°C in the mixed layer.

(6) Combined $\delta^{18}O_{calcite}$ and Mg/Ca-temperatures of *G. sacculifer* yield $\delta^{18}O_{seawater}$ estimates, which show a positive linear relationship with measured *in-situ* $\delta^{18}O_{seawater}$ and salinity.

## Acknowledgements

# CHAPTER 4

# Short and long-term dynamics of planktonic foraminiferal assemblages off Puerto Rico (Caribbean Sea)

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*This chapter is going to be submitted to Caribbean Journal of Science*

## Abstract

Living planktonic foraminifera were studied off southern Puerto Rico in order to assess the distribution, short- and long term changes in the foraminiferal assemblage. Stable oxygen and carbon isotope compositions of the calcite tests of *Globigerinoides ruber* (pink) were analysed and compared with equilibrium values reflecting the prevailing environmental conditions. The foraminifera were collected with plankton nets at three different stations on the shelf and upper slope in October and November 2012. The assemblage was characterized by *Globigerinoides ruber* (pink) and *Globigerinoides sacculifer*. *Globigerinoides ruber* (white) was rare in 2012, which possibly indicates a decline since the late 1990s when it was more common in the Caribbean. The stable oxygen isotopes of *G. ruber* (pink) showed a negative disequilibrium to the ambient seawater, which probably indicates a bias induced by photosymbiont activity. In the deeper water column (>60 m), a change in the faunal composition and lower $\delta^{18}O_{calcite}$ temperatures provided evidence for the influence of the Subtropical Under Water. Hurricane "Sandy" passed the Greater Antilles during the sampling campaign in late October 2012 and affected the foraminiferal assemblage. A drop in the standing stock was observed and the biserial species *Bolivina variabilis* was more abundant in the upper water column after the storm. Additionally, stable carbon isotope values from specimens collected in the upper water column were lower, possibly indicating the response to the increased turbidity.

# 4.1 Introduction

Planktonic foraminifera are unicellular marine organisms that live in the open ocean. They precipitate a calcitic test, which the chemical composition is influenced by the properties of the ambient seawater. The assemblage composition and stable isotope signal in the tests are widely used to reconstruct water mass conditions prevailing today and in the geological past (e.g. Fischer and Wefer, 1999; Kučera, 2007; Regenberg et al., 2009). Investigations on living planktonic foraminiferal faunas in the Caribbean are still sparse.

A survey in September-October 1994 and March 1995 off the southern coast of Puerto Rico assessed the influence of neritic environmental conditions and their seasonal changes on the living planktonic foraminiferal assemblages. The distribution pattern of foraminiferal species and stable isotope composition in their tests was monitored along a transect perpendicular to the shelf break (Schmuker 2000a; Schmuker 2000b). The studies revealed a seasonal influence of the outflow of the Orinoco River on the coast of Puerto Rico in autumn. The outflow raised the nutrient content in surface waters and triggered the composition of the planktonic fauna. In detail, a higher standing stock was observed in autumn with *Globigerinoides ruber* as dominant species. *Globigerinella calida* was the most abundant species during oligotrophic conditions in spring. The studies additionally revealed a faunal-gradient from neritic environments close to the coast to the offshore conditions with lower standing stocks close to the shelf break. Shallow water benthic foraminifera were found in plankton tows as well. Some of those benthic species, for instance *Tretomphalus bulloides*, have a planktonic stage during their life cycle (Rückert-Hilbig, 1983). Others were probably brought in suspension on the shelf and transported further off shore (Schmuker, 2000b; Fornshell, 2005). Stable isotope measurements of Schmuker (2000b) showed higher $\delta^{18}O_{calcite}$ values during spring than during autumn caused by lower temperature of the ambient seawater during spring. Low values of $\delta^{13}C_{calcite}$ during autumn might indicate a reduced photosynthesis of the symbiont due to higher turbidity of the upper water column or a higher cloudiness during the rainy season. This assumption refers on the hypothesis of Spero and Lea (1993) that decreasing light levels lower metabolic activity of the symbiont and thereby reduce the photosynthetic fixation of $^{12}C$ in the calcifying foraminiferal microenvironment.

The results of Schmuker (2000a; 2000b) in 1994 and 1995 were used as background data to assess the changes in plankton communities that happened during the following 17 years. In 2012, plankton net tows were investigated repeatedly over two weeks at three

stations and two depth intervals off the southern coast of Puerto Rico. The sampling sites of 2012 were close to those from 1994 and 1995 to determine the dynamics and spatial distribution of the foraminiferal assemblage in a weekly and decadal perspective. Stable isotopes were also measured and related to *in-situ* temperature and $\delta^{18}O_{seawater}$. During the sampling campaign in 2012, hurricane "Sandy" passed the Caribbean Sea. We used this unforeseen opportunity to examine the impact of such a storm on the foraminiferal community.

## 4.2 Regional settings

The south-western margin of Puerto Rico is characterized by a very steep slope, which commences at 20 m water depth on the shelf and extends to 1000 m water depth. The exceptionally steep southern slope of Puerto Rico is probably created by the anticlockwise rotation of the Puerto Rico Block and associated strike-slip movements along branches of the Great Southern Fault Zone (Glover, 1971; Byrne et al., 1985; Masson and Scanlon, 1991). Different water masses impinge the slope. The uppermost water mass is the Caribbean Water (CW) between 0 and 50–80 m depth. The CW has a low salinity of <35.5 psu and is a mixture of the Amazon and Orinoco river outflow and North Atlantic surface water (Gordon, 1967; Schmuker 2000b). The high saline Subtropical Under Water (SUW) (>37 psu) prevails between 50–250 m. The 18°C Sargasso Sea Water (Eighteen Degree Water = EDW) and the Tropical Atlantic Central Water (TACW) belong to the water mass at depths below (Gordon, 1967, Morrison and Nowlin, 1982; Gallegos, 1996). From August to November, surface waters in the southeastern Caribbean Sea are influenced by plumes of the Amazon and Orinoco rivers (Chérubin and Richardson, 2007). They bring silicate-rich and low saline surface waters into the Caribbean Sea (Froelich et al., 1978; Corredor and Morell, 2001). From June to November, the Atlantic hurricane season affects the Caribbean Sea. On average six hurricanes occurred in the Atlantic Ocean per year between 1981 and 2010, and induce a thorough mixing of the upper water column (Jacob et al., 2000; Blake et al., 2013; NHC, 2014).
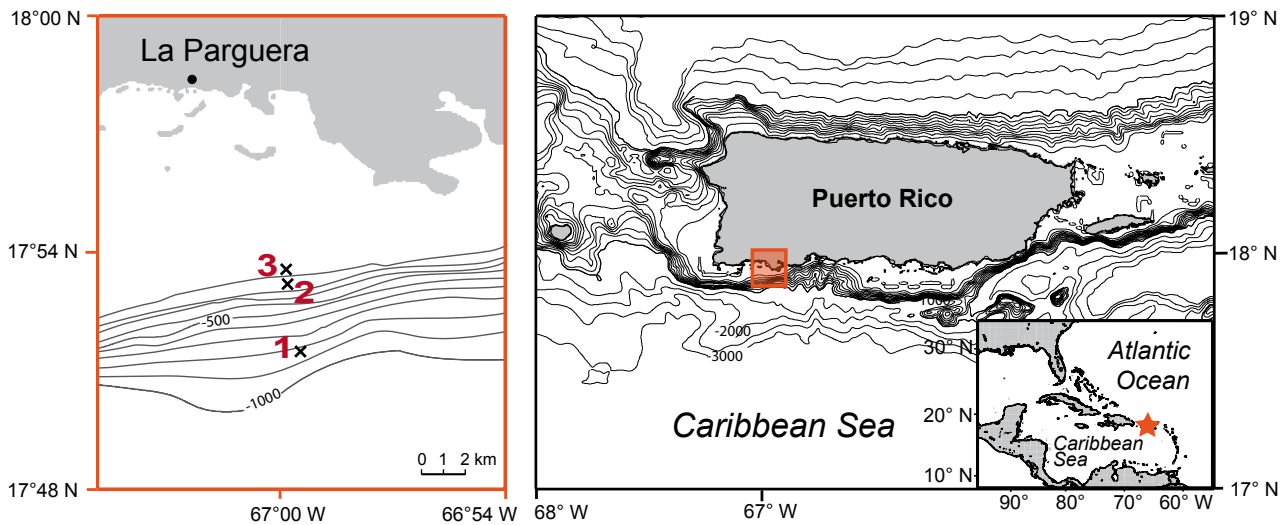
**Figure 4.1:** Location of the study area southwestern Puerto Rico (Caribbean Sea). The black crosses indicate the plankton net stations: Station 1 (Water depth: 850 m), Station 2 (Water depth: 150 m) and Station 3 (Water depth: 20 m).

# 4.3 Material and Methods

## 4.3.1 Sample collection

The sampling took place at three different stations off southern Puerto Rico on four days from October to November 2012 (Fig. 4.1; Tab. 4.1). The stations were located on the upper slope (850 m and 120 m water depth) and the shelf (20 m water depth). An Apstein net (Hydro-Bios) and an open plankton net were used to collect living planktonic foraminifera. At station 1 and station 2, the Apstein net with a mesh size of 100 µm and an aperture of 17 cm in diameter was taken to sample the 0–60 m and 60–100 m depth intervals. The net was heaved two times to double the volume of the filtered water during each haul. A trigger weight was attached to the rope, which released the shutter and closed the aperture of the net afterwards. The open plankton net, which was used at station 3, also had a mesh size of 100 µm but an aperture of 40 cm in diameter. Because of the shallow depth of about 20 m, vertical sampling was not possible. Instead, the open net was pulled with the boat for five minutes horizontally in the upper 5 m of the water column. The collected plankton samples were transferred to PVC vials, diluted with filtered ambient seawater and brought to the laboratory within two hours for further processing.

Additionally to the plankton net hauls, salinity and temperature were measured *in-situ* using a hand-held conductivity meter (LF 320/Standard-conductivity cell TetraCon 325) in

**Table 4.1:** Station list with longitude and latitude, water depth (m), sampling day, sampling depth (m), *in-situ* measured average temperature (°C) and salinity (psu).

| Station | 1 | 2 | 3 |
|---|---|---|---|
| Longitude (W) | 66° 59.13 | 66° 59.49 | 66° 59.51 |
| Latitude (N) | 17° 51.50 | 17° 53.13 | 17° 53.25 |
| Water depth (m) | 850 | 150 | 20 |
| Sampling date (Day/Month/Year) | 22.10.2012 29.10.2012 02.11.2012 05.11.2012 | 22.10.2012 29.10.2012 02.11.2012 05.11.2012 | 29.10.2012 02.11.2012 |
| Sampling depth (m) | 0 – 60 60 – 100 | 0 – 60 60 – 100 | 5 |
| Temperature (°C) | 29.31 | 29.14 | 29.47 |
| Salinity (psu) | 33.75 | 33.82 | 33.63 |

the first 25 m of the water column at stations 1 and station 2, and down to 10 m water depth at station 3. Seawater samples of the surface waters for stable oxygen isotopes were taken with a bucket and filled in 100 ml glass bottles.

## 4.3.2 Preparation of the samples

In the laboratory of Isla Magueyes, the marine station of the University of Puerto Rico, foraminifera were immediately picked wet from the plankton net samples and collected in Plummer slides. Samples that could not be picked on the same day of sampling were preserved in a 50% ethanol-seawater solution and stored at 4°C.

All tests of planktonic foraminifera were filled with yellowish, greenish-grey and green cytoplasm indicating that they were alive at the time of collection. The specimens were identified at species level following the taxonomy of Bé (1967) and Hemleben et al. (1989). We discerned two morphotypes of *Globigerinoides sacculifer* (= *Trilobatus sacculifer*; Spezzaferri et al., 2015): the *sacculifer*-morphotype with the sac-like final chamber, and the *trilobus*-morphotype with a regular, spherical final chamber. Furthermore, we distinguished between *G. ruber* (white), *G. ruber* (pink) and *G. elongatus* following Aurahs et al. (2011).

Benthic foraminiferal species in the plankton net samples were sorted into separate Plummer cell slides by species, fixed with glue and counted. Specimens of *Bolivina variabilis* were filled with orange-red cytoplasm indicating that they were alive at

the time of sampling (Hemleben et al., 1989). *Tretomphalus bulloides* contained yellowish-brown cytoplasm as described by Cushman (1922) from living individuals. Three *Cibicidoides pachyderma* specimens contained a greenish-brown, granular infill, which was interpreted as cytoplasm with food vacuoles. Other individuals and species were empty and the tests were dull, indicating that they were probably not alive at the time of collection.

The standing stock of the foraminiferal assemblages was given as individuals per cubic metre (ind. m$^{-3}$). The filtered seawater volume was estimated by multiplying the lengths of the net hauls with the opening net aperture area. Statistical analyses (paired sample t-test and hierarchical cluster analysis) were performed by using PAST software (Hammer et al., 2001).

### 4.3.3 Analyses of stable isotopes

Stable oxygen and carbon isotopes were analysed on calcite tests ($\delta^{18}O_{calcite}$ and $\delta^{13}C_{calcite}$) of the species *Globigerinoides ruber* (pink). For each analysis, 5 to 10 specimens were taken of different samples (Appendix D). Prior to the measurements, the foraminifera were cracked to open the tests and to remove the remaining cytoplasm with a needle. The measurements were performed on a ThermoScientific MAT 253 mass spectrometer equipped with a carbonate preparation device Kiel CARBO IV at GEOMAR. The stable isotope results were given relative to the Vienna Pee Dee Belemnite (VPDB) in per mil (‰) and calibrated *versus* the National Bureau of Standards (NBS) 19. The reproducibility ($\pm 1\sigma$) of the *in-house* standard (Solnhofen limestone) is <0.06‰ for $\delta^{18}O$ and <0.03‰ for $\delta^{13}C$. Stable oxygen isotope values of the seawater ($\delta^{18}O_{seawater}$) were measured on an Isotope-Ratio Mass Spectrometry (IRMS) at Hydroisotop GmbH (Schweitenkirchen). The results were reported in per mil (‰) *versus* Vienna Standard Mean Ocean Water (VSMOW) and the analytic precision is $\pm 0.15$‰ ($1\sigma$).

# 4.4. Results

## 4.4.1 Seawater properties during sampling

Temperature, salinity and stable oxygen isotopes of the upper water column were measured in order to determine the water mass characteristics. The near-surface waters showed a salinity of 33.4 to 34.2 psu and the temperature ranged from 28.3 to 29.8°C during the sampling period (Appendix D). In general, a very slight salinity increase of 0.2 psu with

depth has been recognised. However, this gradient was not consistent in depth and location, and the differences were close to the precision of the instrument of ± 0.1 psu and ± 0.1°C. As such, the seawater is considered as well-mixed in the upper 25 m. Stable oxygen isotope values of the ambient surface water ($\delta^{18}O_{seawater}$) ranged from 0.76 to 0.91‰ VSMOW (Appendix D). The predicted inorganic calcite value precipitated in thermodynamic equilibrium with the ambient seawater temperature and $\delta^{18}O_{seawater}$ ($\delta^{18}O_{equilibrium}$) averaged -2.13 ± 0.07‰ (Fig. 4.6). At the marine station of Isla Magueyes an increased daily average wind speed (up to ~12 km/h) and a high daily precipitation (up to ~70 mm) were recorded in late October 2012, which most likely indicates the impact of the heavy rainfall from the outer rainbands of hurricane "Sandy" (Fig. 4.2).
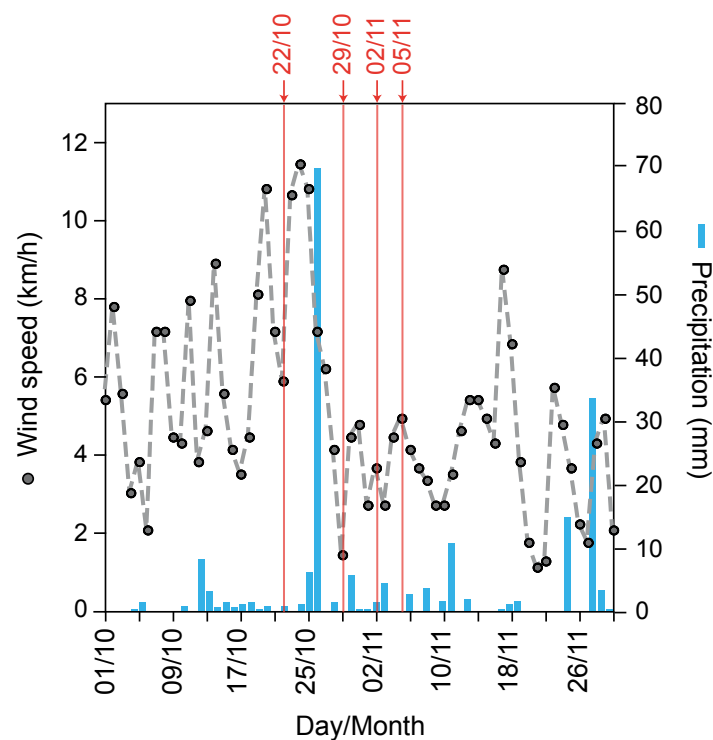


**Figure 4.2:** Wind speed and precipitation record during October and November 2012 from the field station at Isla Magueyes, La Parguera (Puerto Rico) (bio-optics.uprm. edu). Grey dots and dashed line: Average daily wind speed (km/h); Blue bars: Daily precipitation (mm); Red numbers indicate the sampling date (Day/Month) in 2012.

## 4.4.2 Foraminiferal assemblage in plankton net hauls

### 4.4.2.1 Overview

Fifteen living planktonic foraminiferal species and nine benthic species were identified in the plankton net hauls at the different stations  (Tab. 4.2). The planktonic assemblages were dominated by the tropical and subtropical species *Globigerinoides ruber* (pink), *Globigerinoides sacculifer* (both morphotypes) and followed by *Globigerinita glutinata* (Fig. 4.3). *Bolivina variabilis* was dominating the floating benthic assemblage, *Tretomphalus bulloides* and *Trifarina bella* were frequent, and *Cibicidoides pachyderma* was common (Fig. 4.3, Tab. 4.2).

The standing stock of the planktonic foraminiferal assemblage varied highly from 0.2 to 131.6 ind. m$^{-3}$ in single net hauls (Fig. 4.3). The highest standing stock was observed on October 22$^{nd}$. On October 29$^{th}$, the standing stock in the upper sampling interval (0–60 m) was markedly lower and rose again thereafter (Fig. 4.3A). Station 3 was sampled only on the 29.10.12 and 02.11.12. This station was closest to the shelf (Fig. 4.1) and showed the lowest standing stock of planktonic foraminifera in the upper water column (0.2 and 1.5 ind. m$^{-3}$) of all net samples.

The abundance of benthic foraminifera varied from 0.3 to ~21 ind. m$^{-3}$ in single net hauls (Fig. 4.3). A shift to a higher abundance of benthic specimens was observed concomitant to a decline of planktonic foraminifera on the 29$^{th}$ of October at station 1 and 2. *Bolivina variabilis* was still abundant at station 2 after the 29$^{th}$ of October (Fig. 4.3). Even though the species composition showed no significant differences between the sampling days (paired sample t-tests, $p > 0.05$) different Bray-Curtis similarity indices can be observed between each sampling day (Fig. 4.4, Appendix D). The samples of the 2$^{nd}$ and the 5$^{th}$ of November showed the highest similarity index (0.81). The samples on the 29$^{th}$ of October showed a lower similarity (Fig. 4.4), with the lowest similarity index of 0.36 related to the 22$^{nd}$ of October.

### 4.4.2.2 Depth distribution pattern of foraminifera

In order to test whether habitat depths of different species depended on the water masses, two depth intervals (0–60 m and 60–100 m) were sampled at station 1 and station 2. The highest average standing stock of living planktonic foraminifera was found in the upper interval. Differences in the assemblage composition between the upper and the lower interval were depicted by rare species only (Fig. 4.5A). Station 1 had a slightly higher

**Table 4.2:** Species list with maximum abundance (individual m$^{-3}$) for a net haul during the sampling periods and percentage of the planktonic and benthic assemblage. The type references are given in Ellis and Messina (1940). They are not included in the reference list.

| Species | Max. abundance Station | | % |
|---|---|---|---|
| **Planktonic:** | | | |
| *Globigerina bulloides* d`Orbigny, 1826 | 0.39 | Station 2 | 0.16 |
| *Globigerinella calida* (Parker, 1962) | 4.09 | Station 1 | 1.90 |
| *Neogloboquadrina dutertrei* (d`Orbigny, 1839) | 4.68 | Station 2 | 2.54 |
| *Globigerinita glutinata* (Egger, 1893) | 13.67 | Station 1 | 6.03 |
| *Globorotalia menardii* (Parker, Jones and Brady, 1865) | 4.68 | Station 2 | 1.43 |
| *Candeina nitida* d`Orbigny, 1839 | 1.75 | Station 2 | 0.32 |
| *Pulleniatina obliquiloculata* (Parker and Jones, 1865) | 0.58 | Station 2 | 0.05 |
| *Hastigerina pelagica* (d`Orbigny, 1839) | 1.75 | Station 2 | 0.42 |
| *Turborotalita quinqueloba* (Natland, 1938) | 2.34 | Station 2 | 0.53 |
| *Globigerinoides ruber* white (d`Orbigny, 1839) | 5.47 | Station 2 | 3.49 |
| *Globigerinoides ruber* pink (d`Orbigny, 1839) | 49.61 | Station 2 | 36.95 |
| *Globoturborotalita rubescens* Hofker, 1956 | 7.42 | Station 1 | 2.70 |
| *Globigerinoides sacculifer* (Brady, 1877) = *Trilobatus sacculifer* (Spezzaferri et al., 2015) | 53.91 | Station 1 | 39.85 |
| *Globigerinella siphonifera* (d`Orbigny, 1839) | 4.68 | Station 2 | 1.59 |
| *Orbulina universa* d`Orbigny, 1839 | 2.92 | Station 1 | 1.16 |
| | | | |
| **Benthic:** | | | |
| *Asterigerina carinata* d`Orbigny, 1839 | 0.58 | Station 2 | 0.38 |
| *Bolivina minima* Phleger and Parker, 1951 | 0.39 | Station 2 | 0.38 |
| *Bolivina paula* Cushman and Cahill, 1932 | 0.58 | Station 1 | 0.38 |
| *Bolivina striatula* Cushman, 1922 | 0.02 | Station 3 | 0.38 |
| *Bolivina variabilis* (Williamson, 1858) | 12.11 | Station 2 | 70.99 |
| *Cibicidoides pachyderma* (Rzehak, 1886) | 1.17 | Station 2 | 1.91 |
| *Cornuspira involvens* (Reuss, 1850) | 0.02 | Station 3 | 0.38 |
| *Tretomphalus bulloides* (d`Orbigny, 1839) | 1.95 | Station 2 | 6.87 |
| *Trifarina bella* (Phleger and Parker, 1951) | 19.30 | Station 2 | 17.56 |

standing stock (Fig. 4.3A) in the upper interval than station 2, although both stations showed a profound population density fluctuation during the sampling time. This high fluctuation was not recognized in the deeper intervals (Fig. 4.3B). In the upper part of the water column, *G. ruber* (pink), *G. sacculifer* and *G. glutinata* dominated the assemblages. All three species showed the highest standing stock on the 22$^{nd}$ of October. Among the common species, *G. ruber* (white) showed the highest abundance in the upper interval too, as well as *Globoturborotalita rubescens* at both stations on the 22$^{nd}$ of October. In contrast, *Neogloboquadrina dutertrei* did not indicate a preference to one of the sampled depth intervals. Higher abundances in the deeper interval were observed for *Globorotalia menardii*, *Globigerinella calida*, *Globigerinella siphonifera* and *Orbulina universa*

(Fig. 4.3B). All the other planktonic species were very rare and thus no distinctive distribution pattern was recognised.

The highest abundance of benthic species was recorded at station 2 on the first sampling date in the lower depth interval (60–100 m) (Fig. 4.3B), mainly due to a high number of *Trifarina bella*. On the 29th of October, higher specimen densities were found in the upper interval at both stations. This was mainly caused by the exceptionally high

**A: 0 - 60 m water depth**
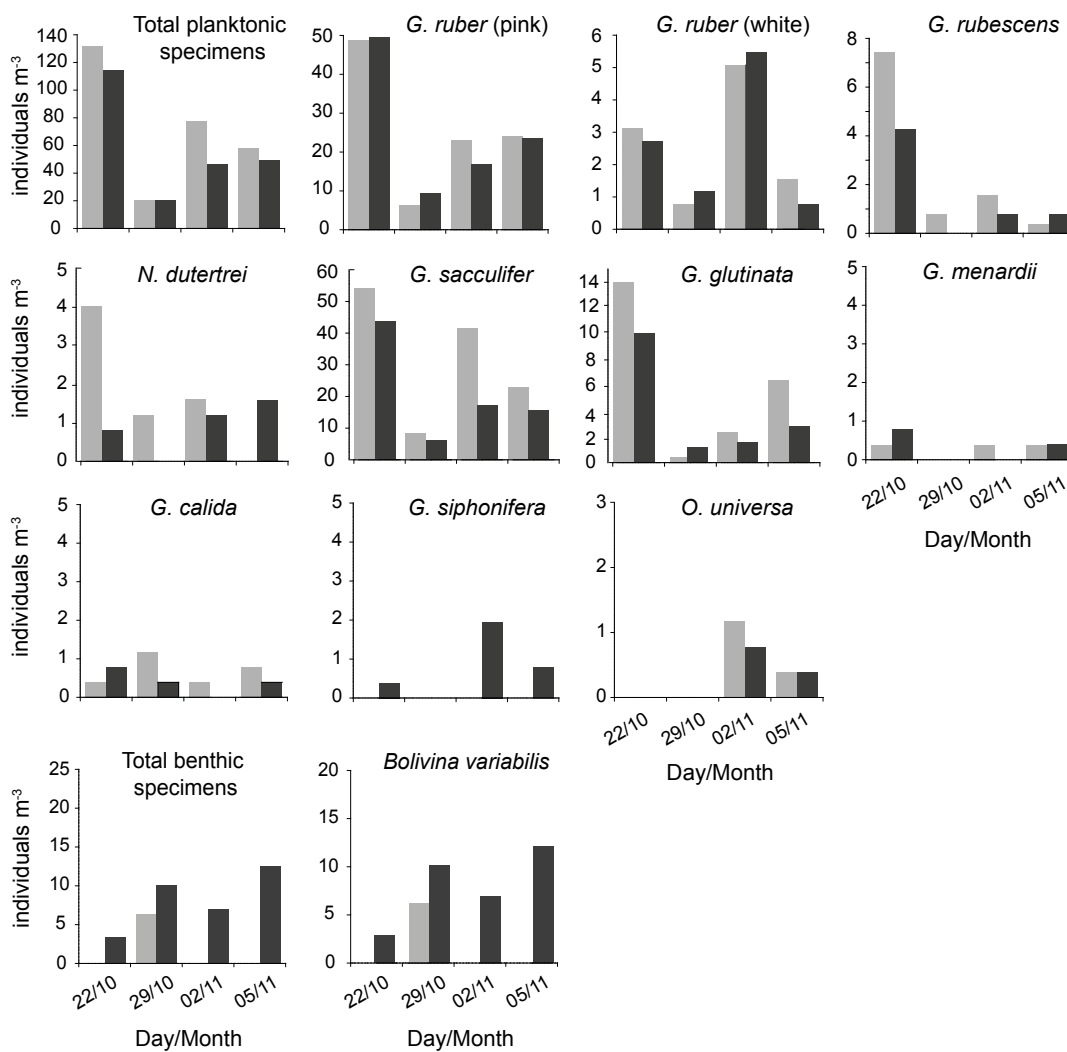


**Figure 4.3 A:** Standing stock of planktonic and benthic species at station 1 and station 2 of the upper sampling interval (0–60 m) in 2012. The number is given in individual m[-3] for each sampling day and depth interval. Living planktonic species >1% of the total assemblages are depicted. Light grey bars: Station 1; Dark grey bars: Station 2.

abundance of *B. variabilis*. On the 2nd and 5th of November, the upper interval at station 2 also depicted a high standing stock of *B. variabilis* (Fig. 4.3A). Station 1 yielded benthic specimens in the plankton nets on the 29th and 2nd of November only. Rare *Bolivina* species, *Asterigerina carinata*, and *Cornuspira involvens* were collected on the 29th of October. *Cibicidoides pachyderma* was found in several net samples and showed no distinctive pattern (Appendix D).

## B: 60 - 100 m water depth
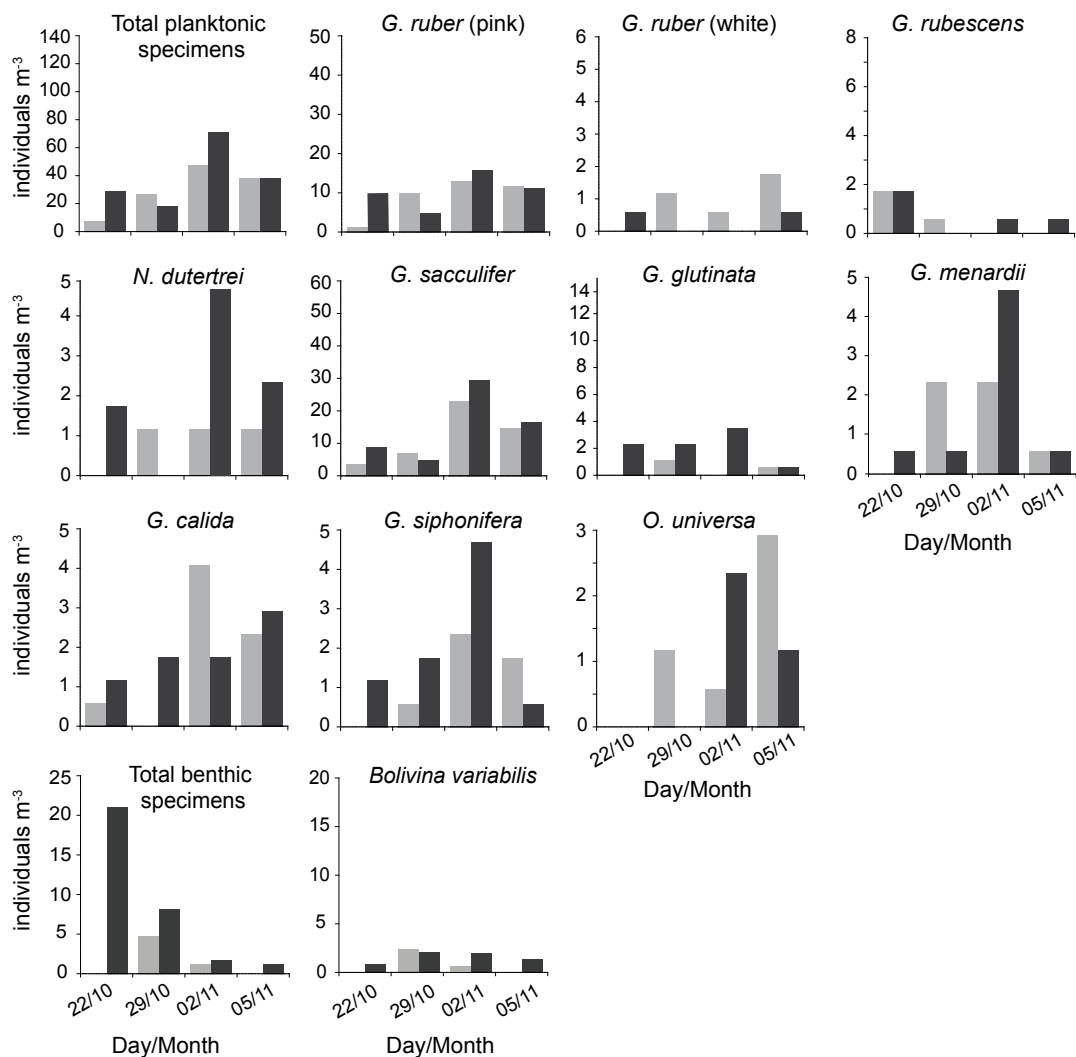


**Figure 4.3 B:** Standing stock of planktonic and benthic species at station 1 and station 2 of the deeper sampling interval (60–100 m) in 2012. The number is given in individual m$^{-3}$ for each sampling day and depth interval. Living planktonic species >1% of the total assemblages are depicted. Light grey bars: Station 1; Dark grey bars: Station 2.
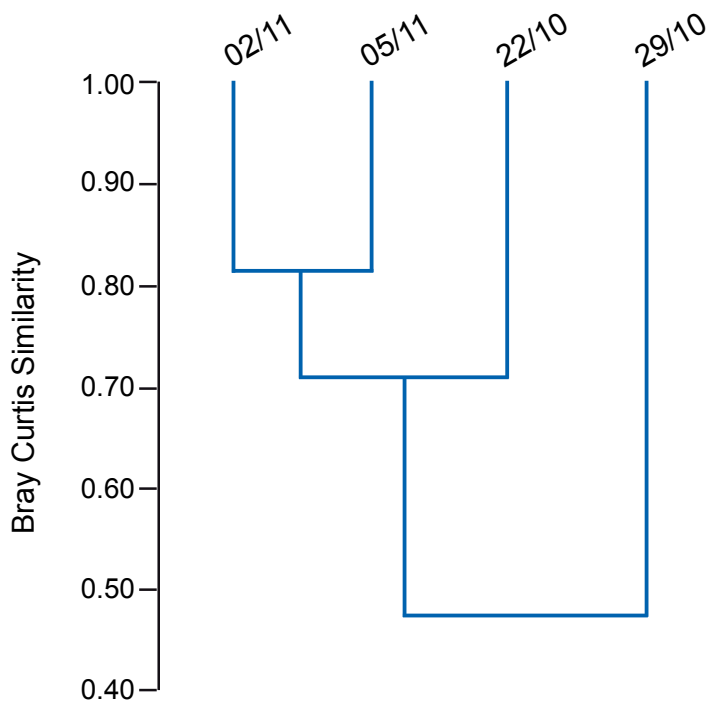
**Figure 4.4:** Hierarchical cluster analysis showing the similarity of foraminiferal assemblages from station 1 and station 2 between different sampling days (Day/Month) in 2012. Cluster analysis was performed using the Unweighted Pair Group Method with Arithmetic mean (UPGMA) based on the Bray-Curtis similarity index (values from 0 to 1). 1 indicates the highest similarity between the fauna.

### 4.4.3 Stable isotopes of *Globigerinoides ruber* (pink) and the ambient seawater

The stable oxygen isotopes ($\delta^{18}O_{calcite}$) of *G. ruber* (pink) averaged -2.54‰ and the stable carbon isotopes ($\delta^{13}C_{calcite}$) 0.49‰ respectively. However, specimens of the deeper net (60–100 m water depth) yielded higher $\delta^{18}O_{calcite}$ and higher $\delta^{13}C_{calcite}$ values than samples of the upper water mass (Fig. 4.6). The lowest $\delta^{13}C_{calcite}$ values were measured of specimens collected on the 29th of October 2012. The sample of station 3 showed the lowest stable isotope values (-2.96‰ for $\delta^{18}O_{calcite}$ and -0.4‰ for $\delta^{13}C_{calcite}$).

# 4.5. Discussion

### 4.5.1 The autumn planktonic foraminiferal assemblage

Previous studies revealed that the distribution and composition of planktonic foraminiferal faunas are generally influenced by biological and physical factors, as well as geographical settings (e.g. Thunell and Reynolds, 1984; Guptha et al., 1997; Schiebel and Hemleben, 2000; Storz et al., 2009; Tedesco et al., 2007).

The data in autumn 2012 showed a similar species inventory as described in 1994 (Fig. 4.5). Schmuker (2000b) reported a seasonal change in the foraminiferal assemblage

between autumn 1994 and spring 1995 at the locations that were revisited in this study. In spring 1995, *G. calida*, *G. siphonifera*, *O. universa*, *Hastigerina pelagica* and *Globorotalia truncatulinoides* were common, whereas the autumn assemblage mainly comprised *G. ruber* (pink and white), *G. sacculifer*, *G. menardii*, *N. dutertrei* and *G. glutinata* (Fig. 4.5B). In our survey from autumn 2012, *G. sacculifer* (~40% of the total planktonic assemblage) and *G. ruber* (pink) (~37%) were the dominant species. Species of Schmuker´s (2000b) spring community were, with the exception of *G. truncatulinoides*, also found in the samples but they occurred in low numbers and mainly in the deeper interval (Fig. 4.5A). Schmuker (2000b) sampled the upper 10 m of the water column and from the surface to 120 m water in one haul. Thus, a change of the habitat depths of the species during different seasons cannot be determined. Our data from 2012 indicated preferred habitats of certain species, although the dominant faunal elements *G. ruber* (pink) and *G. sacculifer* were found in high numbers in the entire sampled water column (Fig. 4.5A). Both species are common in tropical and subtropical oceans and frequent in the Caribbean Sea (Jones, 1968; Bé et al., 1971; Schmuker and Schiebel, 2002; Chapter 2).

The species *G. ruber* (pink) and *G. glutinata* indicate a high nutrient supply (Bé and Tolderlund, 1971; Schiebel et al., 2001; Retailleau et al., 2011). A high nutrient-flux into the Caribbean Sea during autumn is likely caused by the riverine plumes of the Amazon and Orinoco (Bidigare et al., 1993; Corredor and Morell, 2001; Chérubin and Richardson, 2007). The effect of river-plumes on foraminiferal communities has been described in earlier studies (Ufkes et al., 1998; Retailleau et al., 2009; Retailleau et al., 2011; Bahr et al., 2013). Bahr et al. (2013) recorded a low planktonic foraminiferal standing stock in the Gulf of Paria and the main plume of the Orinoco River. Low salinity lenses and high turbidity might be an explanation for the lack of high numbers of planktonic foraminifera in this area (Schmuker and Schiebel, 2002). In the Bay of Biscay and the plume of the Adour River, foraminifera responded to different nutrient and chlorophyll supply, rather than to seasonal salinity changes (Retailleau et al., 2011). Schmuker (2000b) interpreted the changes in planktonic foraminiferal assemblages off Puerto Rico during spring as being driven by a change in food supply as well.

## 4.5.2 Decline of *Globigerinoides ruber* (white) – A long term observation

A slight but conspicuous change of the foraminiferal assemblage composition can be observed between 1994 and 2012. In autumn 1994, *G. ruber* (white) had a substantially higher percentage (37%) than in 2012 (3.5%) (Fig. 4.5). This observation is in agreement with earlier observations during cruise RV Meteor M78/1 in spring 2009, where low numbers of *G. ruber* (white) were found in plankton net samples all over the Caribbean Sea (Schönfeld et al., 2011). In the Gulf of Mexico a higher number of the pink than the white variety was observed in sediment traps in 2008 and 2009 (Poore et al., 2013). Surprisingly, the proportion of *G. ruber* (white) increased again in 2010 (Poore et al., 2013). A conceivable explanation why the proportion has changed and why *G. ruber* (white) was rare in 2008 and 2009 has not been given to date. Another study of plankton net samples from the tropical Atlantic, which were collected in 2008, reported a decrease in numbers of *G. ruber* (white) during the past decades as well. The decline was related to a decadal increase of Atlantic sea surface water temperatures (Harbers, 2011).

Based on the findings within this study and previous investigations, the decrease in abundance of *G. ruber* (white) as compared to *G. ruber* (pink) in the tropical and subtropical Atlantic is ascertainable. It might be possible that *G. ruber* (white and pink) can live under certain conditions in a similar ecological niche. Sharing a common niche may increase competition between both species when the habitat gets under pressure. Thus it is possible that environmental changes (e.g. increase in sea surface temperature, changes in nutrient supply) favour the more tolerant species, which might be *G. ruber* (pink) in our case, whereas *G. ruber* (white) is at its niche limit (Murray and Alve, 2016).

Indeed, previous studies have shown that temperature affects the two species differently. While *G. ruber* (white) shows a worldwide distribution (Tolderlund and Bé, 1971; Watkins et al., 1996), *G. ruber* (pink) is only found in the Atlantic and Mediterranean Sea today. The highest standing stocks were recorded in the central Atlantic, Gulf of Mexico and Caribbean Sea (Bé and Tolderlund, 1971). In the Indian and Pacific Ocean, *G. ruber* (pink) became extinct around 120,000 years BP (Thompson et al., 1979). In general, the modern distribution of *G. ruber* (pink and white) shows that the species are associated with warm sea surface temperatures (e.g. Cifelli, 1965; Tolderlund and Bé, 1971; Žarić et al., 2005). In particular *G. ruber* (pink) is associated with a seasonal peak in boreal summer (Deuser et al., 1981; Tedesco et al., 2009). On the contrary, *G. ruber* (white) was linked to a cooler and deeper habitat, e.g. in the Florida Straits (Jones, 1971).
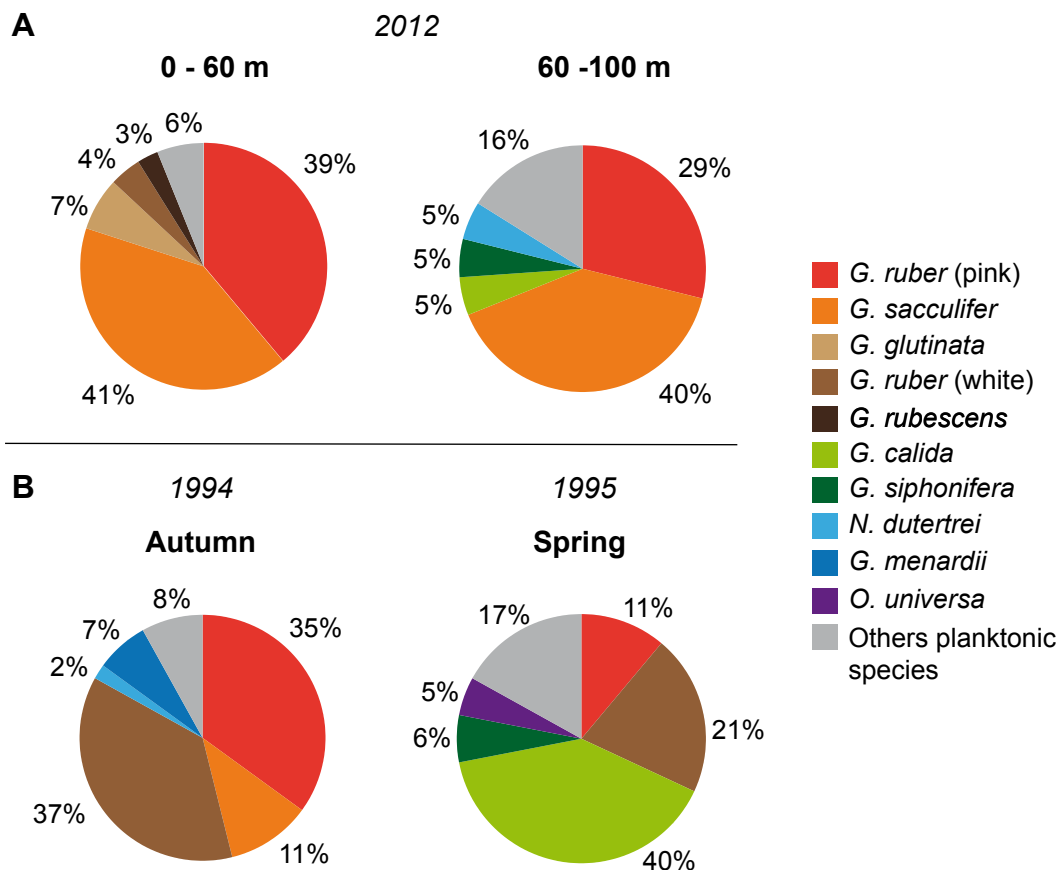
**Figure 4.5 A:** The average assemblage composition of planktonic foraminifera at station 1 and station 2. Percentages were calculated from the total living planktonic assemblage of the sampling interval 0–60 m and 60–100 m water depth. **B:** The average assemblage composition of planktonic foraminifera from autumn 1994 and spring 1995, mesh size >150 μm (based on data from Schmuker, 2000b; cf. Appendix D).

Studies comparing calcification temperature and productivity corroborated that *G. ruber* (pink) prefers seasons or water depths with a higher temperature as compared to *G. ruber* (white) (Žarić et al., 2005; Richey et al., 2012). However, it has to be noted that different genotypes of *G. ruber* (white) exists (Kučera and Darling, 2002; Aurahs et al., 2009; Aurahs et al., 2011). Anticipating that different genotypes have different ecological preferences, conclusions based on those species are yet fairly uncertain.

A decadal increase of sea surface temperature of 0.27°C has been observed in the Caribbean in the time period from 1985–2009, even though a certain spatial variability has to be considered (Chollett et al., 2012). The measurements of the upper water column (0–25 m) in this study showed a mean temperature of 29.8°C (with the given accuracy of customary hand-held conductimeters of ±0.1°C), which was higher by 1.1°C than in 1994 (28.7°C in October, Schmuker, 2000b). It is conceivable that a temperature increase might be responsible for the decline of *G. ruber* (white). However, other factors such as

food competition, change of nutrient supply may also play a certain role in augmenting this dynamics. Therefore, no single factor being solely responsible for the decline of *G. ruber* (white) can be constrained to date.

## 4.5.3 Spatial distribution – The influence of the shelf and benthic species

The near-shore station 3 showed a distinctly lower foraminiferal standing stock (average 1.69 ind. $m^{-3}$) than the other sampling sites. The difference of station 3 to the other stations could partially be due to a different way of sampling (only in ± 5 meter water depth). In comparison with deep-water stations, however, a generally lower standing stock of planktonic foraminifera close to the coast has also been observed, for instance in the Bay of Biscay (Retailleau et al., 2009). There, the input of freshwater discharge has been involved as a factor influencing the foraminiferal community. Another aspect of a low density of living planktonic foraminifera in shallow water is dependent on their reproduction cycle. It is assumed that planktonic foraminifera need a certain water depth to complete their life cycle (Schiebel and Hemleben, 2005). Hence, the reproduction is inhibited in shallow water.

The abundance of benthic foraminifera in the water column in 2012 off Puerto Rico was lower than previously reported by Fornshell (2005) from plankton hauls in the vicinity of reefs around Puerto Rico, but yields similar numbers as reported by Schmuker (2000b) in autumn 1994.

In the plankton net hauls of Puerto Rico meroplanktonic species (such as *Tretomphalus bulloides*) were found. They built a floating chamber in the late stage of their life cycle to release their gametes in the upper water column (Sliter, 1965; Rückert-Hilbig, 1983). The biserial *Bolivina variabilis* (co-specific to *Streptochilus globigerus*) can possibly grow and calcify in both: a planktonic and benthic habitat (tychopelagic lifestyle) (Darling et al., 2009). After October 29th, the abundance of *B. variabilis* increased and was higher in the uppermost 60 m of the water column than at depths below (Fig. 4.3). This species was previously found to be either absent or rare in near-shore sediments off southern Puerto Rico (Brooks, 1973; Seiglie, 1975). It is conceivable that the stormy weather conditions due to hurricane "Sandy" stimulated *B. variabilis* to ascend to the upper water column as part of their lifestyle and ecological advantage (Darling et al., 2009). On the other hand, empty benthic specimens collected in the water column have probably been eroded from the surface sediments or brought in suspension attached on seagrass and transported further

offshore (Loose, 1970; Murray, 1987; Schmuker 2000b; Fornshell, 2005).

## 4.5.4 Stable oxygen isotope signal

In the upper water column stable oxygen isotope values of *G. ruber* (pink) showed an offset of -0.46‰ to the equilibrium values of the ambient seawater (Fig. 4.6). As the species *G. ruber* (pink) host symbionts (e.g. dinoflagellates, Gastrich, 1987), this offset possibly indicates photosymbiont activity. Symbiont activity lowers the stable oxygen isotope composition of calcite tests (Spero and Lea 1993), and high negative disequilibrium values in symbiont-bearing species were recognized in the Caribbean Sea (Chapter 3).

$\delta^{18}O_{calcite}$ values from autumn in 1994 (Schmuker 2000b) of *G. ruber* (white) yield the same average values than *G. ruber* (pink) in 2012 (-2.5‰) and indicate higher temperature in autumn than in spring (Fig. 4.6). On average, higher $\delta^{18}O_{calcite}$ values (+ 0.17‰) were measured in deeper plankton net intervals (60–100 m) than in the upper water column and may indicate a decrease of the ambient seawater temperature. Species-specific $\delta^{18}O$-paleotemperature equations of Bemis et al. (1998) for *O. universa*, Spero et al. (2003) for *G. sacculifer* and Farmer et al. (2007) for *G. ruber* (pink) match very good to our $\delta^{18}O_{calcite}$ and $\delta^{18}O_{seawater}$ data compared to the measured *in-situ* temperature of the upper water column (Fig. 4.7). The average estimated temperature deviated from the *in-situ* surface temperature by -0.36°C (Bemis et al., 1998), -0.11°C (Spero et al., 2003) and -0.34°C (Farmer et al., 2007). Applying the $\delta^{18}O$-paleotemperature equations of Spero et al. (2003), specimens of the deeper water column reveal an estimated temperature of ~25.6°C. This is 3.7°C colder than estimated for the upper water column (~29.3°C) and likely depicts the properties of the SUW below 60 m water depth.

## 4.5.5 Hurricane "Sandy" – A storm affects the foraminiferal assemblage

The results of this study let us speculate that hurricane "Sandy", which passed the Greater Antilles on October 24th, induced higher waves and precipitation at the sampling site of Puerto Rico (Fig. 4.2) and thereby affected the foraminiferal assemblages. After "Sandy", the planktonic foraminiferal density dropped in the upper water column on October 29th and at the same time, a higher number of benthic species was found in the upper water column (Fig. 4.3). The fact that storms can influence a planktonic foraminiferal assemblage was also shown in the North East Atlantic Ocean (Schiebel et al., 1995). However, an opposite effect was observed, namely an increase of the total abundance of small specimens after two
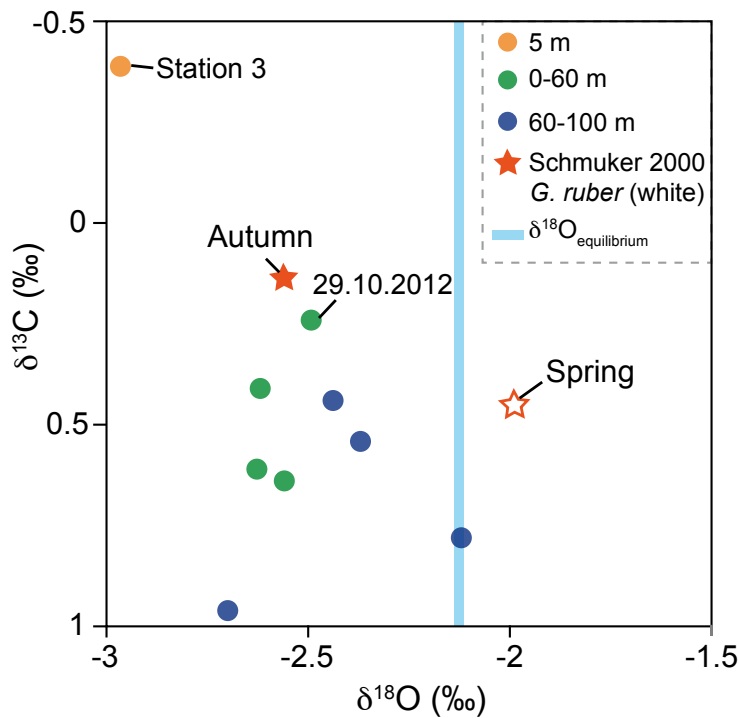
**Figure 4.6:** Stable isotope values of *G. ruber* (pink) and average $\delta^{18}O_{equilibrium}$ value of the ambient surface water. $\delta^{18}O_{equilibrium}$ was calculated after the $\delta^{18}O$-temperature equation of Kim and O´Neil (1997) for inorganic precipitation ($\delta^{18}O_{equilibrium} = 25.778 - 3.333*\sqrt{43.704+T}+\delta^{18}O_{seawater}$) with *in-situ* temperatures recorded during the sampling campaign, and seawater values ($\delta^{18}O_{seawater}$) scaled to PDB by subtracting 0.27‰ (Hut, 1987). Stars indicate the isotope data of Schmuker (2000b) from *G. ruber* (white) collected in autumn 1994 and spring 1995 (cf. Appendix D for data). Green and blue dots indicate the average values of station 1 and station 2 from the four sampling days and two sampling depth intervals. Orange dot: Stable isotope value of specimens collected at station 3 on the 29th of October.
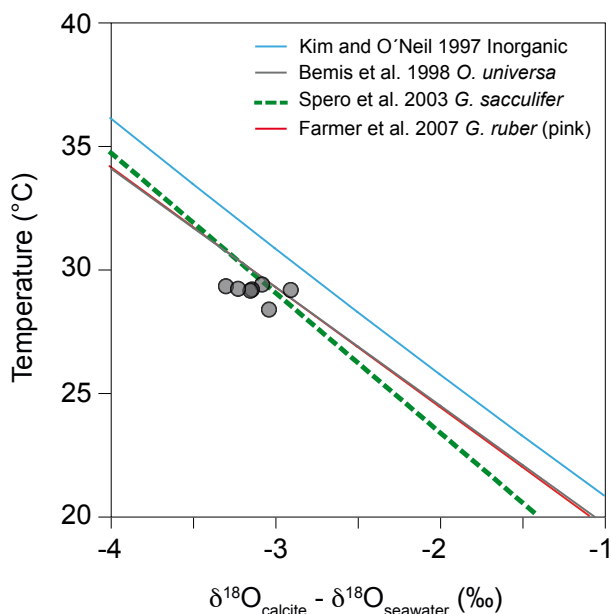


**Figure 4.7:** $\delta^{18}O$-temperature relationship. Grey dots: Difference of $\delta^{18}O_{calcite}$ values of living *G. ruber* (pink) and *in-situ* $\delta^{18}O_{seawater}$ values collected in the upper water column (0–60 m) vs. *in-situ* measured temperature. Different $\delta^{18}O$-temperature equations are depicted as blue line (Kim and O´Neil, 1997), grey line (Bemis et al., 1998), green dashed line (Spero et al., 2003) and red line (Farmer et al., 2007).

storm events. These storm events raised the nutrient and chlorophyll concentrations in the mixed layer and thereby pushed the reproduction. An elevated chlorophyll concentration after hurricanes was reported from the Sargasso Sea (Babin et al., 2004) and from Puerto Rico (Gilbes et al., 2001). On the coast of Puerto Rico higher chlorophyll concentration was measured three days after the hurricane had crossed the island. Additionally, a higher rainfall and river runoff with terrestrial load was found, which affected neritic environments after the storm. Intense precipitation and extensive flooding were recorded on Puerto Rico in late October 2012 due to hurricane "Sandy" (Fig. 4.2) (Blake et al., 2013).

A higher nutrient input in combination with terrestrial runoff might contribute to a higher turbidity in the water column close to the coast. If this was the case, the living conditions changed for a short time and affected the planktonic community observed within this study. On the 29th of October, lower $\delta^{13}C_{calcite}$ values of *G. ruber* (pink) collected in the upper water column and at station 3 probably recorded the storm event the days before (Fig. 4.6). Symbionts photosynthetic activity can strongly influence the incorporation of $\delta^{13}C$ in foraminiferal tests (Spero and DeNiro, 1987; Spero and Lea, 1993; Spero and Williams, 1988). The studies showed that during lower light irradiance the foraminiferal calcite is depleted in $\delta^{13}C_{calcite}$. Lin et al. (2004) and Lin et al. (2011) indicated depleted $\delta^{13}C_{calcite}$ in foraminiferal tests in relation to high nutrient concentration and supply of $^{12}C$ rich water in the South China Sea. Based on those observations we conclude that the vicinity of the coast has influenced the station on the shelf break. The data support the assumption of a higher terrestrial runoff and higher turbidity after the hurricane. They may have caused lower irradiance light levels and reduced photosymbiont activity.

## 4.6. Summary and conclusion

The foraminiferal assemblage in autumn 2012 was largely similar to the autumn assemblage in 1994, although a decline of *G. ruber* (white) can be observed off the coast of Puerto Rico. This decline might indicate a change of environmental factors such as increasing sea surface water temperature during the last decades. Below 60 m water depth, a different depth habitat was observed only for some rare species and $\delta^{18}O_{calcite}$ values indicate lower temperatures due to the influence of the SUW. A negative disequilibrium of $\delta^{18}O_{calcite}$ to the ambient seawater reveals likely photosymbiont activity in *G. ruber* (pink). Hurricane "Sandy" passed the Caribbean Sea during the sampling time and affected the foraminiferal

populations. The storm triggered a decrease of the foraminiferal standing stock and possibly stimulated *B. variabilis* to ascend to the upper water column occupying their plankton habitat. Depleted $\delta^{13}C_{calcite}$ in the upper water column indicate likely a higher turbidity after the storm and the vicinity of the coast. However, the exact mechanism by which stormy weather and heavy rainfall influenced the population cannot be explained exactly by the present study, but it should be considered that such hurricanes make it even more difficult to understand the factors controlling living planktonic foraminifera.

## Acknowledgements

# CHAPTER 5

# Predators of living planktonic foraminifera

Planktonic foraminifera are exposed to natural predators, although only little is known about these. The remains of planktonic foraminiferal tests have been found in the guts of planktonic crabs and Chaetognatha (Berger, 1971b, Terazaki, 1996). In plankton samples, high numbers of Chaetognatha were observed sticking onto living foraminifera (Harbers, 2011; own observations). In plankton net samples, collected during RV Meteor cruises M78/1 in 2009, M94 and M95 in 2013 (cf. Chapter 2 for further description), single foraminifera, mainly *Globigerinita glutinata*, showed multiple borings in their empty tests (Fig. 5.1). These borings probably indicate attacks and feeding of predators on living specimens in the open ocean. Similar borings in planktonic foraminiferal tests were recognized in other studies (Nielsen, 1999; Nielsen and Nielsen, 2001; Nielsen et al., 2003), mainly in chambers of species with a test-size <350 μm. The authors did not identify any predator, but suggested, based on the repeated drilling of different chambers on one individual and on the position of the borings, that the predators target the cytoplasm from outside of the test. Studies of benthic foraminifera discussed borings possibly drilled by nematodes or gastropods (Sliter, 1971; Lipps, 1983; Arnold et al., 1985; Culver and
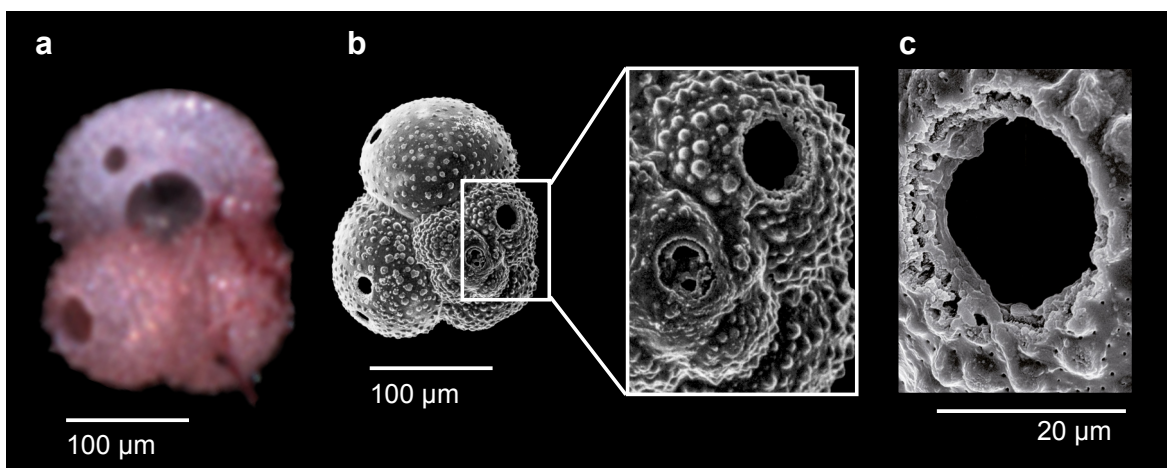


**Figure 5.1:** Photo and SEM images of borings in *G. ruber* (a) and *G. glutinata* (b-c).

Lipps, 2003). In a laboratory culture study, Sliter (1965) observed a nematode in the final chamber of a living *Rosalina globularis*. The author later differentiated between borings of nematodes and those drilled by gastropods (Sliter, 1971). Drilled holes with an irregularly round to oval shape and oblique angle can be attributed to attacks from nematodes (even though a certain attack was never observed), in contrast, the borings of gastropods show smooth walls, bevelled outer edges and are in general circular (Carriker and Yochelson, 1968; Sliter, 1971). Lipps (1983) suggested small naticid gastropods, mainly of the group opisthobranchs, as a potential predator. Arnold et al. (1985) recognized multiple borings in the foraminiferal tests of *Siphouvigerina auberiana* from the Galapagos hydrothermal mounds. These holes had a size range of 10 to 125 μm and the authors suspected a naticid gastropod, which attacks only specific species. The holes presented in the latter study resemble the borings of tests found within this study (Fig. 5.1). Multiple drilled holes in empty tests of *G. glutinata*, and in single tests of juvenile *Globorotalia menardii* and *Globigerinoides ruber* were observed. It is probable that the highest occurrence of borings was found in *G. glutinata* because it also had the highest abundance of empty tests in the water column (cf. Chapter 2). However, on the basis that selective predation on foraminifera is well known (Shonman and Nybakken, 1978; Arnold et al., 1985), the especially small and smooth tests of non-spinose planktonic foraminifera, like *G. glutinata*, are optimal targets for a predator in the open ocean. Even though any attack on living planktonic foraminifera was directly observed, we may assume, based on the shape of the borings, that a group of naticid gastropods was the most likely predator.

# CHAPTER 6

# Summary and Outlook

The focus of this study was to validate and improve the application of planktonic foraminifera for studies in paleoceanography based on their ecology and geochemical signatures. Therefore, habitat patterns, stable isotopes ($\delta^{18}$O and $\delta^{13}$C) and Mg/Ca compositions in tests of living tropical and subtropical planktonic foraminifera in the Caribbean were determined and compared to *in-situ* measurements of the seawater (temperature, salinity, $\delta^{18}$O$_{seawater}$) and to fossil tests from surface sediments.

The study indicates a strong relationship between the living planktonic faunal composition and seawater temperature, particularly in their vertical distribution but also in their horizontal distribution patterns. Chlorophyll concentrations, turbidity and salinity are also potential factors influencing the standing stocks of the foraminiferal assemblages in different ways. In the eastern Caribbean Sea, a high standing stock of planktonic foraminifera was observed close to a transient mega-patch of high chlorophyll concentrations in early spring 2009, with a high population density of *Globigerinita glutinata*. High turbidity and concomitant low salinity, on the other hand, probably expelled planktonic foraminifera from the Gulf of Paria and close from the Orinoco river plume. Single species were related to specific living habitats (e.g. the mixed layer, thermocline) and some species (e.g. *Globorotalia truncatulinoides* dextral and *Globorotalia crassaformis*) point to an ontogenetic variability in their depth habitat. Predators probably attack living planktonic foraminifera, mainly *Globigerinita glutinata*, in the open ocean and target the cytoplasm.

No major change was observed between the living and fossil assemblage compositions over the last millennia. However, the standing stock of *Globigerinoides ruber* (white) in 2012 off the coast of Puerto Rico reveals a decline since the late 1900s. A large number of *Globorotalia ungulata* in the Florida Straits in spring 2009 indicate an increasing standing stock of the assemblage or a unique seasonal occurrence. Furthermore, different species proportion in the living and fossil assemblages reveal seasonal fluctuations in their abundances that are probably linked to temperature variability or riverine outflow.

After hurricane "Sandy" (October 2012), lower numbers of living planktonic foraminifera dwelled in the upper water column. The stormy weather probably stimulated the benthic stages of *Bolivina variabilis* to buoy upwards into surface waters off the southern coast of Puerto Rico and additionally, lower $\delta^{13}C_{calcite}$ values most likely point to higher turbidity of the ambient seawater.

Isotopic compositions and Mg/Ca ratios indicate large "vital effects" (e.g. symbiont activity, ontogenetic development). Photosynthetic processes might cause negative disequilibrium values (up to ~0.5‰) between $\delta^{18}O_{calcite}$ in foraminiferal tests of *Globigerinoides sacculifer*, *Orbulina universa* and *Globigerinoides ruber* (pink) and the ambient seawater in the euphotic zone. The large scatter of Mg/Ca ratios in living planktonic foraminifera collected from the same sample, and heterogeneity of Mg/Ca in single chambers (low and high $Mg^{2+}$ bands) point to large variable $Mg^{2+}$ incorporation during calcification processes. Mg/Ca and stable oxygen isotopic compositions in living foraminiferal tests are broadly consistent with the measured *in-situ* seawater properties and fossil tests in surface sediments. Higher $\delta^{18}O_{calcite}$ values in specimens below the mixed layer and fossil tests are linked to lower *in-situ* temperatures and gametogenic calcification. Mg/Ca values of *G. sacculifer* indicate that the maximum accumulation rates on the seafloor occurs during early spring in the Caribbean Sea and most likely in May in the Florida Straits linked to seawater temperatures of ~26°C. $\delta^{18}O_{seawater}$ estimates of living *G. sacculifer* indicate a positive linear relationship between measured *in-situ* $\delta^{18}O_{seawater}$ and salinity.

This study added further insights into the habitat patterns, trace elemental and isotopic compositions of living planktonic foraminifera in the open ocean, which are important for studies based on foraminiferal census and proxy data. Yet, plankton net samples generally present only a "snap-shot" of a short sampling period, reflecting a seasonal effect. This limits the interpretations in a long-term perspectives and application for sediment samples comprising several hundreds or thousands of years. To identify species-specific seasonal distribution patterns in the water column, and to test if seasonal assemblage variations have a yearly repetition at the same site, further surveys are required covering different seasons over the year. Especially a seasonal migration of single species in the water column in relation to different environmental parameters would elucidate the habitat dynamics of foraminiferal populations and would be helpful for the interpretation of paleoenvironmental

records. Shortly spaced time series over several months are needed to address this problem. Furthermore, only a sparse number of foraminifera can be collected in plankton net samples thus limiting the material available for geochemical analyses. This restricts the interpretation and potential significant statistical analyses of the results. However, studies on living planktonic foraminifera collected with plankton nets are indispensible to understand calcification processes under natural conditions. Further investigations would provide even better and more detailed signals assessing those processes within the water column with higher accuracy.

# References

Anand, P., Elderfield, H., Conte, M.H., 2003. Calibration of Mg/Ca thermometry in planktonic foraminifera from a sediment trap time series. Paleoceanography 18, 1050.

André, A., Weiner, A., Quillévéré, F., Aurahs, R., Morard, R., Douady, C.J., de Garidel-Thoron, T., Escarguel, G., de Vargas, C., Kučera, M., 2013. The cryptic and the apparent reversed: lack of genetic differentiation within the morphologically diverse plexus of the planktonic foraminifer *Globigerinoides sacculifer*. Paleobiology 39, 21-39.

Arbuszewski, J., Kaplan, A., Farmer, E.C., 2010. On the fidelity of shell-derived $\delta^{18}O$ seawater estimates. Earth and Planetary Science Letters 300, 185-196.

Arnold, A.J., d´Escrivan, F., Parker, W.C., 1985. Predation and avoidance responses in the foraminifera of the Galapagos hydrothermal mounds. Journal of Foraminiferal Research 15, 38-42.

Aurahs, R., Treis, Y., Darling, K., Kučera, M., 2011. A revised taxonomic and phylogenetic concept for the planktonic foraminifer species *Globigerinoides ruber* based on molecular and morphometric evidence. Marine Micropaleontology 79, 1-14.

Aurahs, R., Grimm, G.W., Hemleben, V., Hemleben C., Kučera, M., 2009. Geographical distribution of cryptic genetic types in the planktonic foraminifer *Globigerinoides ruber*. Molecular Ecology 18, 1692-1706.

Babin, S.M., Carton, J.A., Dickey, T.D., Wiggert, J.D., 2004. Satellite evidence of hurricane-induced phytoplankton blooms in an oceanic desert. Journal of Geophysical Research 109, C03043.

Bahr, A., Schönfeld, J., Hoffmann, J., Voigt, S., Aurahs, R., Kučera, M., Flögel, S., Jentzen, A., Gerdes, A., 2013. Comparison of Ba/Ca and $\delta^{18}O_{WATER}$ as freshwater proxies: A multi-species core-top study on planktonic foraminifera from the vicinity of the Orinoco River mouth. Earth and Planetary Science Letters 383, 45-57.

Barker, S., Greaves, M., Elderfield, H., 2003. A study of cleaning procedures used for foraminiferal Mg/Ca paleothermometry. Geochemistry, Geophysics, Geosystems 4, 8407.

Bé, A.W.H., 1967. Families: Globigerinidae and Globorotaliidae, Fiche no. 108. In: Frasier, J.H. (Ed.), Fiches d`intification du zooplancton. Conseil International pour l`Exploration de la Mer, 1-9.

Bé, A.W.H., 1977. An ecological, zoogeographic and taxonomic review of recent planktonic foraminifera. In: Ramsay, A.T.S. (Ed.), Oceanic Micropaleontology, Academic Press, London, 1-100.

Bé, A.W.H., 1980. Gametogenic calcification in a spinose planktonic foraminifer, *Globigerinoides sacculifer* (Brady). Marine Micropaleontology 5, 283-310.

Bé, A.W.H., Hamlin, W.H., 1967. Ecology of recent planktonic foraminifera: part 3: distribution in the North Atlantic during the summer of 1962. Micropaleontology 13, 87-106.

Bé, A.W.H., Tolderlund, D.S., 1971. Distribution and ecology of living planktonic foraminifera in surface waters of the Atlantic and Indian Oceans. In: Funnel, B.M., Riedel, W.R. (Eds.), The Micropalaeontology of Oceans. Cambridge University Press, Cambridge, 105-149.

Bé, A.W.H., Anderson, O.R., 1976. Gametogenesis in planktonic foraminifera. Science 192, 890-892.

Bé, A.W.H., Vilks, G., Lott, L., 1971. Winter distribution of planktonic foraminifera between the Grand Banks and the Caribbean. Micropaleontology 17, 31-42.

Bé, A.W.H., Harrison, S.M., Lott, L., 1973. *Orbulina universa* d'Orbigny in the Indian Ocean. Micropaleontology 19, 150-192.

Bé, A.W.H., Spero, H.J., Anderson, O.R., 1982. Effects of symbiont elimination and reinfection on the life processes of the planktonic foraminifer *Globigerinoides sacculifer*. Marine Biology 70, 73-86.

Bé, A.W.H., Bishop, J.K.B., Sverdlove, M.S., Gardner, W.D., 1985. Standing stock, vertical distribution and flux of planktonic foraminifera in the Panama Basin. Marine Micropaleontology 9, 307-333.

Bemis, B.E., Spero, H.J., Bijma, J., Lea, D.W., 1998. Reevaluation of the oxygen isotopic composition of planktonic foraminifera: Experimental results and revised paleotemperature equations. Paleoceanography 13, 150-160.

Bentov, S., Erez, J., 2006. Impact of biomineralization processes on the Mg content of foraminiferal shells: A biological perspective. Geochemistry, Geophysics, Geosystems 7, Q01P08.

Berger, W.H., 1971a. Sedimentation of planktonic foraminifera. Marine Geology 11, 325-358.

Berger, W.H., 1971b. Planktonic foraminifera: Sediment production in an oceanic front. Journal of Foraminiferal Research 1, 95-118.

Berger, W.H., Piper, D.J.W., 1972. Planktonic foraminifera: Differential settling, dissolution, and redeposition. Limnology and Oceanography 17, 275-287.

Betzler, C., Lindhorst, S., Lüdmann, T., Borstel V., F., Büld, M., Djamlan, E., Eberli, G., Eversheim, J., Jentzen, A., Keizer, F., Ludwig, J., Möbius, J., Paulat, M., Reiche, S., Reijmer, J., Reolid, J., Schiebel, L., Schutter, I., Ulferts, L., Winter, S., Wolf, D., Wunsch, M., Rentsch, H., Raeke, A., 2014. CICARB-Current impact on the facies and stratigraphy of the Bahamas Carbonate Platform. Cruise No. M95 - March 29- April 25, 2013 - Kingston (Jamaica) - Pointe à Pitre (Guadeloupe). METEOR-Berichte, M95. 1-36.

Bidigare, R.R., Ondrusek, M.E., Brooks, J.M., 1993. Influence of the Orinoco River Outflow on Distributions of Algal Pigments in the Caribbean Sea. Journal of Geophysical Research 98, 2259-2269.

Bijma, J., Faber, W.W.J., Hemleben, C., 1990. Temperature and salinity limits for growth and survival of some planktonic foraminifers in laboratory cultures. Journal of Foraminiferal Research 20, 95-116.

Bijma, J., Spero, H.J., Lea, D.W., 1999. Reassessing foraminiferal stable isotope geochemistry: Impact of the oceanic carbonate system (experimental results). In: Fischer, G., Wefer, G. (Eds.) Use of proxies in paleoceanography, Springer Berlin, Heidelberg, 489-512.

Bijma, J., Hemleben, C., Oberhaensli, H., Spindler, M., 1992. The effects of increased water fertility on tropical spinose planktonic foraminifers in laboratory cultures. Journal of Foraminiferal Research 22, 242-256.

Birch, H., Coxall, H.K., Pearson, P.N., Kroon, D., O´Regan, M., 2013. Planktonic foraminifera stable isotopes and water column structure: Disentangling ecological signals. Marine Micropaleontology 101, 127-145.

Blake, E.S., Kimberlain, T.B., Berg R.J., Cangialosi, J.P., Beven L.J., 2013. Tropical Cyclone Report Hurricane Sandy (AL182012), 22-29 October 2012. National Hurricane Center, p. 157.

Blanke, B., Arhan, M., Lazar, A., Prévost, G., 2002. A Lagrangian numerical investigation of the origins and fates of the salinity maximum water in the Atlantic. Journal of Geophysical Research 107, 3163.

Bouvier-Soumagnac, Y., Duplessy, J.C., 1985. Carbon and oxygen isotopic composition of planktonic foraminifera from laboratory culture, plankton tows and Recent sediment: implications for the reconstruction of paleoclimatic conditions and of the global carbon cycle. Journal of Foraminiferal Research 15, 302-320.

Bouvier-Soumagnac, Y., Duplessy, J.C., Bé, A.W.H., 1986. Isotopic composition of a laboratory cultured planktonic foraminifer *O. universa*, Implications for paleoclimatic reconstructions. Oceanologica acta 9, 519-522.

Bradshaw, J.S., 1959. Ecology of living planktonic foraminifera in the North and Equatorial Pacific Ocean. Chushman Foundation for Foraminiferal Research: Contributions 10, 25-64.

Brooks, W.W., 1973. Distribution of Recent Foraminifera from the southern coast of Puerto Rico. Micropaleontology 19, 385-416.

Brown, K.R., 2007. Biogeographic and morphological variation in Late Pleistocene to Holocene globorotalid foraminifera. Ph.D. thesis, University of Basel, Faculty of Science, p. 128. Online available http://edoc.unibas.ch.

Brown, S.J., Elderfield, H., 1996. Variations in Mg/Ca and Sr/Ca ratios of planktonic foraminifera caused by postdepositional dissolution: Evidence of shallow Mg-dependent dissolution. Paleoceanography 11, 543-551.

Brunner, C.A., 1979. Distribution of planktonic foraminifera in surface sediments of the Gulf of Mexico. Micropaleontology 25, 325-335.

Byrne, D.B., Suarez, G., McCann, W.R., 1985. Muertos Trough subduction – microplate tectonics in the northern Caribbean?. Nature 317, 420-421.

Carriker, M.R., Yochelson, E.L., 1968. Recent gastropod boreholes and Ordovician cylindrical borings. Contributions to Paleontology, Geological Survey Professional Paper 593-B, p. 48.

CCAR, Colorado Center for Astrodynamics Research. http://eddy.colorado.edu/ccar/ssh/hist_global_grid_viewer. Online access on 28.10.2015.

Chapman, M.R., 2010. Seasonal production patterns of planktonic foraminifera in the NE Atlantic Ocean: Implications for paleotemperature and hydrographic reconstructions. Paleoceanography 25, 1-9.

Chérubin L.M., P. Richardson, 2007. Caribbean current variability and the influence of the Amazon and Orinoco fresh water plumes. Deep Sea Research Part I: Oceanographic Research Papers 54, 1451-1473.

Chollett, I., Müller-Karger, F.E., Heron, S.F., Skirving, W., Mumby, P.J., 2012. Seasonal and spatial heterogeneity of recent sea surface temperature trends in the Caribbean Sea and southeast Gulf of Mexico. Marine Pollution Bulletin 64, 956-965.

Cifelli, R., 1965. Planktonic Foraminifera from the Western North Atlantic. Smithsonian Miscellaneous Collections 148, 1-35.

Cléroux, C., Cortijo, E., Duplessy, J.-C., Zahn, R., 2007. Deep-dwelling foraminifera as thermocline temperature recorders. Geochemistry, Geophysics, Geosystems 8, Q04N11, 1-19.

Cléroux, C., Cortijo, E., Anand, P., Labeyrie, L., Bassinot, F., Caillon, N., Duplessy, J.-C., 2008. Mg/Ca and Sr/Ca ratios in planktonic foraminifera: Proxies for upper water column temperature reconstruction. Paleoceanography 23, PA3214.

Corredor, J.E., Morell, J.M., 2001. Seasonal variation of physical and biogeochemical features in eastern Caribbean Surface Water. Journal of Geophysical Research 106, 4517-4525.

Craig, H., Gordon, L.I., 1965. Deuterium and oxygen-18 variations in the ocean and the marine atmosphere. In: Stable Isotopes in Oceanographic Studies and Paleotemperatures, Tongiorgi, E. (Ed.), Spoleto, 9-130.

Culver, S.J., Lipps, J.H., 2003. Predation on and by Foraminifera. In: Kelley, P.H., Kowalewski, M., Hansen, T.A. (Eds.) Predator-Prey Interactions in the Fossil Record. New York, Kluwer Academic Publishers/Plenum Press, p. 7-32.

Curry, W.B., Thunell, R.C., Honjo, S., 1983. Seasonal changes in the isotopic composition of planktonic foraminifera collected in Panama Basin sediment traps. Earth and Planetary Science Letters 64, 33-43.

Cushman, J.A. 1922. Shallow-water foraminifera of the Tortugas Region. Publications of the Carnegie Institution Washington 311, 1-85.

Darling, K.F., Kučera, M., Kroon, D., Wade, C., 2006. A resolution for the coiling direction paradox in *Neogloboquadrina pachyderma*. Paleoceanography 21, PA2011, 1-14.

Darling, K.F., Kučera, M., Wade, C.M., von Langen, P., Pak, D., 2003. Seasonal distribution of genetic types of planktonic foraminifer morphospecies in the Santa Barbara Channel and its paleoceanographic implications. Paleoceanography 18, 1032.

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, USA 106, 12629-12633.

Dekens, P.S., Lea, D.W., Pak, D.K., Spero, H.J., 2002. Core top calibration of Mg/Ca in tropical foraminifera: Refining paleotemperature estimation. Geochemistry, Geophysics, Geosystems 3.

Deuser, W.G., Ross, E.H., Hemleben, C., Spindler, M., 1981. Seasonal changes in species composition, numbers, mass, size, and isotopic composition of planktonic foraminifera settling into the deep Sargasso Sea. Palaeogeography, Palaeoclimatology, Palaeoecology 33, 103-127.

Dickson, A.G., 1990. Thermodynamics of the dissociation of boric acid in synthetic seawater from 273.15 to 318.15 K. Deep Sea Research Part A. Oceanographic Research Papers 37, 755-766.

Dickson, A.G., Millero, F.J., 1987. A comparison of the equilibrium constants for the dissociation of carbonic acid in seawater media. Deep Sea Research Part A. Oceanographic Research Papers 34, 1733-1743.

Dueñas-Bohórquez, A., da Rocha, R.E., Kuroyanagi, A., de Nooijer, L.J., Bijma, J., Reichart, G.-J., 2011. Interindividual variability and ontogenetic effects on Mg and Sr incorporation in the planktonic foraminifer *Globigerinoides sacculifer*. Geochimica et Cosmochimica Acta 75, 520-532.

Duplessy, J.C., Bé, A.W.H., Blanc, P.L., 1981a. Oxygen and carbon isotopic composition and biogeographic distribution of planktonic foraminifera in the Indian Ocean. Palaeogeography, Palaeoclimatology, Palaeoecology 33, 9-46.

Duplessy, J.C., Blanc, P.L., Bé, A.W.H., 1981b. Oxygen-18 enrichment of planktonic foraminifera due to gametogenic calcification below the euphotic zone. Science 213, 1247-1250.

Eggins, S.M., Sadekov, A., De Deckker, P., 2004. Modulation and daily banding of Mg/Ca in *Orbulina universa* tests by symbiont photosynthesis and respiration: a complication for seawater thermometry?. Earth and Planetary Science Letters 225, 411-419.

Elderfield, H., Ganssen, G., 2000. Past temperature and $\delta^{18}O$ of surface ocean waters inferred from foraminiferal Mg/Ca ratios. Nature 405, 442-445.

Ellis, B. F., Messina, A., 1940. Catalogue of foraminifera. Micropaleontology Press, New York, http://www.micropress.org/em.

Erez, J., 2003. The source of ions for biomineralization in foraminifera and their implications for paleoceanographic proxies. Reviews in Mineralogy and Geochemistry 54, 115-149.

Erez, J., Honjo, S., 1981. Comparison of isotopic composition of planktonic foraminifera in plankton tows, sediment traps and sediments. Palaeogeography, Palaeoclimatology, Palaeoecology 33, 129-156.

Erez, J., Luz, B., 1983. Experimental paleotemperature equation for planktonic foraminifera. Geochimica et Cosmochimica Acta 47, 1025-1031.

Erez, J., Almogi-Labin, A., Avraham, S., 1991. On the life history of planktonic foraminifera: Lunar reproduction cycle in *Globigerinoides sacculifer* (Brady). Paleoceanography 6, 295-306.

Fairbanks, R.G., Wiebe, P.H., 1980. Foraminifera and chlorophyll maximum: Vertical distribution, seasonal succession, and paleoceanographic significance. Science 209, 1524-1526.

Fairbanks, R.G., Sverdlove, M., Free, R., Wiebe, P.H., Bé, A.W.H., 1982. Vertical distribution and isotopic fractionation of living planktonic foraminifera from the Panama Basin. Nature 298, 841-844.

Farmer, E.C., Kaplan, A., de Menocal, P.B., Lynch-Stieglitz, J., 2007. Corroborating ecological depth preferences of planktonic foraminifera in the tropical Atlantic with the stable oxygen isotope ratios of core top specimens. Paleoceanography 22, PA3205.

Field, D.B., 2004. Variability in vertical distributions of planktonic foraminifera in the California Current: Relationships to vertical ocean structure. Paleoceanography 19, PA2014, 1-22.

Fischer, G., Wefer, G., 1999. Use of Proxies in Paleoceanography: Examples from the South Atlantic, Springer-Verlag, Berlin, Heidelberg, p. 735.

Fornshell, J.A., 2005. Planktonic Protozoan Populations of Five West Indian Reefs. Atoll Research Bulletin 553, 93-102.

Franco-Fraguas, P., Costa, K.B., de Lima Toledo, F.A., 2011. Relationship between isotopic composition ($\Delta^{18}O$ and ($\Delta^{13}C$) and planktonic foraminifera test size in core tops from the Brazilian Continental Margin. Brazilian Journal of Oceanography 59, 327-338.

Froelich, P.N., Atwood, D.K., Giese, G.S., 1978. Influence of Amazon River discharge on surface salinity and dissolved silicate concentration in the Caribbean Sea. Deep Sea Research 25, 735-744.

Gallegos, A. 1996. Descriptive physical oceanography of the Caribbean Sea. In Maul, G.A. (Ed.). Small Islands: Marine science and sustainable development coastal and estuarine studies. American Geophysical Union 51, 36-55.

Gastrich, M.D., 1987. Ultrastructure of a new intracellular symbiotic alga found within planktonic foraminifera. Journal of Phycology 23, 623-632.

Gilbes, F., Armstrong, R.A., Webb, R.M.T., Müller-Krager, F.E., 2001. SeaWiFS helps assess hurricane impact on phytoplankton in Caribbean Sea. Eos, Transactions American Geophysical Union 82, 529-533.

Glover, L., 1971. Geology of the Coamo Area, Puerto Rico, and its relation to the volcanic arc-trench association. U.S. Geological Survey Paper 636, 1-102.

Gordon, A.L., 1967. Circulation of the Caribbean Sea. Journal of Geophysical Research 72, 6207-6223.

Greaves, M., Caillon, N., Rebaubier, H., Bartoli, G., Bohaty, S., Cacho, I., Clarke, L., Cooper, M., Daunt, C., Delaney, M., deMenocal, P., Dutton, A., Eggins, S., Elderfield, H., Garbe-Schönberg, D., Goddard, E., Green, D., Groeneveld, J., Hastings, D., Hathorne, E., Kimoto, K., Klinkhammer, G., Labeyrie, L., Lea, D.W., Marchitto, T., Martinez-Boti, M.A., Mortyn, P.G., Ni, Y., Nürnberg, D., Paradis, G., Pena, L., Quinn, T., Rosenthal, Y., Russell, A., Sagawa, T., Sosdian, S., Stott, L., Tachikawa, K., Tappa, E., Thunell, R., Wilson, P.A., 2008. Interlaboratory comparison study of calibration standards for foraminiferal Mg/Ca thermometry. Geochemistry, Geophysics, Geosystems 9, Q08010.

Guptha, M.V.S., Mohan, R., Muralinath, A.S., 1994. Living planktonic foraminifera during the late summer monsoon period in the Arabian Sea. Marine Geology 120, 365-371.

Guptha, M.V.S., Curry, W.B., Ittekkot, V., Muralinath, A.S., 1997. Seasonal variation in the flux of planktic foraminifera: sediment trap results from the Bay of Bengal, northern Indian Ocean. Journal of Foraminiferal Research 27, 5-19.

Hamilton, C.P., Spero, H.J., Bijma, J., Lea, D.W., 2008. Geochemical investigation of gametogenic calcite addition in the planktonic foraminifera *Orbulina universa*. Marine Micropaleontology 68, 256-267.

Hammer, Ø., Harper, D.A.T., Ryan, P.D., 2001. PAST: Paleontological statistics software package for education and data analysis. Palaeontologia Electronica 4, p. 9.

Harbers, A.T.E., 2011. Habitats and chemical characteristics of modern planktonic foraminifera in the Atlantic Ocean. Ph.D. thesis, Christian-Albrechts-University of Kiel, p.105. Online available http://macau.uni-kiel.de.

Hart, M. B., Hylton, M. D., Oxford, M. J., Price, G. D., Hudson, W., Smart, C. W., 2003. The search for the origin of the planktic Foraminifera. Journal of the Geological Society 160, 341-343.

Hathorne, E.C., Gagnon, A., Felis, T., Adkins, J., Asami, R., Boer, W., Caillon, N., Case, D., Cobb, K.M., Douville, E., deMenocal, P., Eisenhauer, A., Garbe-Schönberg, D., Geibert, W., Goldstein, S., Hughen, K., Inoue, M., Kawahata, H., Kölling, M., Cornec, F.L., Linsley, B.K., McGregor, H.V., Montagna, P., Nurhati, I.S., Quinn, T.M., Raddatz, J., Rebaubier, H., Robinson, L., Sadekov, A., Sherrell, R., Sinclair, D., Tudhope, A.W., Wei, G., Wong, H., Wu, H.C., You, C.-F., 2013. Interlaboratory study for coral Sr/Ca and other element/Ca ratio measurements. Geochemistry, Geophysics, Geosystems 14, 3730-3750.

Hemleben, C., Spindler, M., Anderson, O.R., 1989. Modern Planktonic Foraminifera. Springer-Verlag, Berlin, Heidelberg, New York, p. 363.

Hemleben, C., Spindler, M., Breitinger, I., Deuser, W.G., 1985. Field and laboratory studies on the ontogeny and ecology of some Globorotaliid species from the Sargasso Sea off Bermuda. Journal of Foraminiferal Research 15, 254-272.

Hilbrecht, H., 1997. Morphologic gradation and ecology in *Neogloboquadrina pachyderma* and *N. dutertrei* (planktic foraminifera) from core top sediments. Marine Micropaleontology 31, 31-43.

Hübscher, C., Nürnberg, D., Al Hseinat, M., Alvarez Garcia, M., Erdem, Z., Gehre, N., Jentzen, A., Kavelage, C., Karas, C., Kimmel, B., Mildner, T., Ortiz, A.O., Parker, A.O., Petersen, A., Raeke, A., Reiche, S., Schmidt, M., Weiss, B., Wolf, D., 2014. Yucatan Throughflow - Cruise No. M94 - March 12 - March 26, 2013 - Balboa (Panama) - Kingston (Jamaica). METEOR-Berichte, M94. 1-32.

Hut, G., 1987. Stable isotope reference samples for geochemical and hydrological investigations, Consultants Group meeting 16-18.09.1985. International Atomic Energy Agency (I.A.E.A.), Vienna, Austria, p. 42.

Jacob, S.D., Shay, L.K., Mariano, A.J., Black, P.G., 2000. The 3D oceanic mixed layer response to Hurricane Gilbert. Journal of Physical Oceanography 30, 1407-1429.

Jansen, H., Zeebe, R.E., Wolf-Gladrow, D.A., 2002. Modeling the dissolution of settling $CaCO_3$ in the ocean. Global Biogeochemical Cycles 16, 1027.

Jochum, K.P., Weis, U., Stoll, B., Kuzmin, D., Yang, Q., Raczek, I., Jacob, D.E., Stracke, A., Birbaum, K., Frick, D.A., Günther, D., Enzweiler, J., 2011. Determination of reference values for NIST SRM 610–617 glasses following ISO Guidelines. Geostandards and Geoanalytical Research 35, 397-429.

Jones, J.I., 1968. The relationship of planktonic foraminiferal populations to water masses in the western Caribbean and lower Gulf of Mexico. Bulletin of Marine Science 18, 946-982.

Jones, J.I., 1971. The ecology and distribution of living planktonic foraminifera in the Straits of Florida. In: Jones, J.I. and Bock, W.D. (Eds.) A Symposium of Recent South Florida Foraminifera. Memoir 1: Miami Geological Society. 175-188.

Jonkers, L., Kučera, M., 2015. Global analysis of seasonality in the shell flux of extant planktonic foraminifera. Biogeosciences 12, 2207-2226.

Jørgensen, B.B., Erez, J., Revsbech, N.P., Cohen, Y., 1985. Symbiotic photosynthesis in a planktonic foraminiferan, *Globigerinoides sacculifer* (Brady), studied with microelectrodes. Limnology and Oceanography 30, 1253-1267.

Kahn, M.I., 1979. Non-equilibrium oxygen and carbon isotopic fractionation in tests of living planktonic foraminifera. Oceanologica Acta 2, 195-208.

Kahn, M.I., Williams, D.F., 1981. Oxygen and carbon isotopic composition of living planktonic foraminifera from the northeast Pacific Ocean. Palaeogeography, Palaeoclimatology, Palaeoecology 33, 47-69.

Kim, S.-T., O´Neil, J.R., 1997. Equilibrium and nonequilibrium oxygen isotope effects in synthetic carbonates. Geochimica et Cosmochimica Acta 61, 3461-3475.

Kisakürek, B., Eisenhauer, A., Böhm, F., Garbe-Schönberg, D., Erez, J., 2008. Controls on shell Mg/Ca and Sr/Ca in cultured planktonic foraminiferan, *Globigerinoides ruber* (white). Earth and Planetary Science Letters 273, 260-269.

Kroon, D., Darling, K., 1995. Size and upwelling control of the stable isotope composition of *Neogloboquadrina dutertrei* (d´Orbigny), *Globigerinoides ruber* (d´Orbigny) and *Globigerina bulloides* d´Orbigny: Examples from the Panama Basin and Arabian Sea. Journal of Foraminiferal Research 25, 39-52.

Kučera, M., 2007. Planktonic foraminifera as tracers of past oceanic environments. In: Hillaire-Marcel, C., De Vernal, A. (Eds.), Developments in Marine Geology, Proxies in Late Cenozoic Paleoceanography. Elsevier, New York, 213-262.

Kučera, M., Darling, K.F., 2002. Cryptic species of planktonic foraminifera: their effect on palaeoceanographic reconstructions. Philosophical Transactions of the Royal Society of London A: Mathematical, Physical and Engineering Sciences 360, 695-718.

Kunioka, D., Shirai, K, Takahata, N., Sano, Y., Toyofuku, T., Ujiie, Y, 2006. Microdistribution of Mg/Ca, Sr/Ca, and Ba/Ca ratios in *Pulleniatina obliquiloculata* test by using a NanoSIMS: Implication for the vital effect mechanism. Geochemistry, Geophysics, Geosystems 7, Q12P20.

Kuroyanagi, A., Kawahata, H., 2004. Vertical distribution of living planktonic foraminifera in the Japan Sea and northwestern North Pacific Ocean. Marine Micropaleontology 53, 173-196.

Lea, D.W., Mashiotta, T.A., Spero, H.J., 1999. Controls on magnesium and strontium uptake in planktonic foraminifera determined by live culturing. Geochimica et Cosmochimica Acta 63, 2369-2379.

Lea, D.W., Pak, D.K., Spero, H.J., 2000. Climate impact of late Quaternary equatorial Pacific sea surface temperature variations. Science 289, 1719-1724.

Lin, H.-L., Wang, W.-C., Hung, G.-W., 2004. Seasonal variation of planktonic foraminiferal isotopic composition from sediment traps in the South China Sea. Marine Micropaleontology 53, 447-460.

Lin, H.-L., Sheu, D.D.-D., Yang, Y., Chou, W.-C., Hung, G.-W., 2011. Stable isotopes in modern planktonic foraminifera: Sediment trap and plankton tow results from the South China Sea. Marine Micropaleontology 79, 15-23.

Lipps, J.H., 1983. Biotic interactions in benthic foraminifera. In: Trevesz, M.J.S., McCall, P.L. (Eds.) Biotic Interactions in Recent and Fossil Benthic Communities. New York: Plenum, 331-376.

Locarnini, R.A., Mishonov, A.V., Antonov, J.I., Boyer, T.P., Garcia, H.E., Baranova, O.K., Zweng, M.M., Johnson, D.R., 2010. World Ocean Atlas, 2009, Volume 1: Temperature, In: Levitus S. (Ed.), NOAA Atlas NESDIS 68, U.S. Government Printing Office, Washington, D.C., p. 184.

Locarnini, R.A., Mishonov, A.V., Antonov, J.I., Boyer, T.P., Garcia, H.E., Baranova, O.K., Zweng, M.M., Paver, C.R., Reagan, J.R., Johnson, D.R., Hamilton, M., Seidov, D., 2013. World Ocean Atlas 2013, Volume 1: Temperature. In: Levitus, S., Mishonov, A. (Eds), NOAA Atlas NESDIS 73, p. 40.

Lohmann, G.P., Schweitzer, P.N., 1990. *Globorotalia truncatulinoides* Growth and chemistry as probes of the past thermocline: 1. Shell size. Paleoceanography 5, 55-75.

Lombard, F., Labeyrie, L., Michel, E., Spero, H.J., Lea, D.W., 2009. Modelling the temperature dependent growth rates of planktic foraminifera. Marine Micropaleontology 70, 1-7.

Lončarić, N., Peeters, F.J.C., Kroon, D., Brummer, G.-J.A., 2006. Oxygen isotope ecology of recent planktic foraminifera at the central Walvis Ridge (SE Atlantic). Paleoceanography 21, PA3009.

Loose, T.L., 1970. Turbulent transport of benthonic foraminifera. Contributions from the Cushman Foundation for Foraminiferal Research 21, 164-166.

Masson, D.G., Scanlon, K.M., 1991. The neotectonic setting of Puerto Rico. Geological Society of America Bulletin 103, 144-154.

McConnaughey, T., 1989. $^{13}$C and $^{18}$O isotopic disequilibrium in biological carbonates: I. Patterns. Geochimica et Cosmochimica Acta 53, 151-162.

McCrea, J. M., 1950. On the isotopic chemistry of carbonates and a paleotemperature scale. The Journal of Chemical Physics 18, 849-857.

McKenna, V.S., Prell, W.L., 2004. Calibration of *Globorotalia truncatulinoides* (R) for the reconstruction of marine temperature gradients. Paleoceanography 19, PA2006.

Mehrbach, C., Culberson, C.H., Hawley, J.E., Pytkowicz, R.M., 1973. Measurement of the apparent dissociation-constants of carbonic-acid in seawater at atmospheric pressure. Limnology and Oceanography 18, 897–907.

Miró, M.D.D., 1971. Los foraminiferos planctónicos vivos y sedimentados del margen continental de Venezuela (resumen). Acta Geológica Hispánica 4, 102-108.

Morel, A., Claustre, H., Gentili, B., 2010. The most oligotrophic subtropical zones of the global ocean: similarities and differences in terms of chlorophyll and yellow substance. Biogeosciences 7, 3139-3151.

Morrison, J.M., Nowlin, W.D., 1982. General distribution of water masses within the eastern Caribbean Sea during the winter of 1972 and fall of 1973. Journal of Geophysical Research 87, 4207-4229.

Mulitza, S., Boltovskoy, D., Donner, B., Meggers, H., Paul, A., Wefer, G., 2003. Temperature: δ$^{18}$O relationships of planktonic foraminifera collected from surface waters. Palaeogeography, Palaeoclimatology, Palaeoecology 202, 143-152.

Müller-Karger, F.E., McClain, C.R., Fisher, T.R., Esaias, W.E., Varela, R., 1989. Pigment distribution in the Caribbean Sea: Observations from space. Progress in Oceanography 23, 23-64.

Murray, J.W., 1987. Biogenic indicators of suspended sediment transport in marginal marine environments: quantitative examples from SW Britain. Journal of the Geological Society London 144, 127-133.

Murray, J.W., Alve, E., 2016. Benthic foraminiferal biogeography in NW European fjords: A baseline for assessing future change. Estuarine, Coastal and Shelf Science 181, 218-230.

NHC, 2014. National Hurricane Center. URL: http://www.nhc.noaa.gov

Nielsen, K.S.S., 1999. Foraminiferivory revisited: a preliminary investigation of holes in foraminifera. Bulletin of the Geological Society of Denmark 45, 139-142.

Nielsen, K.S.S., Nielsen, J.K., 2001. Bioerosion in Pliocene to late Holocene tests of benthic and planktonic foraminiferans, with a revision of the ichnogenera *Oichnus* and *Tremichnus*. Ichnos 8, 99-116.

Nielsen, K.S.S., Nielsen, J.K., Bromley, R.G., 2003. Palaeoecological and ichnological significance of microborings in Quaternary foraminifera. Palaeontologia Electronica 6, p. 13.

Nouet, J., Bassinot, F., 2007. Dissolution effects on the crystallography and Mg/Ca content of planktonic foraminifera *Globorotalia tumida* (Rotaliina) revealed by X-ray diffractometry. Geochemistry, Geophysics, Geosystems 8, Q10007.

Nürnberg, D., 1995. Magnesium in tests of *Neogloboquadrina pachyderma* sinistral from high northern and southern latitudes. Journal of Foraminiferal Research 25, 350-368.

Nürnberg, D., Bijma, J., Hemleben, C., 1996. Assessing the reliability of magnesium in foraminiferal calcite as a proxy for water mass temperatures. Geochimica et Cosmochimica Acta 60, 803-814.

Nürnberg, D., Müller, A., Schneider, R.R., 2000. Paleo-sea surface temperature calculations in the equatorial east Atlantic from Mg/Ca ratios in planktic foraminifera: A comparison to sea surface temperature estimates from $U_{37}K$, oxygen isotopes, and foraminiferal transfer function. Paleoceanography 15, 124-134.

Nürnberg, D., Schönfeld, J., Dullo, W.C., Rühlemann, C., 2003. RV SONNE cruise report SO164 RASTA: Rapid climate changes in the western tropical Atlantic - Assessment of the biogenous and sedimentary record, Balboa-Balboa, May 22 - June 28, 2002. GEOMAR-Report 109, 1-151.

Nürnberg, D., Ziegler, M., Karas, C., Tiedemann, R., Schmidt, M.W., 2008. Interacting Loop Current variability and Mississippi River discharge over the past 400 kyr. Earth and Planetary Science Letters 272, 278-289.

Ortiz, J.D., Mix, A.C., Collier, R.W., 1995. Environmental control of living symbiotic and asymbiotic foraminifera of the California Current. Paleoceanography 10, 987-1009.

Pak, D.K., Lea, D.W., Kennett, J.P., 2004. Seasonal and interannual variation in Santa Barbara Basin water temperatures observed in sediment trap foraminiferal Mg/Ca. Geochemistry, Geophysics, Geosystems 5,Q12008.

Parker, F.L., Berger, W.H., 1971. Faunal and solution patterns of planktonic foraminifera in surface sediments of the South Pacific, Deep Sea Research and Oceanographic Abstracts 18, 73-107.

Philander, S.G.H., Pacanowski, R.C., 1986. A model of the seasonal cycle in the tropical Atlantic Ocean. Journal of Geophysical Research 91, 14192-14206.

Pierrot, D., Lewis, E., Wallace, D. W. R., 2006. MS Excel Program Developed for CO2 System Calculations. ORNL/CDIAC-105a. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tennessee.

Poore, R.Z., Tedesco, K.A., Spear, J.W., 2013. Seasonal flux and assemblage composition of planktic foraminifers from a sediment-trap study in the northern Gulf of Mexico. Journal of Coastal Research 63, 6-19.

Quillévéré, F., Morard, R., Escarguel, G., Douady, C.J., Ujiié, Y., de Garidel-Thoron, T., de Vargas, C., 2013. Global scale same-specimen morpho-genetic analysis of *Truncorotalia truncatulinoides*: A perspective on the morphological species concept in planktonic foraminifera. Palaeogeography, Palaeoclimatology, Palaeoecology 391, 2-12.

Ravelo, A.C., Fairbanks, R.G., 1992. Oxygen isotopic composition of multiple species of planktonic foraminifera: Recorders of the modern photic zone temperature gradient. Paleoceanography 7, 815-831.

Regenberg, M., Regenberg, A., Garbe-Schönberg, D., Lea, D.W., 2014. Global dissolution effects on planktonic foraminiferal Mg/Ca ratios controlled by the calcite-saturation state of bottom waters. Paleoceanography 29, 127-142.

Regenberg, M., Steph, S., Nürnberg, D., Tiedemann, R., Garbe-Schönberg, D., 2009. Calibrating Mg/Ca ratios of multiple planktonic foraminiferal species with $\delta^{18}$O-calcification temperatures: Paleothermometry for the upper water column. Earth and Planetary Science Letters 278, 324-336.

Regenberg, M., Nielsen, S.N., Kuhnt, W., Holbourn, A., Garbe-Schönberg, D., Andersen, N., 2010. Morphological, geochemical, and ecological differences of the extant menardiform planktonic foraminifera *Globorotalia menardii* and *Globorotalia cultrata*. Marine Micropaleontology 74, 96-107.

Regenberg, M., Nürnberg, D., Steph, S., Groeneveld, J., Garbe-Schönberg, D., Tiedemann, R., Dullo, W.C., 2006. Assessing the effect of dissolution on planktonic foraminiferal Mg/Ca ratios: Evidence from Caribbean core tops. Geochemistry, Geophysics, Geosystems 7, Q07P15.

Retailleau, S., Schiebel, R., Howa, H., 2011. Population dynamics of living planktic foraminifers in the hemipelagic southeastern Bay of Biscay. Marine Micropaleontology 80, 89-100.

Retailleau, S., Howa, H., Schiebel, R., Lombard, F., Eynaud, F., Schmidt, S., Jorissen, F., Labeyrie, L., 2009. Planktic foraminiferal production along an offshore–onshore transect in the south-eastern Bay of Biscay. Continental Shelf Research 29, 1123–1135.

Richey, J.N., Poore, R.Z., Flower, B.P., Hollander, D.J., 2012. Ecological controls on the shell geochemistry of pink and white *Globigerinoides ruber* in the northern Gulf of Mexico: Implications for paleoceanographic reconstruction. Marine Micropaleontology 82-83, 28-37.

Rink, S., Kühl, M., Bijma, J., Spero, H.J., 1998. Microsensor studies of photosynthesis and respiration in the symbiotic foraminifer *Orbulina universa*. Marine Biology 131, 583-595.

Rosenthal, Y., Lohmann, G.P., Lohmann, K.C., Sherrell, R.M., 2000. Incorporation and preservation of Mg in *Globigerinoides sacculifer*: Implications for reconstructing the temperature and $^{18}$O/$^{16}$O of seawater. Paleoceanography 15, 135-145.

Rosenthal, Y., Perron-Cashman, S., Lear, C.H., Bard, E., Barker, S., Billups, K., Bryan, M., Delaney, M.L., deMenocal, P.B., Dwyer, G.S., Elderfield, H., German, C.R., Greaves, M., Lea, D.W., Marchitto, T.M., Pak, D.K., Paradis, G.L., Russell, A.D., Schneider, R.R., Scheidrich, K., Stott, L., Tachikawa, K., Tappa, E., Thunell, R., Wara, M., Weldeab, S., Wilson, P.A., 2004. Interlaboratory comparison study of Mg/Ca and Sr/Ca measurements in planktonic foraminifera for paleoceanographic research. Geochemistry, Geophysics, Geosystems 5, Q04D09.

Rückert-Hilbig, A., 1983. Megalospheric gamonts of *Rosalina globularis* d'Orbigny 1826, *Cymbaloporetta bulloides* (d'Orbigny 1839) and *Cymbaloporetta milletti* (Heron-Allen & Earland 1915) (Foraminifera) with differently constructed swimming apparatus. Tübinger Mikropaläontologische Mitteilungen Nr. 1, p. 69.

Rueda-Roa, D.T., Müller-Karger, F.E., 2013. The southern Caribbean upwelling system: Sea surface temperature, wind forcing and chlorophyll concentration patterns. Deep Sea Research Part I: Oceanographic Research Papers 78, 102-114.

Russel, A.D., Hönisch, B., Spero, H.J., Lea, D.W., 2004. Effects of seawater carbonate ion concentration and temperature on shell U, Mg, and Sr in cultured planktonic foraminifera. Geochimica et Cosmochimica Acta 68, 4347-4361.

Sadekov, A.Y., Eggins, S.M., De Deckker, P., 2005. Characterization of Mg/Ca distributions in planktonic foraminifera species by electron microprobe mapping. Geochemistry, Geophysics, Geosystems 6, Q12P06.

Sadekov, A.Y., Eggins, S.M., De Deckker, P., Ninnemann, U., Kuhnt, W., Bassinot, F., 2009. Surface and subsurface seawater temperature reconstruction using Mg/Ca microanalysis of planktonic foraminifera *Globigerinoides ruber*, *Globigerinoides sacculifer*, and *Pulleniatina obliquiloculata*. Paleoceanography 24, PA3201.

Schiebel, R., 2002. Planktic foraminiferal sedimentation and the marine calcite budget. Global Biogeochemical Cycles 16, 1065.

Schiebel, R., Hemleben, C., 2000. Interannual variability of planktic foraminiferal populations and test flux in the eastern North Atlantic Ocean (JGOFS). Deep Sea Research Part II: Topical Studies in Oceanography 47, 1809-1852.

Schiebel, R., Hemleben, C., 2005. Modern planktic foraminifera. Paläontologische Zeitschrift 79, 135-148.

Schiebel, R., Hiller, B., Hemleben, C., 1995. Impacts of storms on Recent planktic foraminiferal test production and $CaCO_3$ flux in the North Atlantic at 47°N, 20°W (JGOFS). Marine Micropaleontology 26, 115-129.

Schiebel, R., Waniek, J., Bork, M., Hemleben, C., 2001. Planktic foraminiferal production stimulated by chlorophyll redistribution and entrainment of nutrients. Deep Sea Research Part I: Oceanographic Research Papers 48, 721–740.

Schlitzer, R., 2009. Ocean data view. http://odv.awi.de.

Schmidt, G. A., 1999. Error analysis of paleosalinity calculations. Paleoceanography 14, 422-429.

Schmidt, G.A., Bigg, G.R., Rohling, E.J., 1999. "Global Seawater Oxygen-18 Database –v1.21". http://data.giss.nasa.gov/o18data.

Schmidt, M.W., Spero, H.J., Lea, D.W., 2004. Links between salinity variation in the Caribbean and North Atlantic thermohaline circulation. Nature 428, 160-163.

Schmuker, B., 2000a. The influence of shelf vicinity on the distribution of planktic foraminifera south of Puerto Rico. Marine Geology 166, 125-143.

Schmuker, B., 2000b. Recent planktic foraminifera in the Caribbean Sea: Distribution, Ecology and Taphonomy. Ph.D. thesis, Eidgenössische Technische Hochschule, Zürich, p. 179. Online available http://e-collection.library.ethz.ch.

Schmuker, B., Schiebel, R., 2002. Planktic foraminifers and hydrography of the eastern and northern Caribbean Sea. Marine Micropaleontology 46, 387-403.

Schönfeld, J., Bahr, A., Bannert, B., Bayer, A.S., Bayer, M., Beer, C., Blanz, T., Dullo, W.C., Flögel, S., Garlichs, T., Haley, B.A., Hübscher, C., Joseph, N., Kučera, M., Langenbacher, J., Nürnberg, D., Ochsenhirt, W.T., Petersen, A., Pulm, P., Titschack, J., Troccoli, L., 2011. Surface and Intermediate water hydrography, planktonic and benthic biota in the Caribbean Sea - Climate, Bio and Geosphere linkages (OPOKA). Cruise No. 78, Leg 1, February 22 - March 28, 2009, Colón (Panama) - Port of Spain (Trinidad and Tobago). METEOR-Berichte. 1-196.

Schott, W., 1937. Die Foraminiferen in dem äquatorialen Teil des Atlantischen Ozeans. In: Defant, A. (Ed.), Wissenschaftliche Ergebnisse III, Deutsche Atlantische Expedition der METEOR 1925-1927. 1-132.

Schweitzer, P.N., Lohmann, G.P., 1991. Ontogeny and habitat of modern menardiiform planktonic foraminifera. Journal of Foraminiferal Research 21, 332-346.

Seears, H.A., Darling, K.F., Wade, C.M., 2012. Ecological partitioning and diversity in tropical planktonic foraminifera. BMC Evolutionary Biology 12, 54.

Seiglie, G.A., 1975. Foraminifers of Guyanilla Bay and their use as environmental indicators. Revista Espanola de Micropaleontologia 7, 453-487.

Shackleton, N.J., 1974. Attainment of isotopic equilibrium between ocean water and the benthonic foraminifera genus *Uvigerina*: Isotopic changes in the ocean during the last glacial. Colloques Internationaux du C.N.R.S. 219, 203–209.

Shackleton, N.J., Wiseman, J.D.H., Buckley, H.A., 1973. Non-equilibrium isotopic fractionation between seawater and planktonic foraminiferal tests. Nature 242, 177-179.

Shonman, D., Nybakken, J.W., 1978. Food preferences, food availability and food resource partioning in two sympatric species of Cephalaspidean Opisthobranchs. The Veliger 21, 120-126.

Siccha, M., Schiebel, R., Schmidt, S., Howa, H., 2012. Short-term and small-scale variability in planktic foraminifera test flux in the Bay of Biscay. Deep Sea Research Part I: Oceanographic Research Papers 64, 146-156.

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

Sliter, W.V., 1971. Predation on benthic foraminifers. Journal of Foraminiferal Research 1, 20-29.

Spear, J.W., Reynolds, C.E., Poore, R.Z., 2011. Seasonal flux and assemblage composition of planktic foraminifera from the northern Gulf of Mexico, 2008-2010. U.S. Geological Survey Open-File Report 2011-1215, p. 19.

Spero, H.J., 1988. Ultrastructural examination of chamber morphogenesis and biomineralization in the planktonic foraminifer *Orbulina universa*. Marine Biology 99, 9-20.

Spero, H.J., 1992. Do planktic foraminifera accurately record shifts in the carbon isotopic composition of seawater $\sum CO_2$?. Marine Micropaleontology 19, 275-285.

Spero, H.J., Parker, S.L., 1985. Photosynthesis in the symbiotic planktonic foraminifer *Orbulina universa*, and its potential contribution to oceanic primary productivity. Journal of Foraminiferal Research 15, 273-281.

Spero, H.J., DeNiro, M.J., 1987. The influence of symbiont photosynthesis on the $\delta^{18}O$ and $\delta^{13}C$ values of planktonic foraminiferal shell calcite. Symbiosis 4, 213-228.

Spero, H.J., Williams, D.F., 1988. Extracting environmental information from planktonic foraminiferal $\delta^{13}C$ data. Nature 335, 717-719.

Spero, H.J., Lea, D.W., 1993. Intraspecific stable isotope variability in the planktic foraminifera *Globigerinoides sacculifer*: Results from laboratory experiments. Marine Micropaleontology 22, 221-234.

Spero, H.J., Lea, D.W., 1996. Experimental determination of stable isotope variability in *Globigerina bulloides*: implications for paleoceanographic reconstructions. Marine Micropaleontology 28, 231-246.

Spero, H.J., Bijma, J., Lea, D.W., Bemis, B.E., 1997. Effect of seawater carbonate concentration on foraminiferal carbon and oxygen isotopes. Nature 390, 497-500.

Spero, H.J., Mielke, K.M., Kalve, E.M., Lea, D.W., Pak, D.K., 2003. Multispecies approach to reconstructing eastern equatorial Pacific thermocline hydrography during the past 360 kyr. Paleoceanography 18, 1022.

Spero, H.J., Eggins, S.M., Russell, A.D., Vetter, L., Kilburn, M.R., Hönisch, B., 2015. Timing and mechanism for intratest Mg/Ca variability in a living planktic foraminifer. Earth and Planetary Science Letters 409, 32-42.

Spezzaferri, S., Kučera, M., Pearson, P.N., Wade, B.S., Rappo, S., Poole, C.R., Morard, R., Stalder, C., 2015. Fossil and Genetic Evidence for the Polyphyletic Nature of the Planktonic Foraminifera "*Globigerinoides*", and Description of the New Genus *Trilobatus*. PLOS ONE, 10, e0128108.

Spindler, M., Hemleben, C., Salomons, J.B., Smit, L.P., 1984. Feeding behavior of some planktonic foraminifers in laboratory cultures. Journal of Foraminiferal Research 14, 237-249.

Spindler, M., Hemleben, C., Bayer, U., Bé, A.W.H., Anderson, O.R., 1979. Lunar periodicity of reproduction in the planktonic foraminifer *Hastigerina pelagica*. Marine Ecology Progress Series 1, 61-64.

Steph, S., Regenberg, M., Tiedemann, R., Mulitza, S., Nürnberg, D., 2009. Stable isotopes of planktonic foraminifera from tropical Atlantic/Caribbean core-tops: Implications for reconstructing upper ocean stratification. Marine Micropaleontology 71, 1-19.

Storz, D., Schulz, H., Waniek, J.J., Schulz-Bull, D.E., Kučera, M., 2009. Seasonal and interannual variability of the planktic foraminiferal flux in the vicinity of the Azores Current. Deep Sea Research Part I: Oceanographic Research Papers 56, 107-124.

Takahashi, K., Bé, A.W.H., 1984. Planktonic foraminifera: Factors controlling sinking speeds. Deep Sea Research Part A. Oceanographic Research Papers 31, 1477-1500.

Tedesco, K.A., Thunell, R.C., 2003. Seasonal and interannual variations in planktonic foraminiferal flux and assemblages composition in the Cariaco Basin, Venezuela. Journal of Foraminiferal Research 33, 192-210.

Tedesco, K.A., Thunell, R., Astor, Y., Muller-Karger, F., 2007. The oxygen isotope composition of planktonic foraminifera from the Cariaco Basin, Venezuela: Seasonal and interannual variations. Marine Micropaleontology 62, 180-193.

Tedesco, K.A., Spear, J.W., Tappa, E., Poore, R.Z., 2009. Seasonal Flux and Assemblage Composition of Planktic Foraminifera from the Northern Gulf of Mexico. U.S. Geological Survey Open-File Report 2009-1293, p. 19.

Terazaki, M., 1996. Vertical distribution of pelagic chaetognaths and feeding of *Sagitta enflata* in the Central Equatorial Pacific. Journal of Plankton Research 18, 673-682.

Thompson, P.R., Bé, A.W.H., Duplessy, J.C., Shackleton, N.J., 1979. Disappearance of pink-pigmented *Globigerinoides ruber* at 120,000 yr BP in the Indian and Pacific Oceans. Nature 280, 554-558.

Thunell, R.C., Reynolds, L.A., 1984. Sedimentation of planktonic foraminifera: Seasonal changes in species flux in the Panama Basin. Micropaleontology 30, 243-262.

Tolderlund, D.S., Bé, A.W.H., 1971. Seasonal Distribution of Planktonic Foraminifera in the Western North Atlantic. Micropaleontology 17, 297-329.

Ufkes, E., Jansen, J.F., Brummer, G.-J.A., 1998. Living planktonic foraminifera in the eastern South Atlantic during spring: Indicators of water masses, upwelling and the Congo (Zaire) River plume. Marine Micropaleontology 33, 27-53.

Urey, H.C., 1947. The thermodynamic properties of isotopic substances. Journal of the Chemical Society, 562–581.

Vénec-Peyré, M.T., Caulet, J.P., Grazzini, C.V., 1995. Paleohydrographic changes in the Somali Basin (5°N upwelling and equatorial areas) during the last 160 kyr, based on correspondence analysis of foraminiferal and radiolarian assemblages. Paleoceanography 10, 473-491.

Vergnaud-Grazzini, C., 1976. Non-equilibrium isotopic compositions of shells of planktonic foraminifera in the Mediterranean Sea. Palaeogeography, Palaeoclimatology, Palaeoecology 20, 263-276.

Vidal, V.M.V., Vidal, F.V., Hernández, A.F., Meza, E., Zambrano, L., 1994. Winter water mass distributions in the western Gulf of Mexico affected by a colliding anticyclonic ring. Journal of Oceanography 50, 559-588.

Vukovich, F.M., 2007. Climatology of Ocean Features in the Gulf of Mexico Using Satellite Remote Sensing Data. Journal of Physical Oceanography 37, 689-707.

Watanabe, T., Winter, A., Oba, T., 2001. Seasonal changes in sea surface temperature and salinity during the Little Ice Age in the Caribbean Sea deduced from Mg/Ca and $^{18}$O/$^{16}$O ratios in corals. Marine Geology 173, 21-35.

Watkins, J.M., Mix, A.C., Wilson, J., 1996. Living planktic foraminifera: tracers of circulation and productivity regimes in the central equatorial Pacific. Deep Sea Research II: Topical studies in Oceanography 43, 1257-1282.

Weiner, A., 2014. Genetic diversity, biogeography and the morpho-genetic relationship in extant planktonic foraminifera. Ph.D. thesis, University of Bremen, p. 145. Online available http://www.elib.suub.uni-bremen.de.

Weiner, A., Aurahs, R., Kurasawa, A., Kitazato, H., Kučera, M., 2012. Vertical niche partitioning between cryptic sibling species of a cosmopolitan marine planktonic protist. Molecular Ecology 21, 4063-4073.

Weiner, S., Dove, P.M., 2003. An overview of biomineralization processes and the problem of the vital effect. Reviews in Mineralogy and Geochemistry 54, p. 29.

Williams, D.F., Bé, A.W.H., Fairbanks, R.G., 1981. Seasonal stable isotopic variations in living planktonic foraminfera from Bermuda plankton tows. Palaeogeography, Palaeoclimatology, Palaeoecology 33, 71-102.

Wüst, G., 1964. Stratification and circulation in the Antillean-Caribbean Basins. Columbia University Press, New York, p. 201.

Xu, X., Yamasaki, M., Oda, M., Honda, M.C., 2005. Comparison of seasonal flux variations of planktonic foraminifera in sediment traps on both sides of the Ryukyu Islands, Japan. Marine Micropaleontology 58, 45-55.

Yu, J., Elderfield, H., Greaves, M., Day, J., 2007. Preferential dissolution of benthic foraminiferal calcite during laboratory reductive cleaning. Geochemistry, Geophysics, Geosystems 8, Q06016.

Žarić, S., Schulz, M., Mulitza, S., 2006. Global prediction of planktic foraminiferal fluxes from hydrographic and productivity data. Biogeosciences 3, 187-207.

Žarić, S., Donner, B., Fischer, G., Mulitza, S., Wefer, G., 2005. Sensitivity of planktic foraminifera to sea surface temperature and export production as derived from sediment trap data. Marine Micropaleontology 55, 75-105.

Zweng, M.M, Reagan, J.R., Antonov, J.I., Locarnini, R.A., Mishonov, A.V., Boyer, T.P., Garcia, H.E., Baranova, O.K., Johnson, D.R., Seidov, D., Biddle, M.M., 2013. World Ocean Atlas 2013, Volume 2: Salinity, Levitus, S., Mishonov, A. (Eds.), NOAA Atlas NESDIS 74, p. 39.

# APPENDIX A

## Supplementary information of Chapter 2

**Table A.1:** Station list of sediment, water and plankton samples. MUC: Multicorer; GKG: Giant box corer; CTD: Conductivity Temperature Depth profiler; MSN: Hydrobios midi multiple opening-closing plankton net; AN: Apstein net; PF: Plankton filter; PP: Plankton pump; TS: Thermosalinograph.

| Cruise | Date | Device | Station No. | Latitude N (Start-End) | Longitude W (Start-End) | Water depth (m) | Depth intervals | Water volume (m³) |
|---|---|---|---|---|---|---|---|---|
| SO164 | 27.05.2002 | MUC | 02-3 | 15°18.29 | 72°47.06 | 2977 | 0–1 cm | - |
| SO164 | 07.06.2002 | MUC | 22-2 | 15°24.00 | 68°12 | 4506 | 0–1 cm | - |
| SO164 | 09.06.2002 | MUC | 24-3 | 14°11.89 | 63°25.43 | 1545 | 0–1 cm | - |
| M78/1 | 10.03.2009 | MUC | 212-1 | 24°11.10 | 81°15.74 | 723 | 0–1 cm | - |
| M78/1 | 19.03.2009 | GKG | 222-8 | 12°1.48 | 64°28.50 | 1019 | surface | - |
| M78/1 | 10.03.2009 | CTD | 211 | 24°15.50 | 80°54.81 | 456 | - | - |
| M78/1 | 15.03.2009 | CTD | 219 | 15°18.30 | 72°47.06 | 2961 | - | - |
| M78/1 | 16.03.2009 | CTD | 220 | 15°24.00 | 68°12.00 | 4484 | - | - |
| M78/1 | 18.03.2009 | CTD | 221 | 14°11.95 | 63°25.42 | 1536 | - | - |
| M78/1 | 19.03.2009 | CTD | 222 | 12°1.57 | 64°28.80 | 1031 | - | - |
| M78/1 | 10.03.2009 19:19 | MSN | 211-5 | 24°15.50 | 80°54.81 | 456 | 0–60, 60–100, 100–200, 200–300, 300–400 m | |
| M78/1 | 15.03.2009 12:26 | MSN | 219-8 | 15°18.30 | 72°47.06 | 2960 | 0–60, 60–125, 125–180, 180–220, 220–400 m | |
| M78/1 | 17.03.2009 07:03 | MSN | 220-9 | 15°23.99 | 68°12.00 | 4482 | 0–70, 70–110, 110–150, 150–220, 220–300 m | |
| M78/1 | 18.03.2009 17:11 | MSN | 221-7 | 14°11.89 | 63°25.43 | 1533 | 0–40, 40–60, 60–150, 150–210, 210–300 m | |
| M78/1 | 19.03.2009 10:58 | MSN | 222-6 | 12°1.57 | 64°28.80 | 1031 | 0–40, 40–80, 80–120, 120–180, 180–300 m | |
| M94 | 18.03.2013 14:45 | AN | 474 | 21°45.50 | 86°8.50 | - | 0–20, 20–40, 40–60, 60–100 m | |
| M95 | 01.04.2013 21:14 | AN | 487 | 23°29.48 | 79°25.288 | 581 | 0–20, 20–40, 40–60, 60–100 m | |
| M95 | 05.04.2013 08:24 | AN | 506 | 23°35.24 | 79°23.423 | 530 | 20–40, 40–60, 60–100 m | |
| M95 | 09.04.2013 20:23 | AN | 531 | 24°13.11 | 79°51.551 | 595 | 0–20, 20–40, 40–60, 60–100 m | |
| M95 | 17.04.2013 01:12 | AN | 584 | 23°52.27 | 79°26.246 | 555 | 0–20, 20–40, 40–60, 60–100 m | |
| M78/1 | 24.02.2009 | PF | 1 | 13°5.8–14°12.61 | 77°30.7–77°23.48 | - | 3.5 m | 1.967 |
| M78/1 | 24.02.2009 | PF/TS | 2 | 14°12.55–15°22.41 | 77°23.47–77°56.03 | - | 3.5 m | 8.469 |
| M78/1 | 25.02.2009 | PF | 3 | 16°48.86–80°14.07 | 80°14.07–82°46.6 | - | 3.5 m | 6.532 |
| M78/1 | 27.02.2009 | PF/TS | 4 | 18°35.05–19°54.50 | 83°38.07–84°58.71 | - | 3.5 m | 2.609 |
| M78/1 | 27.02.2009 | PF/TS | 5 | 20°02.15–21°44.80 | 85°5.37–86°02.44 | - | 3.5 m | 4.757 |

**Table A.1:** Continued.

| Cruise | Date | Device | Station No. | Latitude N (Start-End) | Longitude W (Start-End) | Water depth (m) | Depth intervals | Water volume (m³) |
|--------|------|--------|-------------|------------------------|-------------------------|-----------------|-----------------|-------------------|
| M78/1 | 01.03.2009 | PF/TS | 6 | 22°21.4–22°50.86 | 86°29.42–86°36.27 | - | 3.5 m | 1.529 |
| M78/1 | 03.03.2009 | PF | 7 | 26°31.38–27°39.86 | 87°5.32–88°16.23 | - | 3.5 m | 3.720 |
| M78/1 | 04.03.2009 | PF | 8 | 28°59.9–29°00 | 88°13.23–87°49.99 | - | 3.5 m | 2.561 |
| M78/1 | 04.03.2009 | PF | 9 | 28°12.58–27°44.20 | 85°50.67–85°33.22 | - | 3.5 m | 1.013 |
| M78/1 | 05.03.2009 | PF/TS | 10 | 27°01.83–26°36.30 | 85°07.33–84°51.80 | - | 3.5 m | 1.195 |
| M78/1 | 06.03.2009 | PF/TS | 11 | 26°18.35–26°12.21 | 84°44.97–84°41.92 | - | 3.5 m | 1.218 |
| M78/1 | 06.03.2009 | PF | 12 | 26°10.7–26°12.48 | 84°44.08–84°43.40 | - | 3.5 m | 1.087 |
| M78/1 | 06.03.2009 | PF | 13 | 26°19.38–26°15.5 | 84°45.15–84°44.31 | - | 3.5 m | 1.324 |
| M78/1 | 06.03.2009 | PF/TS | 14 | 26°12.18–26°12.40 | 84°43.84–84°45.41 | - | 3.5 m | 0.795 |
| M78/1 | 06.03.2009 | PF/TS | 15 | 26°12.51–26°12.51 | 84°46.24–84°46.23 | - | 3.5 m | 1.270 |
| M78/1 | 06.03.2009 | PF/TS | 16 | 26°11.81–26°11.80 | 84°43.98–84°43.95 | - | 3.5 m | 1.029 |
| M78/1 | 07.03.2009 | PF/TS | 17 | 26°11.77–26°12.18 | 84°43.96–84°43.87 | - | 3.5 m | 0.899 |
| M78/1 | 07.03.2009 | PF/TS | 18 | 26°12.18–26°12.18 | 84°43.87–84°43.87 | - | 3.5 m | 1.267 |
| M78/1 | 07.03.2009 | PF/TS | 19 | 26°12.18–26°12.18 | 84°43.87–84°43.87 | - | 3.5 m | 1.707 |
| M78/1 | 07.03.2009 | PF/TS | 20 | 26°12.18–26°12.17 | 84°43.87–84°43.94 | - | 3.5 m | 0.954 |
| M78/1 | 07.03.2009 | PF/TS | 21 | 26°11.07–26°11.39 | 84°44.05–84°44.24 | - | 3.5 m | 1.200 |
| M78/1 | 08.03.2009 | PF/TS | 23 | 24°71.47–23°56.72 | 81°33.17–81°24.31 | - | 3.5 m | 0.508 |
| M78/1 | 10.03.2009 | PF/TS | 24 | 24°15.12-24°13.09 | 80°54.85-81°5.29 | - | 3.5 m | 2.189 |
| M78/1 | 12.03.2009 | PF | 25 | 23°47.15–23°18.97 | 80°42.75–80°11.37 | - | 3.5 m | 1.029 |
| M78/1 | 12.03.2009 | PF | 26 | 22°18.61–22°6.71 | 77°40.84–77°26.68 | - | 3.5 m | 0.533 |
| M78/1 | 13.03.2009 | PF | 27 | 21°36.99–21°24.72 | 76°39.4–76°9.47 | - | 3.5 m | 1.812 |
| M78/1 | 13.03.2009 | PF | 28 | 20°56.42–19°39.31 | 74°20.04–74°12.45 | - | 3.5 m | 0.668 |
| M78/1 | 14.03.2009 | PF | 29 | 16°45.79–15°50.48 | 73°46.39–73°8.84 | - | 3.5 m | 2.600 |
| M78/1 | 17.03.2009 | PF | 31 | 14°46.66-–14°45.04 | 65°43.73–65°37.18 | - | 3.5 m | 2.389 |
| M78/1 | 18.03.2009 | PF | 32 | 13°27.81 | 63°52.38 | - | 3.5 m | 0.800 |
| M78/1 | 19.03.2009 | PF/TS | 33 | 11°37.93–11°38.34 | 64°18.41–64°14.02 | - | 3.5 m | 0.644 |
| M78/1 | 20.03.2009 | PF/TS | 34 | 11°40.7–11°37.78 | 62°39.24–62°39.51 | - | 3.5 m | 1.406 |
| M78/1 | 20.03.2009 | PF/TS | 35 | 11°47.53–11°47.54 | 62°38.56–62°38.6 | - | 3.5 m | 2.051 |
| M78/1 | 21.03.2009 | PF/TS | 36 | 10°59.38–10°56.82 | 62°28.4–61°59.4 | - | 3.5 m | 0.766 |
| M78/1 | 21.03.2009 | PF/TS | 37 | 10°37.48–10°37.48 | 61°36.23–61°36.22 | - | 3.5 m | 1.598 |
| M78/1 | 21.03.2009 | PF/TS | 38 | 10°48.12–10°52.60 | 61°40.02–61°36.51 | - | 3.5 m | 0.678 |
| M78/1 | 21.03.2009 | PF/TS | 39 | 10°52.60–10°59.68 | 61°36.51–61°30.69 | - | 3.5 m | 2.932 |
| M78/1 | 22.03.2009 | PF/TS | 40 | 11°36.20–11°36.54 | 60°58.24–60°57.86 | - | 3.5 m | 1.370 |
| M78/1 | 22.03.2009 | PF/TS | 41 | 11°55.23–11°0.81 | 60°15.74–60°12.56 | - | 3.5 m | 0.298 |
| M78/1 | 23.03.2009 | PF/TS | 42 | 10°45.74–10°42.24 | 59°53.44–59°48.88 | - | 3.5 m | 1.124 |
| M78/1 | 23.03.2009 | PF/TS | 43 | 10°88.74–10°8.93 | 59°23.29–59°2.22 | - | 3.5 m | 1.065 |
| M78/1 | 25.03.2009 | PF/TS | 44 | 9°59.5–9°55.92 | 59°56.99–59°51.74 | - | 3.5 m | 1.398 |
| M78/1 | 26.03.2009 | PF/TS | 45 | 9°99.01–9°6.88 | 59°54.13–59°56.85 | - | 3.5 m | 0.832 |
| M78/1 | 26.03.2009 | PF/TS | 46 | 8°58 | 60°50.07 | - | 3.5 m | 0.398 |
| M78/1 | 26.03.2009 | PF/TS | 47 | 9°14.24–9°22.95 | 60°56.73–60°2.98 | - | 3.5 m | 0.695 |
| M94 | 14.03.2013 | PF/TS | 2 | 10°1.18–10°18.56 | 80°00.93–80°03.70 | - | 3.5 m | 1.120 |
| M94 | 14.03.2013 | PF/TS | 3 | 10°40.93–11°10.84 | 80°07.21–80°11.71 | - | 3.5 m | 2.078 |
| M94 | 15.03.2013 | PF/TS | 4 | 13°29.76–13°57.97 | 80°30.89–80°34.80 | - | 3.5 m | 1.958 |
| M94 | 15.03.2013 | PF/TS | 5 | 14°32.81–15°1.26 | 80°39.62–80°43.61 | - | 3.5 m | 1.988 |
| M94 | 16.03.2013 | PF/TS | 6 | 17°14.03–17°37.58 | 81°48.19–82°08.18 | - | 3.5 m | 1.926 |
| M94 | 16.03.2013 | PF/TS | 7 | 18°8.72–18°36.21 | 82°34.86–82°54.45 | - | 3.5 m | 1.949 |
| M94 | 17.03.2013 | PF/TS | 8 | 20°41.88–21°03.98 | 84°50.26–85°12.18 | - | 3.5 m | 1.988 |
| M94 | 17.03.2013 | PF/TS | 9 | 21°33.79–21°40.63 | 85°46.10–85°58.30 | - | 3.5 m | 1.481 |
| M94 | 18.03.2013 | PF/TS | 10 | 21°51.25–21°42.12 | 86°1.61–86°13.35 | - | 3.5 m | 1.770 |
| M94 | 19.03.2013 | PF/TS | 11 | 22°38.60–22°41.99 | 86°25.53–86°26.25 | - | 3.5 m | 1.904 |
| M94 | 20.03.2013 | PF/TS | 13 | 23°1.03–23°12 | 86°28.62–86°17.81 | - | 3.5 m | 1.701 |

**Table A.1:** Continued.

| Cruise | Date | Device | Station No. | Latitude N (Start–End) | Longitude W (Start–End) | Water depth (m) | Depth intervals | Water volume (m³) |
|---|---|---|---|---|---|---|---|---|
| M94 | 20.03.2013 | PF/TS | 14 | 23°24.92–23°24.95 | 86°29.83–86°45.97 | - | 3.5 m | 1.743 |
| M94 | 21.03.2013 | PF/TS | 15 | 23°48.08–23°38.7 | 87°00.89–87°6.16 | - | 3.5 m | 1.701 |
| M94 | 21.03.2013 | PF/TS | 16 | 23°49.01–23°49.71 | 87°7.96–87°7.14 | - | 3.5 m | 1.047 |
| M94 | 22.03.2013 | PF/TS | 17 | 23°5.05–22°56.99 | 86°43.43–86°41.51 | - | 3.5 m | 1.866 |
| M94 | 22.03.2013 | PF/TS | 18 | 22°49.63–22°40.43 | 86°39.28–86°22.05 | - | 3.5 m | 1.766 |
| M94 | 23.03.2013 | PF/TS | 19 | 22°1.20–21°53.10 | 86°30.72–86°12.82 | - | 3.5 m | 2.065 |
| M95 | 01.04.2013 | PF/TS | 1 | 23°6.86–23°16.29 | 78°55.89–79°4.44 | - | 3.5 m | 2.010 |
| M95 | 02.04.2013 | PF/TS | 2 | 24°23.76–24°33.96 | 79°18.1–79°18.61 | - | 3.5 m | 1.974 |
| M95 | 02.04.2013 | PF/TS | 3 | 24°27.3–24°17.92 | 79°23.15–79°27.26 | - | 3.5 m | 2.065 |
| M95 | 03.04.2013 | PF/TS | 4 | 23°36.95–23°40.19 | 79°32.97–79°19.77 | - | 3.5 m | 2.062 |
| M95 | 03.04.2013 | PF/TS | 5 | 23°39.04–23°41.31 | 79°5.02–79°5.17 | - | 3.5 m | 1.472 |
| M95 | 05.04.2013 | PF/TS | 6 | 23°35.10–23°39 | 79°29.42–79°32.18 | - | 3.5 m | 1.218 |
| M95 | 06.04.2013 | PF/TS | 7 | 23°36.52–23°34.24 | 79°21.6–79°28.75 | - | 3.5 m | 1.999 |
| M95 | 06.04.2013 | PF/TS | 8 | 23°34.54–23°39.15 | 79°29.44–79°23.88 | - | 3.5 m | 2.458 |
| M95 | 07.04.2013 | PF/TS | 9 | 23°38.06–23°37.05 | 79°16.14–79°30.64 | - | 3.5 m | 1.963 |
| M95 | 07.04.2013 | PF/TS | 10 | 23°56.09–24°8.39 | 79°42.39–79°46.06 | - | 3.5 m | 1.846 |
| M95 | 08.04.2013 | PF/TS | 11 | 24°11.90–24°11.51 | 79°29.94–79°13.71 | - | 3.5 m | 1.795 |
| M95 | 10.04.2013 | PF/TS | 13 | 24°25.57–24°9.01 | 79°14.60–79°12.55 | - | 3.5 m | 2.065 |
| M95 | 10.04.2013 | PF/TS | 14 | 24°2.55–24°1.40 | 79°11.23–79°11.97 | - | 3.5 m | 1.401 |
| M95 | 11.04.2013 | PF/TS | 16 | 24°8.66–24°8.85 | 79°47.14–79°49.8 | - | 3.5 m | 1.410 |
| M95 | 12.04.2013 | PF/TS | 17 | 24°11.91–24°18.29 | 80°00.80–80°1.95 | - | 3.5 m | 1.658 |
| M95 | 12.04.2013 | PF/TS | 18 | 24°24.01–24°24.02 | 79°41.2–79°24.31 | - | 3.5 m | 2.022 |
| M95 | 13.04.2013 | PF/TS | 19 | 24°18.04–24°15.13 | 79°44.19–79°54.34 | - | 3.5 m | 2.427 |
| M95 | 14.04.2013 | PF/TS | 20 | 23°51.9–23°46.8 | 79°8.54–79°7.01 | - | 3.5 m | 1.798 |
| M95 | 14.04.2013 | PF/TS | 21 | 23°52.13–23°50.81 | 79°9.61–79°9.61 | - | 3.5 m | 2.317 |
| M95 | 15.04.2013 | PF/TS | 22 | 24°8.05–24°8.39 | 79°15.31–79°12.28 | - | 3.5 m | 2.362 |
| M95 | 15.04.2013 | PF/TS | 23 | 24°13.69–24°13.9 | 79°14.47–79°15.1 | - | 3.5 m | 1.612 |
| M95 | 16.04.2013 | PF/TS | 25 | 23°53.89–23°52.26 | 79°15.34–79°26.26 | - | 3.5 m | 2.899 |
| M95 | 17.04.2013 | PF/TS | 26 | 24°6.38–24°12.51 | 79°43.4–79°55.61 | - | 3.5 m | 1.871 |
| M95 | 18.04.2013 | PF/TS | 27 | 23°59.49–23°50.40 | 79°46.52–79°19.4 | - | 3.5 m | 2.422 |
| M95 | 18.04.2013 | PF/TS | 28 | 23°36.92–23°37.23 | 79°2.45–79°2.5 | - | 3.5 m | 1.509 |
| M95 | 19.04.2013 | PF/TS | 29 | 23°27.65–23°29.02 | 79°28.08–79°24.44 | - | 3.5 m | 3.156 |
| M78/1 | 26.02.2009 | PP | 164-6 | 18°30.52 | 83°38.53 | - | 160 | 8.820 |
| M78/1 | 27.02.2009 | PP | 164-7 | 18°30.52 | 83°38.28 | - | 80 | 8.000 |
| M78/1 | 06.03.2009 | PP | 191-5 | 26°12.51 | 84°46.24 | - | 140 | 2.000 |
| M78/1 | 25.03.2009 | PP | 247-2 | 9°6.01 | 59°57.00 | - | 41; 42 | 7.410 |

**Table A.2:** List of species found in plankton and sediment samples. The species were identified following the taxonomy of Bé (1967) and Hemleben et al. (1989). Based on morpho-genetic studies we distinguished the species marked as 1, 2, 3, 4, 5 and 6 following Darling et al. (2009), Weiner (2014), Aurahs et al. (2011), André et al. (2013) Darling et al. (2006), Spezzaferri et al. (2015). Type references are found in the Ellis and Messina (1940) catalogue.

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*Bolivina variabilis* (Williamson, 1858) = *Streptochilus globigerus* (Schwager, 1866)[1]

*Candeina nitida* d´Orbigny, 1839

*Dentagloborotalia anfracta* (Parker, 1967) = *Globorotalia anfracta*

*Globigerina bulloides* d´Orbigny, 1826

*Globigerinella calida* (Parker, 1962)[2]

*Globigerinoides conglobatus* (Brady, 1879)

*Globorotalia crassaformis* (Galloway and Wissler 1927) =
                    syn. *Globorotalia crassula* Cushman, Stewart and Stewart, 1930

*Globigerinoides elongatus* (d´Orbigny, 1826)[3]

*Globigerina falconensis* Blow, 1959

*Globigerinita glutinata* (Egger, 1893) = *Globigerina glutinata*

*Globorotalia hirsuta* (d´Orbigny, 1839)

*Globorotalia inflata* (d'Orbigny, 1839) = *Globigerina inflata*

*Globorotalia menardii* (Parker, Jones and Brady, 1865) = syn. *Globorotalia cultrata* (d'Orbigny)

*Globigerinita minuta* (Natland, 1938) = *Globigerinoides minuta*

*Globigerinoides ruber* (d´Orbigny, 1839)[3]

*Globoturborotalita rubescens* Hofker, 1956

*Globigerinoides sacculifer* (Brady, 1877)[4] = *Trilobatus sacculifer*[6]

*Globorotalia scitula* (Brady, 1882) = syn. *Globorotalia bermudezi* Roegl and Bolli, 1973

*Globigerinella siphonifera* (d´Orbigny, 1839)[2]

*Globoturborotalita tenella* (Parker, 1958)

*Globorotalia tumida* (Brady, 1877) = *Pulvinulina menardii* (d'Orbigny) var. *tumida*

*Globorotalia truncatulinoides* (d´Orbigny, 1839)

*Globorotalia ungulata* Bermúdez, 1960

*Globigerinita uvula* (Ehrenberg, 1861) = syn. *Globigerinita bradyi* Wiesner, 1931

*Hastigerina pelagica* (d´Orbigny, 1839)

*Neogloboquadrina dutertrei* (d´Orbigny, 1839) = *Globigerina dutertrei*

*Neogloboquadrina incompta* (Cifelli, 1961)[5]

*Orbulina universa* d´Orbigny, 1839

*Pulleniatina obliquiloculata* (Parker and Jones, 1865)

*Sphaeroidinella dehiscens* (Parker and Jones, 1865) =
                    *Sphaeroidina bulloides* (d'Orbigny) var. *dehiscens*

*Tenuitella iota* (Parker, 1962) = *Globigerinita iota*

*Tenuitella parkerae* (Broennimann and Resig, 1972)

*Turborotalita humilis* (Brady, 1884) = syn. *Globigerina humilis*

*Turborotalita quinqueloba* (Natland, 1938) = *Globigerina quinqueloba*

*Tretomphalus bulloides* (d`Orbigny, 1839) = *Rosalina bulloides*

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**Table A.3:** Foraminiferal census data. Plankton samples

Cruise: M78/1 · Date: 10.03.2009 · Station: 211-5 · Device: MSN (all columns)

| Planktonic species | 0–60 >500 cb | 0–60 >500 wc | 0–60 400–500 cb | 0–60 400–500 wc | 0–60 300–400 cb | 0–60 300–400 wc | 0–60 250–300 cb | 0–60 250–300 wc | 0–60 150–250 cb | 0–60 150–250 wc | 0–60 125–150 cb | 0–60 125–150 wc | 0–60 100–125 cb | 0–60 100–125 wc | 60–100 >500 cb | 60–100 >500 wc | 60–100 400–500 cb | 60–100 400–500 wc | 60–100 300–400 cb | 60–100 300–400 wc | 60–100 250–300 cb | 60–100 250–300 wc | 60–100 150–250 cb | 60–100 150–250 wc | 60–100 125–150 cb | 60–100 125–150 wc | 60–100 100–125 cb | 60–100 100–125 wc |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *C. nitida* | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *D. anfracta* | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *G. bulloides* | | | | | | | | | 1 | 1 | | | | | | | | | | | | | | | | | | |
| *G. calida* | 1 | | | | 11 | | 11 | 4 | 72 | 6 | 28 | 10 | 12 | 5 | | | | | 1 | | 2 | 2 | 4 | 4 | 1 | | 1 | 1 |
| *G. conglobatus* | | | | | | | | | | | | | | | | | | | | | | | | | 1 | | | |
| *G. crassaformis* | | | | | | | | | 1 | | | | | | | | | | | | | | 1 | | | | | |
| *G. elongatus* | | | | | | | | | | | | | | | | | | | | | | | 1 | | | | | |
| *G. falconensis* | | | | | | | | | | 1 | | | | | | | | | | | | | | | | | | |
| *G. glutinata* | | | | | | | | | 2 | 1 | 8 | 4 | 99 | 10 | | | | | | | | | | | 2 | 1 | 8 | 3 |
| *G. hirsuta* | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *T. humilis* | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *T. iota* | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *G. menardii* | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *G. minuta* | 15 | | 15 | | 48 | | 58 | | 182 | | 57 | | 29 | | | | | | | | | | 14 | | 9 | | | |
| *G. ruber* (p/w) | | | | | | | | | | | | | | | | | | | | | | | 14 | | 9 | | | |
| *G. ruber* pink | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *G. ruber* white | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *G. rubescens* | | | | | | | | | 9 | 33 | 2 | 3 | 3 | 3 | | | | | | | | | | | | | 3 | |
| *G. sacculifer* | 141 | 7 | 38 | | 43 | 4 | 15 | 14 | 75 | | 14 | 7 | 11 | 1 | 26 | | 8 | | 3 | | 3 | | 2 | 1 | 3 | 1 | 1 | |
| *G. sacculifer* (ws) | 1 | | | | | | | | | | | | | | 2 | | | | | | | | | | | | | |
| *G. scitula* | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *G. siphonifera* | | | 1 | | 3 | 1 | 1 | | 10 | 2 | | | | | | | | | 3 | | | | 2 | 1 | | | | |
| *G. tenella* | | | | | | | | | | | | | | | | | 1 | | | | | | | | | | | |
| *G. tumida* | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *G. truncatulinoides* d. | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *G. truncatulinoides* s. | | | | | | | | | | | | | | | 1 | | | | | | | | | | | | | |
| *G. ungulata* | 3 | | 13 | | 23 | 1 | 18 | | 31 | 4 | 8 | 1 | 5 | 2 | 2 | | 13 | | 14 | | 7 | 2 | 15 | 4 | 1 | | | |
| *G. uvula* | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *H. pelagica* | 2 | | 1 | | 1 | | | 1 | 1 | 1 | 1 | | | | | | | | | | | | 1 | | 2 | | | |
| *N. dutertrei* | | | 1 | | 1 | | 2 | 2 | 12 | 6 | 7 | 4 | 14 | 4 | | | | | | | | | 1 | 3 | 1 | | | |
| *N. incompta* | | | | | | | 1 | | 1 | | 1 | | | | | | | | | | | | 1 | | | | | |
| *O. universa* | 11 | | 2 | | 2 | | 1 | | 1 | | | | | | 11 | 3 | 2 | | | | | | | | | | | |
| *P. obliquiloculata* | | | | | 3 | | 1 | | 1 | | | | | | | | | | | | | | 1 | | | | | |
| *S. dehiscens* | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *T. parkerae* | | | | | | | | | | | | | | | | | | | | | | | | | | | 1 | |
| *T. quinqueloba* | | | | | | | | | | | 3 | 1 | 3 | 1 | | | | | | | | | | | | | 6 | 1 |
| unidentified/juveniles | | | | | | | 1 | | 21 | | 12 | 2 | | | | | | | | | | | | | | | | |

ws = with sac-like chamber; d. = dextral/s. = sinistral; cb = cytoplasm bearing (alive)/wc = without cytoplasm (empty test)

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**Table A.3:** Foraminiferal census data. Plankton samples

All samples: Cruise M78/1 · Date 10.03.2009 · Station 211-5 · Device MSN

Column headers below are given as: Sampling interval (m) / Size-class (µm) / (cb = cytoplasm bearing [alive], wc = without cytoplasm [empty test]).

| Planktonic species | 200-300 100-125 cb | wc | 200-300 125-150 cb | wc | 200-300 150-250 cb | wc | 200-300 250-300 cb | wc | 200-300 300-400 cb | wc | 200-300 400-500 cb | wc | 200-300 >500 cb | wc | 100-200 100-125 cb | wc | 100-200 125-150 cb | wc | 100-200 150-250 cb | wc | 100-200 250-300 cb | wc | 100-200 300-400 cb | wc | 100-200 400-500 cb | wc | 100-200 >500 cb | wc |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C. nitida |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 1 |  |  |  |
| D. anfracta |  |  |  | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| G. bulloides |  |  |  | 1 |  | 11 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| G. calida | 1 |  |  | 3 | 1 |  |  | 3 |  |  |  |  |  |  |  |  | 5 | 6 | 6 | 11 | 3 | 1 |  |  |  |  |  |  |
| G. conglobatus |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 1 |  |  |  |  |  |  |  |  |  |
| G. crassaformis |  |  | 1 |  | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  | 1 |  |  |  |  |  |  |  |  |  |
| G. elongatus |  |  |  |  | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  | 1 |  |  |  |  |  |  |  |  |  |
| G. falconensis |  |  |  |  | 1 | 1 |  |  |  |  |  |  |  |  |  |  | 1 |  | 1 | 1 |  |  |  |  |  |  |  |  |
| G. glutinata | 5 | 7 | 4 | 9 | 1 | 2 |  |  |  |  |  |  |  |  | 16 | 13 | 3 |  | 1 |  |  |  |  |  |  |  |  |  |
| G. hirsuta |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| T. humilis |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| T. iota |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| G. menardii | 1 |  | 9 |  |  |  |  |  |  |  |  |  | 1 |  |  |  |  |  | 3 |  | 3 |  | 5 |  |  |  |  |  |
| G. minuta |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 11 | 2 |  |  |  |  |  |  |  |  |  |  |
| G. ruber (p/w) |  | 5 |  |  | 17 |  | 1 |  |  |  |  |  |  |  | 1 | 1 | 1 |  | 25 |  | 3 |  | 1 |  |  |  |  |  |
| G. ruber pink |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 1 |  |  |  |  |  |  |  |  |  |
| G. ruber white |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| G. rubescens | 3 | 3 |  |  |  |  |  |  |  |  |  |  |  |  | 2 | 4 | 3 | 1 |  |  |  |  |  |  |  |  |  |  |
| G. sacculifer |  |  |  | 2 |  | 3 | 1 | 3 | 1 |  |  |  |  |  |  |  | 1 |  | 4 | 5 |  | 2 | 3 | 2 | 1 | 1 |  |  |
| G. sacculifer (ws) |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 1 |  |  |  |
| G. scitula |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 6 |  | 3 | 2 | 6 | 2 |  |  |  |  |
| G. siphonifera |  |  |  |  |  |  |  |  |  |  |  | 1 |  |  |  |  |  |  |  |  |  |  |  |  | 1 |  |  |  |
| G. tenella |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| G. tumida |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| G. truncatulinoides d. |  |  |  | 2 | 1 |  | 2 |  | 1 |  |  |  |  |  |  |  | 1 |  | 10 | 6 | 2 | 2 | 5 |  |  |  |  |  |
| G. truncatulinoides s. |  |  |  |  |  |  |  |  | 2 | 1 | 2 |  |  |  |  |  |  |  | 1 |  |  |  |  |  |  |  |  |  |
| G. ungulata | 3 | 2 | 2 | 2 |  | 1 |  | 3 |  | 1 |  | 1 |  |  | 7 |  | 9 | 2 | 17 | 6 | 11 | 6 | 17 | 5 | 14 |  |  |  |
| G. uvula |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| H. pelagica |  |  |  |  | 1 | 1 | 2 |  |  |  |  |  | 1 |  |  |  | 1 | 1 |  |  |  |  | 1 |  |  |  |  |  |
| N. dutertrei |  |  |  |  | 1 |  |  |  |  |  | 1 |  |  |  |  | 4 | 1 |  | 2 |  |  |  | 2 |  |  | 2 |  | 1 |
| N. incompta | 2 |  | 2 | 2 |  | 1 |  |  |  |  |  |  |  |  |  |  |  | 1 | 1 |  |  |  | 2 |  |  |  |  |  |
| O. universa | 2 |  |  |  | 1 |  | 1 |  |  |  | 1 | 1 | 1 | 1 |  |  |  |  | 1 |  |  |  | 1 | 1 | 3 | 1 |  |  |
| P. obliquiloculata |  |  |  |  |  |  | 1 |  |  |  |  |  | 1 |  |  |  |  |  | 1 |  |  |  | 1 |  |  |  |  |  |
| S. dehiscens |  |  |  |  |  |  |  |  | 5 |  | 5 |  | 15 |  |  |  |  |  |  |  |  |  |  |  | 4 | 1 | 16 | 3 |
| T. parkerae |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 3 |  |  |  |  |  |  |  |  |  |  |  |  |  |
| T. quinqueloba | 3 | 2 |  |  |  |  |  |  |  |  |  |  |  |  | 4 | 3 |  |  |  |  |  |  |  |  |  |  |  |  |
| unidentified/juveniles |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |

ws = with sac-like chamber; d. = dextral/s. = sinistral; cb = cytoplasm bearing (alive)/wc = without cytoplasm (empty test)

**Table A.3:** Foraminiferal census data. Plankton samples

All samples: Cruise M78/1, Device MSN. Columns are grouped by Station / Date / Sampling interval (m), then Size-class (µm) with sub-columns cb and wc.

| Planktonic species | 211-5 · 10.03.2009 · 300–400 >500 cb | wc | 400–500 cb | wc | 300–400 cb | wc | 250–300 cb | wc | 150–250 cb | wc | 125–150 cb | wc | 100–125 cb | wc | 219-8 · 15.03.2009 · 0–60 >500 cb | wc | 400–500 cb | wc | 300–400 cb | wc | 250–300 cb | wc | 150–250 cb | wc | 125–150 cb | wc | 100–125 cb | wc |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C. nitida | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| D. anfracta | | | | | | | | | | | | | | 1 | | | | | | | | | | | | | | |
| G. bulloides | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. calida | | | | | 3 | | | | | | | | 3 | 1 | | | | | | | | | 10 | 2 | 4 | 1 | 10 | 6 |
| G. conglobatus | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. crassaformis | | | | | | | | | | | 1 | | | | | | | | | | | | | | | | | |
| G. elongatus | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. falconensis | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. glutinata | | | | | | | | | | | | | 4 | 7 | | | | | | | | | 4 | 1 | 9 | 1 | 87 | 25 |
| G. hirsuta | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| T. humilis | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| T. iota | | | | | | | | | 1 | | | | 1 | | | | | | | | 1 | | 1 | | | 2 | 4 | |
| G. minuta | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. ruber (p/w) | | | | | 2 | | | | 15 | 5 | 5 | | | 5 | | | 4 | | 12 | | 12 | | 23 | | | | 5 | 1 |
| G. ruber pink | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. ruber white | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. rubescens | | | | 1 | | | | | | | | 1 | | 23 | | | | | | | | | | | 3 | | 9 | 4 |
| G. sacculifer | | | 1 | | | 1 | | | | 3 | | 3 | 2 | 1 | 59 | | 48 | | 63 | 3 | 60 | 2 | 107 | | 17 | | 16 | |
| G. sacculifer (ws) | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. scitula | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. siphonifera | | | | 1 | | | | | 1 | | | | | | | | | | 1 | | | | 1 | | | | | |
| G. tenella | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. tumida | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. truncatulinoides d. | | | 1 | | | | | 2 | 2 | 2 | 3 | | | | | | | | | | 1 | 1 | | | | | | |
| G. truncatulinoides s. | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. ungulata | | | | | | 2 | | 1 | 2 | | | | | | | | | | | | | | | | | | | |
| G. uvula | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| H. pelagica | | | 2 | | | | | | 1 | 1 | | | | 1 | | | | | | 1 | | | | | | | | |
| N. dutertrei | | | | | | | | | | 3 | 3 | | 3 | 1 | | | | | | | | | 10 | | 1 | | 13 | 2 |
| N. incompta | | | | | | | 1 | | 2 | | 2 | | | | | | | | | | | | | | | | | |
| O. universa | 2 | | | | | | | | | | 2 | | | | 2 | | 1 | | 1 | | | | | | | | | |
| P. obliquiloculata | | | | | | | | | | | | | | | | | | | 1 | 1 | | | | | | | | |
| S. dehiscens | 1 | 4 | | 2 | | | | | | | | | | | | | | | | | 2 | | | | | | | |
| T. parkerae | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| T. quinqueloba | | | | | | | | | | | | | 18 | | | | | | | | | | | | | | 3 | |
| unidentified/juveniles | | | | | | | | | 1 | | 3 | | 4 | 3 | | | | | | | | | 1 | | 1 | | 15 | 3 |

ws = with sac-like chamber; d. = dextral/s. = sinistral; cb = cytoplasm bearing (alive)/wc = without cytoplasm (empty test)

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**Table A.3:** Foraminiferal census data. Plankton samples

All samples: Cruise M78/1, Date 15.03.2009, Station 219-8, Device MSN. Columns grouped by Sampling interval (m) / Size-class (µm) / cb | wc.

| Planktonic species | 125-180 100-125 cb | wc | 125-180 125-150 cb | wc | 125-180 150-250 cb | wc | 125-180 250-300 cb | wc | 125-180 300-400 cb | wc | 125-180 400-500 cb | wc | 125-180 >500 cb | wc | 60-125 100-125 cb | wc | 60-125 125-150 cb | wc | 60-125 150-250 cb | wc | 60-125 250-300 cb | wc | 60-125 300-400 cb | wc | 60-125 400-500 cb | wc | 60-125 >500 cb | wc |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C. nitida | | | | | | | | | | | | | | | | | | | 2 | | | | | | | | | |
| D. anfracta | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. bulloides | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. calida | 4 | 2 | 1 | 2 | 1 | 2 | 1 | | 1 | | | | | | 3 | 2 | 9 | 2 | 8 | 5 | | | | | | | | |
| G. conglobatus | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. crassaformis | | | 1 | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. elongatus | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. falconensis | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. glutinata | 11 | 38 | 1 | 2 | 1 | | | | | | | | | | 33 | 37 | 8 | 4 | 1 | | 20 | | 25 | | 15 | | | |
| G. hirsuta | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| T. humilis | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| T. iota | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. menardii | 2 | | | | 1 | | | | | | | | | | 1 | 1 | 1 | | 1 | | 1 | | 1 | | | | | |
| G. minuta | | | | 1 | | | | | | | | | | | | | | | | | | | 1 | | | | | |
| G. ruber (p/w) | | 3 | 1 | 1 | 4 | 1 | 1 | | 1 | | | | | | | 2 | | 1 | 12 | | 1 | | 2 | | | | | |
| G. ruber pink | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. ruber white | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. rubescens | 3 | 9 | 1 | | 1 | | | | | | 1 | | 1 | | 3 | 11 | 4 | 2 | | 2 | | | | | | | 21 | |
| G. sacculifer | 3 | | 4 | 1 | 3 | 2 | 5 | 2 | 3 | 1 | | | | | 6 | 2 | 15 | 4 | 57 | 4 | | 1 | 25 | | 15 | | | |
| G. sacculifer (ws) | | | | | | | | | | | | | | | | | | | | | 1 | | | | | | 1 | |
| G. scitula | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. siphonifera | | | | | 1 | | | | | | | | | | | | | | | | | | 1 | | | | | |
| G. tenella | | | | | 2 | | | | | | | | | | | | | | | | 1 | | | | | | | |
| G. tumida | | | | | | | | | | | 1 | | 1 | | | | | | 1 | | | | | | 1 | | | |
| G. truncatulinoides d. | | | | | | | 2 | | | | | | | | 1 | | | | | | | | | | | | | |
| G. truncatulinoides s. | | | | | | | | | | | | | | | 1 | | | | | | | | | | | | | |
| G. ungulata | | | | | | | 1 | | | | | | | | | | 1 | | 3 | | | | | | | | | |
| G. uvula | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| H. pelagica | | | | | 1 | 1 | 1 | | 1 | | | | | | | | | | | | | | | | | | | |
| N. dutertrei | 1 | | 1 | | 3 | | | | 1 | | 1 | | | | 10 | 3 | 4 | 1 | 15 | | 4 | 1 | 4 | | | | | |
| N. incompta | | | | | | | | | 1 | | | | | | | | 7 | | | | | | | | | | | |
| O. universa | | | | | | | | | | | | | | | | | | | 1 | | 2 | | | | | | | |
| P. obliquiloculata | | | | | | | 1 | | | | 1 | | | | | | | | 4 | | | | 1 | | 1 | | | |
| S. dehiscens | | | | | | | | | 2 | | 3 | | 6 | | | | | | | | | | 4 | | | | | |
| T. parkerae | | | | | | | | | | | | | | | 1 | | | | | | | | | | | | | |
| T. quinqueloba | 6 | 1 | 1 | | 1 | | | | | | | | | | 11 | 2 | | | | | | | | | | | | |
| unidentified/juveniles | | | | | | | | | 1 | | | | | | 8 | | 5 | | | | | | | | | | | |

ws = with sac-like chamber; d. = dextral/s. = sinistral; cb = cytoplasm bearing (alive)/wc = without cytoplasm (empty test)

**Table A.3:** Foraminiferal census data. Plankton samples

All columns: Cruise M78/1; Date 15.03.2009; Station 219-8; Device MSN.

| Planktonic species | 180–220 >500 cb | 180–220 >500 wc | 180–220 400–500 cb | 180–220 400–500 wc | 180–220 300–400 cb | 180–220 300–400 wc | 180–220 250–300 cb | 180–220 250–300 wc | 180–220 150–250 cb | 180–220 150–250 wc | 180–220 100–125 cb | 180–220 100–125 wc | 220–400 >500 cb | 220–400 >500 wc | 220–400 400–500 cb | 220–400 400–500 wc | 220–400 300–400 cb | 220–400 300–400 wc | 220–400 250–300 cb | 220–400 250–300 wc | 220–400 150–250 cb | 220–400 150–250 wc | 220–400 125–150 cb | 220–400 125–150 wc | 220–400 100–125 cb | 220–400 100–125 wc |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C. nitida | | | | | | | | | | | | | | | | | | | | | | | | | | |
| D. anfracta | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. bulloides | | | | | | | | | | | | | | | | | | | | | | | | 6 | | |
| G. calida | | | | | 1 | | | | | 1 | | 2 | | | | | 1 | | 1 | 2 | 1 | | | 3 | | 2 |
| G. conglobatus | | | | | 1 | | | | | | | | | | | | | | | | | | | | | |
| G. crassaformis | | | | | | | 1 | | | | | | | | | | 2 | | | | | | | | | |
| G. elongatus | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. falconensis | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. glutinata | | | | | | | | | 1 | 3 | 7 | 29 | | | | | | | | 5 | | | | 23 | 2 | 133 |
| G. hirsuta | | | | | | | | | | | | | | | | | | | | | | | | | | |
| T. humilis | | | | | | | | | | | | | | | | | | | | | | | | | | |
| T. iota | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. menardii | | | | | | | | | | | | | | | | | | | 1 | 3 | 1 | | | 1 | 2 | 1 |
| G. minuta | | | | | | | | | 4 | 2 | | | | | | | 2 | | 12 | | 3 | 1 | | 1 | | 2 |
| G. ruber (p/w) | | | | | | 1 | 3 | | | | | | | | | | 2 | | | | 3 | | | | | 2 |
| G. ruber pink | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. ruber white | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. rubescens | | | | | | | | | | | | 15 | | | | | 3 | | 3 | 12 | | | | 5 | 2 | 95 |
| G. sacculifer | | | | | 1 | 1 | | 2 | | | | | 2 | 1 | 3 | 1 | 4 | 3 | 2 | | 1 | | | 12 | | 4 |
| G. sacculifer (ws) | | | | | 1 | | 4 | | | | | | | | | 1 | | 1 | | | | | | | | |
| G. scitula | | | | | | | 1 | | | | | | | | | | | | | | | | | | | |
| G. siphonifera | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. tenella | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. tumida | 2 | | | | | | 5 | | | | | | 5 | | 3 | | 1 | | | | | | | | | |
| G. truncatulinoides d. | | | | | | | | | | | | | | | 1 | | | | | | | | | | | |
| G. truncatulinoides s. | | | | | | | | | | | | | | | 1 | | | | | | | | | | | |
| G. ungulata | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. uvula | | | | | | | | | | | | | | | | | | | | | | | | | | |
| H. pelagica | | | | | | | | | | | | | | | | | | | | | | | | | | |
| N. dutertrei | | | | | | | | | | | | 3 | | | | | | | | | | | | | | |
| N. incompta | | | | | | | | | | 2 | 1 | | | | | | | | | | | 2 | | 2 | | |
| O. universa | | | | | | | | | | | | | | 2 | | 1 | | | | 2 | | | | | | |
| P. obliquiloculata | 2 | | | | 1 | | | | 1 | | | | | | 1 | | 1 | | | 1 | | | | | | |
| S. dehiscens | 3 | | | | | | | | | | | | 7 | | 4 | | 4 | | | | | | | | | |
| T. parkerae | | | | | | | | | | | | | | | | | | | | | | | | | | |
| T. quinqueloba | | | | | | | | | | | | | | | | | | | | | | | | | | |
| unidentified/juveniles | | | | | | | 1 | | | | | | | | | | | | 3 | | 1 | | | | | 12 |

ws = with sac-like chamber; d. = dextral/s. = sinistral; cb = cytoplasm bearing (alive)/wc = without cytoplasm (empty test)

**Table A.3:** Foraminiferal census data. Plankton samples

All columns: Cruise M78/1 · Date 17.03.2009 · Station 220-9 · Device MSN. Sampling intervals (m) and size-classes (µm) as indicated in the header. cb = cytoplasm bearing; wc = without cytoplasm.

| Planktonic species | 0–70 >500 cb | 0–70 >500 wc | 0–70 400–500 cb | 0–70 400–500 wc | 0–70 300–400 cb | 0–70 300–400 wc | 0–70 250–300 cb | 0–70 250–300 wc | 0–70 150–250 cb | 0–70 150–250 wc | 0–70 125–150 cb | 0–70 125–150 wc | 0–70 100–125 cb | 0–70 100–125 wc | 70–110 >500 cb | 70–110 >500 wc | 70–110 400–500 cb | 70–110 400–500 wc | 70–110 300–400 cb | 70–110 300–400 wc | 70–110 250–300 cb | 70–110 250–300 wc | 70–110 150–250 cb | 70–110 150–250 wc | 70–110 125–150 cb | 70–110 125–150 wc | 70–110 100–125 cb | 70–110 100–125 wc |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C. nitida | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| D. anfracta | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. bulloides | | | | | | | | | 1 | | | | | | | | | | | | | | 1 | | | | | |
| G. calida | | | 3 | | 1 | | 2 | | 13 | 2 | 4 | | 2 | 1 | | | | | | | | | 1 | 2 | | | | 1 |
| G. conglobatus | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. crassaformis | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. elongatus | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. falconensis | | | | | | | | | | | | | | | | | | | | | | | | | | | | 1 |
| G. glutinata | | | | | | | | | 6 | 2 | 34 | 9 | 98 | 23 | | | | | | | | | 2 | 1 | | | 10 | 15 |
| G. hirsuta | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| T. humilis | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| T. iota | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. menardii | | | | | | | 1 | | 1 | | | | 2 | | | | | | | | | 1 | 1 | 1 | | | | 1 |
| G. minuta | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. ruber (p/w) | | | 3 | | 10 | | 18 | 1 | 22 | | 4 | | | | | | | | 1 | | 4 | | 2 | 1 | | | | |
| G. ruber pink | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. ruber white | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. rubescens | | | | | | | | | 3 | | 10 | 2 | 2 | 4 | | | | | | | | 10 | | 6 | | | 1 | 22 |
| G. sacculifer | 72 | | 41 | | 86 | 6 | 42 | 2 | 97 | 18 | 24 | 3 | 14 | 1 | | | 2 | 1 | 5 | | 8 | | 3 | 3 | | | 1 | |
| G. sacculifer (ws) | 2 | | | | 1 | | | | | | | | | | | | 1 | | | | | | | | | | | |
| G. scitula | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. siphonifera | | | | | 1 | | | | 3 | | | | | | | | 1 | | 3 | | | | 1 | 1 | | | | |
| G. tenella | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. tumida | | | | | | | 1 | | | | | | | | | | | | | | | | | | | | | |
| G. truncatulinoides d. | | | | | | | | | | | | | | | | | | | | | | 1 | | | | | | |
| G. truncatulinoides s. | | | | | | | | | | | | | | | | | | | | 1 | | | | | | | | |
| G. ungulata | | | | | | | | | 1 | | 1 | | | | | | | | | | | | | | | | | |
| G. uvula | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| H. pelagica | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| N. dutertrei | | | | | | | | | 6 | 3 | 2 | 2 | 3 | | | | | | 1 | | 1 | 2 | 1 | | | | | |
| N. incompta | | | | | 1 | | | | | | 3 | | | | | | | | | | | | | | | | | |
| O. universa | 6 | | 1 | | | | | | | | | | | | | 3 | | | | | | | | | | | | |
| P. obliquiloculata | | | 1 | | 2 | | | | | | | | | | | | | | | | | | | | | | | |
| S. dehiscens | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| T. parkerae | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| T. quinqueloba | | | | | | | | | | | | | 2 | | | | | | | | | | | | | | 1 | 4 |
| unidentified/juveniles | | | | | | | | | | | | | 16 | 2 | | | | | | | | | | | | | 4 | 5 |

ws = with sac-like chamber; d. = dextral/s. = sinistral; cb = cytoplasm bearing (alive)/wc = without cytoplasm (empty test)

**Table A.3:** Foraminiferal census data. Plankton samples

All samples: Cruise M78/1 · Date 17.03.2009 · Station 220-9 · Device MSN

| Sampling interval (m) → | 110–150 | | 110–150 | | 110–150 | | 110–150 | | 110–150 | | 110–150 | | 110–150 | | 150–220 | | 150–220 | | 150–220 | | 150–220 | | 150–220 | | 150–220 | | 150–220 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Size-class (µm) → | >500 | | 400–500 | | 300–400 | | 250–300 | | 150–250 | | 125–150 | | 100–125 | | >500 | | 400–500 | | 300–400 | | 250–300 | | 150–250 | | 125–150 | | 100–125 | |
| Planktonic species ↓ | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc |
| C. nitida | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| D. anfracta | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. bulloides | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. calida | | | | | | | | | 1 | 1 | | | | | | | | | | | 1 | | 1 | 1 | 3 | | | 1 |
| G. conglobatus | | | 1 | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. crassaformis | | | | | | | | | | | | | | | | | | | 1 | | | | | | 2 | | | |
| G. elongatus | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. falconensis | | | | | | | | | 1 | | | | | | | | | | | | | | | | | | | |
| G. glutinata | | | | | | | | | 1 | | | | 4 | 30 | | | | | | | | | | 2 | | 13 | 2 | 22 |
| G. hirsuta | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| T. humilis | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| T. iota | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. menardii | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. minuta | | | | | | | | | | 3 | | | | | | | | | | | | | | 3 | | | | |
| G. ruber (p/w) | | | | | | | | | | | | 1 | | | | | | | | | 1 | | 1 | 1 | | 1 | 1 | 1 |
| G. ruber pink | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. ruber white | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. rubescens | | | | | | | | | 1 | 2 | | | 32 | 1 | | | | | | | | 2 | | 1 | | 7 | 1 | 26 |
| G. sacculifer | | | 2 | 1 | 1 | 1 | | | | 3 | | 2 | | | | | | | | 2 | 1 | 3 | | 3 | | 1 | | |
| G. sacculifer (ws) | 3 | | 1 | | 2 | | | | | | | | | | | | | | | | | | | | | | | |
| G. scitula | | | | | | | | | 1 | | | | | | | | | | | | | | 1 | | | | | |
| G. siphonifera | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. tenella | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. tumida | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. truncatulinoides d. | | | | | | | | | 1 | | | | | | | | | | 1 | | 2 | | 1 | 1 | | | 1 | 1 |
| G. truncatulinoides s. | | | | | | | | | | | | | | | | | | | | | | | 1 | | | | | |
| G. ungulata | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. uvula | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| H. pelagica | | | | | 1 | | 1 | | 1 | | | | | | | | | | | | | | | | | | | |
| N. dutertrei | | | | | | | | | 1 | 1 | 1 | | | 3 | | | | | | | 1 | | | 3 | | 2 | | |
| N. incompta | | | | | | | | | 1 | | 2 | 1 | | | | | | | | | | | | | | 1 | | |
| O. universa | 1 | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| P. obliquiloculata | | | | | 1 | | | | | | | | | | 3 | | | | | | | | | | | | | |
| S. dehiscens | 1 | | | | | | | | | | | | | | | | 2 | | | | 1 | | | | | | | |
| T. parkerae | | | | | | | | | | | | | 1 | | | | | | | | | | | | | | | |
| T. quinqueloba | | | | | | | | | | | | | 1 | 1 | | | | | | | | | | | | | | |
| unidentified/juveniles | | | | | | | | | | | | | 2 | 4 | | | | | | | | | | | | | | 6 |

ws = with sac-like chamber; d. = dextral/s. = sinistral; cb = cytoplasm bearing (alive)/wc = without cytoplasm (empty test)

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**Table A.3:** Foraminiferal census data. Plankton samples

All samples: Cruise M78/1; Device MSN. Stations 221-7 (18.03.2009, sampling interval 0–40 m) and 220-9 (17.03.2009, sampling interval 220–300 m). cb = cytoplasm bearing (alive); wc = without cytoplasm (empty test).

| Planktonic species | 221-7 100-125 cb | 221-7 100-125 wc | 221-7 125-150 cb | 221-7 125-150 wc | 221-7 150-250 cb | 221-7 150-250 wc | 221-7 250-300 cb | 221-7 250-300 wc | 221-7 300-400 cb | 221-7 300-400 wc | 221-7 400-500 cb | 221-7 400-500 wc | 221-7 >500 cb | 221-7 >500 wc | 220-9 100-125 cb | 220-9 100-125 wc | 220-9 125-150 cb | 220-9 125-150 wc | 220-9 150-250 cb | 220-9 150-250 wc | 220-9 250-300 cb | 220-9 250-300 wc | 220-9 300-400 cb | 220-9 300-400 wc | 220-9 400-500 cb | 220-9 400-500 wc | 220-9 >500 cb | 220-9 >500 wc |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C. nitida | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| D. anfracta | 7 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. bulloides | | | | | | | 2 | 1 | | | | | | | | | | | | | | | | | | | | |
| G. calida | 4 | | | | 33 | | 6 | | 2 | | | | | | | | 1 | 1 | | 1 | | | | | | | | |
| G. conglobatus | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. crassaformis | | | | | | | | | | | | | | | | | 1 | | | | | | 1 | | | | | |
| G. elongatus | | | | | | | | | | | 2 | | | | | | | | | | | | | | | | | |
| G. falconensis | | | 2 | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. glutinata | 461 | 21 | 76 | 3 | 101 | 4 | 4 | | | | | | | | 1 | 26 | 1 | 14 | 1 | 1 | | | | | | | | |
| G. hirsuta | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| T. humilis | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| T. iota | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. menardii | 3 | | 1 | | 2 | | 3 | | 1 | | 1 | | | | | 1 | | | | | | | | | | | | |
| G. minuta | 4 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. ruber (p/w) | 6 | | 7 | | 94 | | 57 | | 42 | | 22 | | | | | | | 1 | | 4 | | 1 | | | | | | |
| G. ruber pink | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. ruber white | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. rubescens | | | 1 | | 5 | | 5 | | | | | | | | | 15 | 2 | 3 | 2 | 1 | 2 | 2 | | | | | | |
| G. sacculifer | 9 | 1 | 3 | | 125 | 2 | 102 | | 98 | | 64 | | 28 | | | 1 | 1 | 2 | 2 | 1 | 2 | 2 | 1 | 1 | | 2 | | |
| G. sacculifer (ws) | | | | | | | | | | | 1 | | 2 | | | | | | | | | | | | | | | |
| G. scitula | | | | | | | 9 | | 8 | | | | | | | | | 1 | | | | | | | | | | |
| G. siphonifera | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. tenella | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. tumida | | | | | | | | | | | | | | | | | | | | | 2 | | | | | | | |
| G. truncatulinoides d. | | | | | | | | | | | | | | | | | | | | | | | | | 1 | | | |
| G. truncatulinoides s. | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. ungulata | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. uvula | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| H. pelagica | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| N. dutertrei | 8 | 2 | 4 | | 64 | 3 | 20 | 1 | 24 | | | | | | | | | | 1 | | | | | | | | | |
| N. incompta | 2 | | 4 | | | 1 | | | | | | | | | | | 1 | 1 | 1 | 1 | | | | | | | | |
| O. universa | | | | | 2 | | 5 | | | | 2 | | 15 | | | | | | | | | | | | | | 1 | |
| P. obliquiloculata | | | 1 | | 10 | | 6 | | 3 | | 1 | | | | | | | | | | | | | 1 | | | | |
| S. dehiscens | | | | | | | | | | | | | | | | | | | | | | | | | 1 | | 1 | |
| T. parkerae | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| T. quinqueloba | 9 | | | | | | | | | | | | | | | 1 | | | | | | | | | | | | |
| unidentified/juveniles | 17 | | 20 | | 4 | | 1 | | 1 | | | | | | | 5 | | | | | | | | | | | | |

ws = with sac-like chamber; d. = dextral/s. = sinistral; cb = cytoplasm bearing (alive)/wc = without cytoplasm (empty test)

**Table A.3:** Foraminiferal census data. Plankton samples

All samples — Cruise: M78/1; Date: 18.03.2009; Station: 221-7; Device: MSN.

| | 40-60 >500 | | 40-60 400-500 | | 40-60 300-400 | | 40-60 250-300 | | 40-60 150-250 | | 40-60 125-150 | | 40-60 100-125 | | 60-150 >500 | | 60-150 400-500 | | 60-150 300-400 | | 60-150 250-300 | | 60-150 150-250 | | 60-150 125-150 | | 60-150 100-125 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Planktonic species | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc |
| C. nitida | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| D. anfracta | | | | | | | | | | | | | | | | | | | | | | | | | | | 5 | 1 |
| G. bulloides | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. calida | | | | | 8 | | | | 20 | | 1 | | | | | | 1 | | | | 5 | | 8 | 1 | 4 | | | |
| G. conglobatus | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. crassaformis | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. elongatus | | | | | | | | | | | | | | | | | 1 | | | | | | 1 | | | | | |
| G. falconensis | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. glutinata | | | | | | | 76 | 3 | | | 15 | 1 | 274 | 14 | | | | | | | | | 24 | 6 | 3 | 9 | 89 | 209 |
| G. hirsuta | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| T. humilis | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| T. iota | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. menardii | | | | | 1 | | 1 | | | | | | | | 1 | | | | 2 | | 2 | | 2 | | | | | |
| G. minuta | | | 2 | | 14 | | | | | | | | | | | | | | | | | | 4 | 1 | | | | |
| G. ruber (p/w) | | | 2 | | 14 | | 12 | | 31 | | | | 5 | | 2 | | | | 6 | | 6 | | | | | | | |
| G. ruber pink | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. ruber white | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. rubescens | | | | | | | | | | | | | | 1 | | 1 | | | | | | | 4 | 1 | | | | |
| G. sacculifer | 4 | | 11 | | 41 | | 31 | 2 | 43 | 1 | 1 | 1 | | 1 | 2 | 1 | 2 | 2 | 8 | 2 | 12 | 2 | 11 | 2 | 2 | | | |
| G. sacculifer (ws) | 1 | | 3 | | 4 | | | | | | | | | | | | 1 | | 1 | | | | | | | | | |
| G. scitula | | | | | | | | | | | | | | | | | | | 3 | | 3 | | | | | | | |
| G. siphonifera | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. tenella | | | | | | | | | | | | | | | | | | | 1 | | | | | | | | | |
| G. tumida | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. truncatulinoides d. | | | | | 1 | | | | | | | | | | | | | | 1 | | | | 3 | | | | | |
| G. truncatulinoides s. | | | | | | | | | 1 | | | | | | | | | | | | | | 1 | | | | | |
| G. ungulata | | | | | | | 1 | | | | | | | | | | | | | | | | | | | | | |
| G. uvula | | | | | | | | | | | | | | | | | | | | | | | | | | | | 1 |
| H. pelagica | | | | | 2 | | | | | | | | | | | | 1 | | 3 | | | | 3 | | 1 | | | |
| N. dutertrei | | | | | 10 | | | | 23 | 1 | 1 | | | 1 | 2 | | 1 | | 8 | 1 | 11 | 1 | 16 | 5 | 1 | 2 | 10 | 2 |
| N. incompta | | | | | 3 | | 2 | | | | 1 | | | | 7 | | | | | | | | | | | | | |
| O. universa | 6 | | 1 | | | | | | | | 1 | | | | | | 7 | | | | | | | | | | | |
| P. obliquiloculata | | | 3 | | 7 | | 3 | | 3 | | | | | | | | 2 | | 8 | | 2 | | 4 | | | | | |
| S. dehiscens | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| T. parkerae | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| T. quinqueloba | | | | | | | | | 2 | | 2 | | 5 | | | | | | | | 1 | | 2 | | | | 6 | 1 |
| unidentified/juveniles | | | | | 1 | | | | 4 | | 20 | | 25 | 2 | | | | | | | | | | | | | | |

ws = with sac-like chamber; d. = dextral/s. = sinistral; cb = cytoplasm bearing (alive)/wc = without cytoplasm (empty test)

**Table A.3:** Foraminiferal census data. Plankton samples

All samples: Cruise M78/1; Date 18.03.2009; Station 221-7; Device MSN.

| Planktonic species | 150–210 >500 cb | 150–210 >500 wc | 150–210 400–500 cb | 150–210 400–500 wc | 150–210 300–400 cb | 150–210 300–400 wc | 150–210 250–300 cb | 150–210 250–300 wc | 150–210 150–250 cb | 150–210 150–250 wc | 150–210 125–150 cb | 150–210 125–150 wc | 150–210 100–125 cb | 150–210 100–125 wc | 210–300 >500 cb | 210–300 >500 wc | 210–300 400–500 cb | 210–300 400–500 wc | 210–300 300–400 cb | 210–300 300–400 wc | 210–300 250–300 cb | 210–300 250–300 wc | 210–300 150–250 cb | 210–300 150–250 wc | 210–300 125–150 cb | 210–300 125–150 wc | 210–300 100–125 cb | 210–300 100–125 wc |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C. nitida | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| D. anfracta | | | | | | | | | | | | 1 | | | | | | | | | | | | | | 3 | 4 | 5 |
| G. bulloides | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. calida | | | | | | | 1 | | | 1 | | 1 | | 1 | | | | | | | | | 1 | | | | | |
| G. conglobatus | | | | | 1 | | | | | | | | | | | | | | | | | | | | | | | |
| G. crassaformis | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. elongatus | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. falconensis | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. glutinata | | | | | | | | | 9 | 23 | 3 | 19 | 25 | 170 | | | | | | | | | 11 | 31 | 15 | 101 | 15 | 134 |
| G. hirsuta | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| T. humilis | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| T. iota | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. menardii | 2 | | 1 | | 1 | | | | | | | | | | | | | | | | | | | | | 1 | 1 | |
| G. minuta | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. ruber (p/w) | | | | | | | | | | | | | | | | | | | 2 | | 1 | | 3 | 1 | | | | |
| G. ruber pink | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. ruber white | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. rubescens | | | | | | | | | | | | | | 3 | | | | | | | | | | | | | | 1 |
| G. sacculifer | | | | | 1 | | 4 | | 3 | 1 | 3 | 1 | | 1 | | | | | 1 | | 1 | | 1 | 1 | | 1 | | 1 |
| G. sacculifer (ws) | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. scitula | | | | | | | | | | | | | | | | | 1 | | | | 1 | | | | | | 1 | |
| G. siphonifera | | | | | | | | | | | | | | | | | | | 1 | | 1 | | | | | | | |
| G. tenella | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. tumida | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. truncatulinoides d. | | | 1 | | 5 | | 1 | | 2 | | 2 | | 1 | 1 | | | 4 | | 3 | | 1 | | 1 | | | | | |
| G. truncatulinoides s. | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. ungulata | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. uvula | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| H. pelagica | | | | | | | | | | | | | | | | | | | | | | | 1 | | | | | |
| N. dutertrei | | | | | | | | | 7 | | | | 3 | | | | 1 | | | | 1 | 1 | 12 | 1 | 2 | 1 | 2 | 3 |
| N. incompta | | | | | | | | | 1 | 1 | | | | | | | | | | | | | 2 | 1 | 5 | | | 2 |
| O. universa | | | | | | | | | | | | | | | | 1 | | | | | | | | | | | | |
| P. obliquiloculata | | | | | | | | | | | | | | | | | | | 1 | | | | | | | | | |
| S. dehiscens | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| T. parkerae | | | | | | | | | | | 1 | | | | | | | | | | | | | | | | 1 | 1 |
| T. quinqueloba | | | | | | | | | | | | | | 15 | | | | | | | | | | | 2 | | 3 | 1 |
| unidentified/juveniles | | | | | | | | | | | | | 4 | 6 | | | | | | | | | | | | | 1 | 3 |

ws = with sac-like chamber; d. = dextral/s. = sinistral; cb = cytoplasm bearing (alive)/wc = without cytoplasm (empty test)

**Table A.3:** Foraminiferal census data. Plankton samples

All columns: Cruise M78/1; Date 19.03.2009; Station 222-6; Device MSN.

| Planktonic species | 0–40 >500 cb | 0–40 >500 wc | 0–40 400–500 cb | 0–40 400–500 wc | 0–40 300–400 cb | 0–40 300–400 wc | 0–40 250–300 cb | 0–40 250–300 wc | 0–40 150–250 cb | 0–40 150–250 wc | 0–40 125–150 cb | 0–40 125–150 wc | 0–40 100–125 cb | 0–40 100–125 wc | 40–80 >500 cb | 40–80 >500 wc | 40–80 400–500 cb | 40–80 400–500 wc | 40–80 300–400 cb | 40–80 300–400 wc | 40–80 250–300 cb | 40–80 250–300 wc | 40–80 150–250 cb | 40–80 150–250 wc | 40–80 125–150 cb | 40–80 125–150 wc | 40–80 100–125 cb | 40–80 100–125 wc |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C. nitida |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| D. anfracta |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 1 |  |  |  |
| G. bulloides |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| G. calida |  |  |  |  |  |  | 2 |  | 2 |  | 2 |  | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| G. conglobatus |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| G. crassaformis |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| G. elongatus |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 1 |  |  |  |  |  |  |  |
| G. falconensis |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| G. glutinata |  |  |  |  |  |  |  |  | 6 |  | 10 | 1 | 56 | 10 |  |  |  |  |  |  |  |  | 1 |  | 2 |  | 16 | 3 |
| G. hirsuta |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| T. humilis |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| T. iota |  |  |  |  |  |  |  |  | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| G. menardii |  |  | 1 |  | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| G. minuta |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| G. ruber (p/w) |  |  | 1 |  | 7 |  | 10 |  | 32 |  | 8 | 1 | 2 | 1 |  |  |  |  | 3 |  | 1 |  | 6 |  | 2 |  |  | 1 |
| G. ruber pink |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| G. ruber white |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| G. rubescens |  |  |  |  |  |  |  |  | 3 |  | 3 |  |  | 1 |  |  |  |  |  |  |  |  |  |  | 1 |  |  |  |
| G. sacculifer | 4 |  | 7 |  | 30 |  | 26 | 2 | 39 | 10 | 10 |  |  |  | 1 |  | 1 |  | 5 |  | 2 |  | 3 |  |  |  |  |  |
| G. sacculifer (ws) | 2 |  | 1 |  | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| G. scitula |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 1 |
| G. siphonifera |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 2 |  |  |  |  |  |  |  |  |  |
| G. tenella |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 1 |
| G. tumida |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| G. truncatulinoides d. |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| G. truncatulinoides s. |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| G. ungulata |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| G. uvula |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| H. pelagica |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| N. dutertrei |  |  |  |  | 2 |  |  |  | 6 |  | 2 | 1 | 5 |  |  |  | 1 |  | 2 |  | 2 |  | 4 |  | 2 |  | 4 | 2 |
| N. incompta |  |  |  |  |  |  |  |  | 4 |  | 2 |  | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| O. universa | 4 |  | 1 |  |  |  |  |  |  |  |  |  |  |  | 4 |  | 2 |  |  |  |  |  |  |  |  |  |  |  |
| P. obliquiloculata |  |  |  |  | 3 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| S. dehiscens |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| T. parkerae |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 2 |  |
| T. quinqueloba |  |  |  |  |  |  |  |  | 2 |  | 2 |  | 5 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| unidentified/juveniles |  |  |  |  |  |  | 1 |  |  |  |  |  | 10 |  |  |  |  |  |  |  |  |  |  |  | 1 |  |  | 2 |

ws = with sac-like chamber; d. = dextral/ s. = sinistral; cb = cytoplasm bearing (alive)/ wc = without cytoplasm (empty test)

**Table A.3:** Foraminiferal census data. Plankton samples

All samples: Cruise M78/1, Date 19.03.2009, Station 222-6, Device MSN. Columns are grouped by Sampling interval (m) and Size-class (µm); each sample has cb and wc sub-columns.

| Planktonic species | 80–120 >500 cb | wc | 80–120 400–500 cb | wc | 80–120 300–400 cb | wc | 80–120 250–300 cb | wc | 80–120 150–250 cb | wc | 80–120 125–150 cb | wc | 80–120 100–125 cb | wc | 120–180 >500 cb | wc | 120–180 400–500 cb | wc | 120–180 300–400 cb | wc | 120–180 250–300 cb | wc | 120–180 150–250 cb | wc | 120–180 125–150 cb | wc | 120–180 100–125 cb | wc |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C. nitida | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| D. anfracta | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. bulloides | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. calida | | | | | | | | | | | | | | | | | | | | | | | | | | | 1 | |
| G. conglobatus | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. crassaformis | | | | | | | | | | | | | | | | | | | | | | | 1 | | 5 | | | |
| G. elongatus | | | | | | | 5 | | 4 | | | | | | | | | | | | | | | | | | | |
| G. falconensis | | | | | | | | | 1 | | | | | | | | | | | | | | | | | | | |
| G. glutinata | | | | | | | | | 1 | | 1 | 1 | 6 | 3 | | | | | | | | | | | 2 | 1 | 2 | 9 |
| G. hirsuta | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| T. humilis | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| T. iota | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. menardii | | | | | | | | | | | | | | 1 | | | | | | | | | | | | | | |
| G. minuta | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. ruber (p/w) | | | | | 1 | | 4 | 1 | 4 | 3 | | 1 | 2 | 1 | | | | | | | 1 | | | 1 | | | | |
| G. ruber pink | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. ruber white | | | | | | | | | | | | | 1 | 1 | | | | | | | | | | | | | | 2 |
| G. rubescens | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. sacculifer | | | | | | | 1 | | | | | | | 1 | | | | | 1 | | 1 | | | | | | | 1 |
| G. sacculifer (ws) | | | | | | | | | | | | | | | | | | | 1 | | | | | | | | | |
| G. scitula | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. siphonifera | | | | | 2 | | | | | | | | | | | | | | | | | | | | | | | |
| G. tenella | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. tumida | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. truncatulinoides d. | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. truncatulinoides s. | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. ungulata | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. uvula | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| H. pelagica | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| N. dutertrei | | | | | 1 | | | | 3 | | | | 2 | 1 | | | | | | | | | | | | | | |
| N. incompta | | | | | | | | | | | | | | | | | | | | | | | | | | | 1 | |
| O. universa | 2 | | 2 | | | | | | | | | | | | | | | | | | | | | | | | | |
| P. obliquiloculata | | | | | 1 | | | | | | | | | | | | | | | | | | | | | | | |
| S. dehiscens | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| T. parkerae | | | | | | | | | | | | | 2 | | | | | | | | | | | | | | | |
| T. quinqueloba | | | | | | | | | | | | | | | | | | | | | | | | | | | 2 | 9 |
| unidentified/juveniles | | | | | | | | | | | | | | 2 | | | | | | | | | | 1 | | | 3 | |

ws = with sac-like chamber; d. = dextral/s. = sinistral; cb = cytoplasm bearing (alive)/wc = without cytoplasm (empty test)

**Table A.3:** Foraminiferal census data. Plankton samples

| Planktonic species | M78/1 >500 cb | wc | M78/1 400–500 cb | wc | M78/1 300–400 cb | wc | M78/1 250–300 cb | wc | M78/1 150–250 cb | wc | M78/1 125–150 cb | wc | M78/1 100–125 cb | wc | M94 0–20 cb | wc | M94 20–40 cb | wc | M94 40–60 cb | wc | M94 60–100 cb | wc | M95 0–20 cb | wc | M95 20–40 cb | wc | M95 40–60 cb | wc |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date | 19.03.2009 | | 19.03.2009 | | 19.03.2009 | | 19.03.2009 | | 19.03.2009 | | 19.03.2009 | | 19.03.2009 | | 18.03.2013 | | 18.03.2013 | | 18.03.2013 | | 18.03.2013 | | 01.04.2013 | | 01.04.2013 | | 01.04.2013 | |
| Station | 222-6 | | 222-6 | | 222-6 | | 222-6 | | 222-6 | | 222-6 | | 222-6 | | 474 | | 474 | | 474 | | 474 | | 487 | | 487 | | 487 | |
| Device | MSN | | MSN | | MSN | | MSN | | MSN | | MSN | | MSN | | AN | | AN | | AN | | AN | | AN | | AN | | AN | |
| Sampling interval (m) | 180–300 | | 180–300 | | 180–300 | | 180–300 | | 180–300 | | 180–300 | | 180–300 | | 0–20 | | 20–40 | | 40–60 | | 60–100 | | 0–20 | | 20–40 | | 40–60 | |
| Size-class (µm) | >500 | | 400–500 | | 300–400 | | 250–300 | | 150–250 | | 125–150 | | 100–125 | | >100 | | >100 | | >100 | | >100 | | >100 | | >100 | | >100 | |
| C. nitida | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| D. anfracta | | | | | | | | | | | | | | | | | | | | | | | 2 | | | | | |
| G. bulloides | | | | | | | | | | 14 | | | | | 2 | | | | 2 | | 3 | | 6 | | 3 | | | |
| G. calida | | | | | | | 1 | | | | | | | | 30 | | | | | | | | | | | | | |
| G. conglobatus | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. crassaformis | | | 4 | | | | | | 28 | 3 | 4 | | | | | | | | | | | | | | | | | |
| G. elongatus | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. falconensis | | | | | | | | | | | | | | | 2 | | | | | | | | | | | | | |
| G. glutinata | | | | | | | 1 | | 2 | 1 | 2 | | 2 | 11 | 42 | 1 | 3 | | 3 | | 3 | | 6 | | 6 | | 5 | |
| G. hirsuta | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| T. humilis | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| T. iota | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. menardii | | | | | | | | | | | | | | | 2 | | 3 | | 2 | | | | | | | | 1 | |
| G. minuta | | | | | | | | | | | | | 1 | | | | | | | | | | | | | | | |
| G. ruber (p/w) | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. ruber pink | | | | | | | | | | | | | | | 18 | 1 | 4 | 1 | 2 | | 3 | 1 | 5 | | 5 | | 2 | |
| G. ruber white | | | | | | | | | | | | | | | 7 | | | | | | | | 9 | | 3 | | | |
| G. rubescens | | | | | | | | | | 1 | 1 | | | 1 | 2 | | | | | | | | 7 | | 3 | | 7 | |
| G. sacculifer | | | | | | | | | | 4 | | | | | 32 | 2 | 5 | | 4 | | 3 | | 15 | | 2 | | 2 | |
| G. sacculifer (ws) | | | 1 | | | | | 2 | | 1 | | | | | | | | | | | | | | | | | | |
| G. scitula | | | | | | | 3 | | 3 | | 2 | | 5 | | 4 | | 6 | | | | | | 4 | | | | 3 | |
| G. siphonifera | | | | | | | | | | | | | | | 4 | 1 | | | | | 1 | | 4 | | | | | |
| G. tenella | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. tumida | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. truncatulinoides d. | | | 1 | | 1 | | | | 1 | | | | | | | | | | | | | | | | | | | |
| G. truncatulinoides s. | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. ungulata | | | | | | | | | | | | | | | 15 | | 10 | | 6 | | 4 | | | | | | | |
| G. uvula | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| H. pelagica | 1 | | | | 1 | | 2 | | 3 | | | | | | | | | | | | | | | | | | | |
| N. dutertrei | | | | | | | | | | 1 | | | | 1 | 10 | 1 | 6 | 1 | 2 | | 2 | | 3 | | 1 | | | |
| N. incompta | | | | | | | | | | | | | | | | | | | | | 3 | | | | | | | |
| O. universa | | | | | | | | | | | | | | | | | | | 2 | | 3 | 1 | | | | | 2 | |
| P. obliquiloculata | | | | | | | | | | | | | | | 4 | | | | | | | | | | 2 | | 2 | |
| S. dehiscens | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| T. parkerae | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| T. quinqueloba | 1 | | | | | | | | | | | | 6 | 11 | 2 | | | | | | | | 2 | | 1 | | 2 | |
| unidentified/juveniles | | | | | | | | | 4 | | 4 | | 2 | 3 | | | | | | 1 | | | 4 | | | | 3 | |

ws = with sac-like chamber; d. = dextral/s. = sinistral; cb = cytoplasm bearing (alive)/wc = without cytoplasm (empty test)

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**Table A.3:** Foraminiferal census data. Plankton samples

| Cruise | M95 | | M95 | | M95 | | M95 | | M95 | | M95 | | M95 | | M95 | | M95 | | M95 | | M95 | | M95 | | M78/1 | | M78/1 | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Date | 01.04.2013 | | 05.04.2013 | | 05.04.2013 | | 05.04.2013 | | 09.04.2013 | | 09.04.2013 | | 09.04.2013 | | 09.04.2013 | | 17.04.2013 | | 17.04.2013 | | 17.04.2013 | | 17.04.2013 | | 24.02.2009 | | 24.02.2009 | |
| Station | 487 | | 506 | | 506 | | 506 | | 531 | | 531 | | 531 | | 531 | | 584 | | 584 | | 584 | | 584 | | 1* | | 2* | |
| Device | AN | | AN | | AN | | AN | | AN | | AN | | AN | | AN | | AN | | AN | | AN | | AN | | PF | | PF | |
| Sampling interval (m) | 60–100 | | 20–40 | | 40–60 | | 60–100 | | 0–20 | | 20–40 | | 40–60 | | 60–100 | | 0–20 | | 20–40 | | 40–60 | | 60–100 | | 3.5 | | 3.5 | |
| Size-class (µm) | >100 | | >100 | | >100 | | >100 | | >100 | | >100 | | >100 | | >100 | | >100 | | >100 | | >100 | | >100 | | >100 | | >100 | |
| Planktonic species | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc |
| C. nitida | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| D. anfracta | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. bulloides | | | | | | | | | | | | | 2 | | 2 | | | | | | | | | | | 8 | | |
| G. calida | 4 | | 6 | | | | 2 | | 1 | | 1 | | 3 | | 5 | | 1 | | | | 2 | | 4 | | 3 | 3 | | 1 |
| G. conglobatus | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. crassaformis | | | | | | | | | | | | | | | | | | | | | | | | | | | | 1 |
| G. elongatus | | | | | | | | | | | | | | | | | | | | | | | | | | 1 | | |
| G. falconensis | | | | | | | | | | | | 1 | | | | | | | | | | | | | | | | |
| G. glutinata | 12 | | 10 | 1 | | | 3 | | 6 | | 29 | | 22 | | 16 | | 2 | | 1 | | 6 | | 5 | 1 | | 20 | 8 | 1 |
| G. hirsuta | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| T. humilis | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| T. iota | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. menardii | | | | | | | | | | | 1 | | 2 | | 2 | | 1 | | 2 | | 2 | | | | 1 | | | |
| G. minuta | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. ruber (p/w) | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. ruber pink | 1 | | 3 | | | | | | 4 | | 2 | | 6 | | 5 | | | | | | | | | | 3 | 3 | 6 | 1 |
| G. ruber white | 2 | | 4 | 1 | 1 | | | | 3 | | 8 | | 8 | | 5 | | | | | | 1 | | | | 1 | | | |
| G. rubescens | 22 | | 3 | | | 1 | | 1 | | | 7 | | 10 | 1 | 9 | | 1 | 1 | 2 | | 1 | | 2 | 1 | 5 | 4 | 6 | 1 |
| G. sacculifer | 6 | | 9 | | 1 | | 3 | | 3 | | 7 | | 5 | | 10 | | 1 | | 1 | | 1 | | | | 12 | 19 | 7 | 3 |
| G. sacculifer (ws) | | | | | | | | | | | | | | | 1 | | | | | | | | | | | | | |
| G. scitula | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. siphonifera | 2 | | | | 2 | | 2 | | | | 1 | | | | 1 | | | | 2 | | 2 | | 2 | | | | | |
| G. tenella | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. tumida | | | | 1 | | | | | | | | | | | | | | | | | | | | | | | | |
| G. truncatulinoides d. | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. truncatulinoides s. | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. ungulata | | | | | | | | | 4 | | 4 | | | | | | | | | | 3 | | 2 | | 3 | | 4 | 1 |
| G. uvula | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| H. pelagica | | | | | | | | | | | | | 1 | | 2 | | | | | | | | | | | | | |
| N. dutertrei | 3 | | 1 | 1 | | | 2 | | 4 | | 5 | | 7 | 1 | 6 | | | | | | | | | | 2 | 3 | | |
| N. incompta | | | | | | | | | | | | | | | | | | | | | | | | 2 | | | | |
| O. universa | 2 | | | | | | 1 | | | | | | 4 | | 3 | | | | | | | | 1 | | | | | |
| P. obliquiloculata | | | | | | | | | | | | | | | 1 | | | | | | | | | | | | | |
| S. dehiscens | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| T. parkerae | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| T. quinqueloba | 2 | | 1 | | | | 3 | | | | 3 | | 3 | | 16 | | 1 | | | | 1 | | 1 | | 1 | 2 | 1 | |
| unidentified/juveniles | 2 | | 1 | | | | | | 2 | | 3 | | 4 | | 8 | 2 | | | | | 2 | | 2 | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Bolivina variabilis* | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Meroplanktonic species | | | | | | | | | | | | | | | | | | | | | | | | | 3 | | 1 | |

* = ½ Split; ws = with sac-like chamber; d. = dextral/s. = sinistral; cb = cytoplasm bearing (alive)/wc = without cytoplasm (empty test)

**Table A.3:** Foraminiferal census data. Plankton samples

| Cruise | M78/1 | | M78/1 | | M78/1 | | M78/1 | | M78/1 | | M78/1 | | M78/1 | | M78/1 | | M78/1 | | M78/1 | | M78/1 | | M78/1 | | M78/1 | | M78/1 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date | 25.02.2009 | | 27.02.2009 | | 27.02.2009 | | 01.03.2009 | | 03.03.2009 | | 04.03.2009 | | 04.03.2009 | | 05.03.2009 | | 06.03.2009 | | 06.03.2009 | | 06.03.2009 | | 06.03.2009 | | 06.03.2009 | | 06.03.2009 | |
| Station | 3* | | 4* | | 5* | | 6* | | 7* | | 8* | | 9* | | 10* | | 11* | | 12* | | 13* | | 14* | | 15* | | 16* | |
| Device | PF | | PF | | PF | | PF | | PF | | PF | | PF | | PF | | PF | | PF | | PF | | PF | | PF | | PF | |
| Sampling interval (m) | 3.5 | | 3.5 | | 3.5 | | 3.5 | | 3.5 | | 3.5 | | 3.5 | | 3.5 | | 3.5 | | 3.5 | | 3.5 | | 3.5 | | 3.5 | | 3.5 | |
| Size-class (µm) | >100 | | >100 | | >100 | | >100 | | >100 | | >100 | | >100 | | >100 | | >100 | | >100 | | >100 | | >100 | | >100 | | >100 | |
| **Planktonic species** | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc |
| *C. nitida* | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *D. anfracta* | | | | | | | | | | 1 | | | | | | | | | | | | | | | | | | |
| *G. bulloides* | | | | | | | | | | | 1 | | | | 1 | | 1 | 2 | 6 | | 3 | | 3 | | | 3 | | 2 |
| *G. calida* | 8 | | 3 | | 5 | | 7 | | 8 | 2 | | | 5 | | 1 | | 5 | | 7 | | 5 | | 9 | 1 | | | | |
| *G. conglobatus* | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *G. crassaformis* | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *G. elongatus* | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *G. falconensis* | | | | | | | | | | | | | 1 | | | | | | | | | | | | 2 | | | |
| *G. glutinata* | 6 | | 2 | | 4 | | 3 | | 5 | 1 | 12 | | 7 | 1 | | | 7 | | 3 | | 10 | | 14 | | 7 | | 3 | |
| *G. hirsuta* | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *T. humilis* | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *T. iota* | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *G. menardii* | 2 | | | | | | | | 1 | | 1 | | 1 | | 2 | | | | 3 | | 1 | | 2 | | | | 4 | |
| *G. minuta* | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *G. ruber* (p/w) | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *G. ruber* pink | 10 | | 2 | | 3 | 1 | 4 | 3 | 8 | | 2 | 2 | 1 | | | | 1 | | 2 | 1 | | | | | 3 | | 2 | 1 |
| *G. ruber* white | 1 | | | | 5 | 1 | 3 | 2 | 6 | | | | | | 1 | | | | 3 | | 1 | | 2 | | 1 | | 1 | |
| *G. rubescens* | 2 | | 2 | | 1 | | 2 | 1 | 2 | 2 | 1 | 1 | | | | | 2 | 2 | | | | | | | | | 1 | |
| *G. sacculifer* | 19 | 3 | 3 | | 6 | 4 | 5 | 1 | 8 | 1 | 3 | | 3 | | 2 | | 2 | | 3 | | 2 | | 6 | | 5 | 1 | 2 | |
| *G. sacculifer* (ws) | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *G. scitula* | | | | | | | 2 | | | | | | | | | | 2 | | | | | | | | | | | |
| *G. siphonifera* | | | | | | | | | | | | | | | | | | | | | 1 | | | | 7 | | | |
| *G. tenella* | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *G. tumida* | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *G. truncatulinoides* d. | | | | | | | | | | | 2 | | | | 1 | | 2 | | 2 | | 2 | | 1 | | | | | |
| *G. truncatulinoides* s. | | | | | | | | | | | | | | | | | | | 3 | 2 | | | | | | | | |
| *G. ungulata* | 13 | | 1 | | 11 | | 10 | | 24 | | 2 | | | | 1 | | 5 | | 2 | | 5 | | 5 | | 1 | | | |
| *G. uvula* | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *H. pelagica* | 1 | | | | | | | | | | | | 1 | | | | 2 | | 2 | | 1 | | 1 | | 1 | | | |
| *N. dutertrei* | 1 | | 2 | | 1 | 1 | 3 | | 1 | | 7 | 2 | 3 | | 3 | | 5 | | 11 | | 15 | | 16 | | 15 | | 6 | |
| *N. incompta* | | | 1 | | 1 | | | | | | | | | | | | | | 3 | | | | | | | | | |
| *O. universa* | | | 1 | | | | | | | | | | | | | | 3 | | 3 | | 3 | | 2 | | 2 | 2 | | |
| *P. obliquiloculata* | | | | | | | 1 | | 1 | | 1 | | 3 | | 1 | | 2 | | 3 | | | | | | 4 | | | |
| *S. dehiscens* | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *T. parkerae* | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *T. quinqueloba* | | | 1 | | | | | | | | | | | | | | 2 | 1 | | | | | 1 | | 3 | | | |
| unidentified/juveniles | | | 1 | | 3 | | | | 2 | 1 | 1 | 1 | 1 | | 2 | | 2 | | 3 | | 2 | | 1 | | 4 | | 1 | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Bolivina variabilis* | | | | | | | | | | | | | | | | | 1 | | | | 1 | | | | | | | |
| Meroplanktonic species | 8 | | 3 | | 2 | | 1 | 1 | 2 | | 1 | | | | | | 1 | | | | | | | | | | | |

\* = ½ Split; ws = with sac-like chamber; d. = dextral/s. = sinistral; cb = cytoplasm bearing (alive)/wc = without cytoplasm (empty test)

**Table A.3:** Foraminiferal census data. Plankton samples

| Cruise | M78/1 | | M78/1 | | M78/1 | | M78/1 | | M78/1 | | M78/1 | | M78/1 | | M78/1 | | M78/1 | | M78/1 | | M78/1 | | M78/1 | | M78/1 | | M78/1 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date | 07.03.2009 | | 07.03.2009 | | 07.03.2009 | | 07.03.2009 | | 07.03.2009 | | 08.03.2009 | | 10.03.2009 | | 12.03.2009 | | 12.03.2009 | | 13.03.2009 | | 13.03.2009 | | 14.03.2009 | | 17.03.2009 | | 18.03.2009 | |
| Station | 17* | | 18* | | 19* | | 20* | | 21* | | 23* | | 24* | | 25* | | 26* | | 27* | | 28* | | 29* | | 31* | | 32* | |
| Device | PF | | PF | | PF | | PF | | PF | | PF | | PF | | PF | | PF | | PF | | PF | | PF | | PF | | PF | |
| Sampling interval (m) | 3.5 | | 3.5 | | 3.5 | | 3.5 | | 3.5 | | 3.5 | | 3.5 | | 3.5 | | 3.5 | | 3.5 | | 3.5 | | 3.5 | | 3.5 | | 3.5 | |
| Size-class (μm) | >100 | | >100 | | >100 | | >100 | | >100 | | >100 | | >100 | | >100 | | >100 | | >100 | | >100 | | >100 | | >100 | | >100 | |
| **Planktonic species** | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc |
| *C. nitida* | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *D. anfracta* | | | 2 | | 2 | | | | | | | | | | | | | | | | | | | | | | | |
| *G. bulloides* | | | 3 | | 6 | | 2 | | 2 | | | | | | | | | | | | | | | | | | 2 | |
| *G. calida* | 1 | | 3 | | 4 | | 2 | | 2 | | 1 | | 7 | | 2 | | 2 | | 1 | | 1 | | 2 | | 7 | | 8 | 1 |
| *G. conglobatus* | | | | | | | | | | | | | | | | | | | | | | | | | 1 | | | |
| *G. crassaformis* | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *G. elongatus* | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *G. falconensis* | | | | | 2 | 1 | | | | | | | | | | | | | | | | | | | | | | |
| *G. glutinata* | 5 | | 13 | | 14 | | 3 | | 1 | | 2 | | 6 | | | | 2 | | 2 | | | | 6 | | 26 | | 38 | 1 |
| *G. hirsuta* | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *T. humilis* | | | | | | | | | | | | | | | | | 2 | | | | | | | | | | | |
| *T. iota* | | | | | | | 2 | | 2 | | | | | | | | | | | | | | | | | | | 1 |
| *G. menardii* | | | 3 | | 1 | | 2 | | | | | | | | | | | | | | | | | | | | 2 | |
| *G. minuta* | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *G. ruber* (p/w) | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *G. ruber* pink | 1 | | 1 | | 1 | | 2 | | | | | | 9 | 3 | 1 | | | | 2 | | 1 | | 7 | | 12 | 3 | 11 | 3 |
| *G. ruber* white | | | 1 | | 1 | | 1 | | | | 3 | 2 | 5 | 1 | | | | | | | 1 | | 1 | | 3 | | 2 | 1 |
| *G. rubescens* | | | | | | 1 | | | | | | | 3 | 1 | | | | | 1 | | | | 6 | 2 | 4 | | | |
| *G. sacculifer* | 6 | | 5 | | 6 | | 3 | | 1 | | | | 11 | 2 | 3 | 1 | | | 3 | | 1 | | 19 | 1 | 11 | 1 | 16 | 3 |
| *G. sacculifer* (ws) | | | | | | | | | | | | | | | | | | | | | | | | 2 | | | | |
| *G. scitula* | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *G. siphonifera* | | | 2 | | | | | | | | | | | | | | | | 2 | | | | | | | | | |
| *G. tenella* | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *G. tumida* | | | 1 | | 3 | | | | | | | | | | | | | | 3 | | | | | | | | | |
| *G. truncatulinoides* d. | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *G. truncatulinoides* s. | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *G. ungulata* | | | 2 | | 5 | | 1 | | | | 2 | | 3 | | | | | | | | | | | | | | | |
| *G. uvula* | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *H. pelagica* | | | | | | 1 | | | | | | | 1 | | | | | | 2 | | | | | | | | | |
| *N. dutertrei* | 2 | | 7 | | 7 | | 3 | | 6 | | 1 | | 1 | | 1 | | 1 | | | | | | | | 3 | | 1 | |
| *N. incompta* | 1 | | 2 | | 5 | | 1 | | 1 | | | | 1 | | | | 1 | | | | | | | | 3 | | 5 | 1 |
| *O. universa* | | | | | | | | 1 | | | | | | | | | | | | | | | | | 1 | | | |
| *P. obliquiloculata* | | | 5 | | 3 | | 2 | | | | | | | | | | | | | | | | | | 3 | | | |
| *S. dehiscens* | | | | | | | | | | | | | | | 1 | | | | | | | | | | | | | |
| *T. parkerae* | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *T. quinqueloba* | | | 2 | | 2 | | | | 2 | | | | 3 | | | | | | | | | | | | 4 | 1 | 2 | |
| unidentified/juveniles | 3 | | 3 | | 2 | | 2 | | 2 | | | | | | | | | | | | | | 12 | | 149 | | 3 | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Bolivina variabilis* | | | | | | | | | 1 | | 1 | | 1 | | | | 1 | | | | | | | | | | 40 | |
| Meroplanktonic species | | | | | | | | | | | | | | | | | | | 2 | | | | | | | | | |

* = ½ Split; ws = with sac-like chamber; d. = dextral/s. = sinistral; cb = cytoplasm bearing (alive)/wc = without cytoplasm (empty test)

**Table A.3:** Foraminiferal census data. Plankton samples

| Cruise | M78/1 | | M78/1 | | M78/1 | | M78/1 | | M78/1 | | M78/1 | | M78/1 | | M78/1 | | M78/1 | | M78/1 | | M78/1 | | M78/1 | | M78/1 | | M78/1 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date | 19.03.2009 | | 20.03.2009 | | 20.03.2009 | | 21.03.2009 | | 21.03.2009 | | 21.03.2009 | | 21.03.2009 | | 22.03.2009 | | 22.03.2009 | | 23.03.2009 | | 23.03.2009 | | 25.03.2009 | | 26.03.2009 | | 26.03.2009 | |
| Station | 33* | | 34* | | 35* | | 36* | | 37* | | 38* | | 39* | | 40* | | 41* | | 42* | | 43* | | 44* | | 45* | | 46* | |
| Device | PF | | PF | | PF | | PF | | PF | | PF | | PF | | PF | | PF | | PF | | PF | | PF | | PF | | PF | |
| Sampling interval (m) | 3.5 | | 3.5 | | 3.5 | | 3.5 | | 3.5 | | 3.5 | | 3.5 | | 3.5 | | 3.5 | | 3.5 | | 3.5 | | 3.5 | | 3.5 | | 3.5 | |
| Size-class (µm) | >100 | | >100 | | >100 | | >100 | | >100 | | >100 | | >100 | | >100 | | >100 | | >100 | | >100 | | >100 | | >100 | | >100 | |
| **Planktonic species** | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc |
| *C. nitida* | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *D. anfracta* | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *G. bulloides* | | | | | | | | | | | | | | | | | | | | 1 | | | | | | | | |
| *G. calida* | | | 1 | | 2 | | | | | | | | | | | | 2 | | 6 | | 3 | | 2 | | | | | |
| *G. conglobatus* | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *G. crassaformis* | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *G. elongatus* | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *G. falconensis* | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *G. glutinata* | 23 | | 3 | | 25 | | 4 | 1 | 3 | | | | 1 | | 11 | | 6 | | 34 | | 36 | 4 | 33 | 5 | | | | |
| *G. hirsuta* | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *T. humilis* | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *T. iota* | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *G. menardii* | | | | | | | | | | | | | | | | | | | | | 1 | | 2 | 1 | | | | |
| *G. minuta* | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *G. ruber* (p/w) | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *G. ruber* pink | 7 | | 7 | | 15 | | 1 | | | | | | | | 1 | | 8 | | 8 | | 10 | 3 | 17 | 2 | | | | 1 |
| *G. ruber* white | | | | | | 1 | | | | | | | | | | | | | 3 | | 5 | | 9 | 1 | | | | |
| *G. rubescens* | | | | | 3 | 2 | | | | | | | | | 2 | 1 | 6 | | 7 | | | | 2 | 4 | | | | |
| *G. sacculifer* | 7 | | | | 23 | | | | | | | | | | 8 | | 17 | | 35 | | 48 | 5 | 30 | 5 | | | | 1 |
| *G. sacculifer* (ws) | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *G. scitula* | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *G. siphonifera* | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *G. tenella* | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *G. tumida* | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *G. truncatulinoides* d. | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *G. truncatulinoides* s. | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *G. ungulata* | 1 | | 1 | | 2 | | | | | | | | | | | | 1 | | 2 | | | | | 1 | | | | |
| *G. uvula* | | | | | | | 1 | | | | | | | | | | | | | | | | | | | | | |
| *H. pelagica* | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *N. dutertrei* | 5 | | 2 | | 15 | | 3 | | | | | 1 | | | 6 | | 5 | | 10 | | 8 | 4 | 1 | | | | | |
| *N. incompta* | | | | | | | | | | | | | | | | | | | | | 2 | 1 | 10 | | | | | |
| *O. universa* | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *P. obliquiloculata* | | | 1 | | 1 | | | | | | | | | | | | | | | | | | | | | | | |
| *S. dehiscens* | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *T. parkerae* | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *T. quinqueloba* | 1 | | | | 1 | | 1 | | 1 | 1 | | | | | 2 | 2 | 3 | | 4 | | | | | | | | | |
| unidentified/juveniles | | | | | | | 1 | | | | | | | | 1 | | | | 3 | | | | | 3 | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Bolivina variabilis* | 3 | | | | | | 4 | | 2 | | 17 | | 2 | | 5 | | 1 | | 3 | | | | | | | | | |
| Meroplanktonic species | 7 | | 10 | | 18 | | 6 | | 8 | | 11 | | 4 | | 22 | | 4 | | 12 | | 24 | | 50 | | 15 | | 21 | |

\* = ½ Split; ws = with sac-like chamber; d. = dextral/s. = sinistral; cb = cytoplasm bearing (alive)/wc = without cytoplasm (empty test)

**Table A.3:** Foraminiferal census data. Plankton samples

Cruise / Station / Date — Device: PF; Sampling interval: 3.5 m; Size-class: >100 µm (all stations)

- St. 47*: Cruise M78/1, 26.03.2009
- St. 2: M94, 14.03.2013
- St. 3: M94, 14.03.2013
- St. 4: M94, 15.03.2013
- St. 5: M94, 15.03.2013
- St. 6: M94, 16.03.2013
- St. 7: M94, 16.03.2013
- St. 8: M94, 17.03.2013
- St. 9: M94, 17.03.2013
- St. 10: M94, 18.03.2013
- St. 11: M94, 19.03.2013
- St. 13: M94, 20.03.2013
- St. 14: M94, 20.03.2013
- St. 15: M94, 21.03.2013

| Planktonic species | 47* cb | 47* wc | 2 cb | 2 wc | 3 cb | 3 wc | 4 cb | 4 wc | 5 cb | 5 wc | 6 cb | 6 wc | 7 cb | 7 wc | 8 cb | 8 wc | 9 cb | 9 wc | 10 cb | 10 wc | 11 cb | 11 wc | 13 cb | 13 wc | 14 cb | 14 wc | 15 cb | 15 wc |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C. nitida | | | | | | | | | | | | | | | | | | | | | | | | | 1 | | | |
| D. anfracta | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. bulloides | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. calida | | | 5 | | | | 3 | 2 | 12 | | 3 | | 11 | | 4 | | 8 | | 5 | 1 | | | 5 | | 9 | | 13 | |
| G. conglobatus | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. crassaformis | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. elongatus | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. falconensis | | | | 1 | | | | | | | | | 1 | | | | | | | | | | | | | | | |
| G. glutinata | 4 | | 5 | | 16 | | 11 | 5 | 28 | 4 | 7 | 1 | 24 | 2 | 4 | 2 | 8 | | 11 | | | | 3 | | 9 | 1 | 13 | |
| G. hirsuta | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| T. humilis | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| T. iota | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. menardii | | | | | 5 | | 2 | | 4 | | 3 | | 4 | | 1 | | | | 1 | | 3 | | 3 | | | | 4 | |
| G. minuta | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. ruber (p/w) | 2 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. ruber pink | | | 7 | | 10 | | 6 | 3 | 14 | | 14 | | 25 | | | | | | 3 | | | | 1 | | | 1 | | |
| G. ruber white | | | 2 | | 4 | | 1 | | 3 | | 1 | | 1 | | 1 | | 2 | | 2 | 2 | 2 | | | | | | 2 | |
| G. rubescens | | | 5 | | 6 | | 1 | 3 | 3 | 1 | 6 | 1 | 23 | 1 | 6 | 1 | | | | | | | | | | | | 1 |
| G. sacculifer | 3 | | 18 | | 16 | | 28 | | 17 | 3 | 22 | | 44 | 4 | | | 4 | | 6 | | 2 | | 3 | | 4 | | 9 | |
| G. sacculifer (ws) | | | | 2 | | | | | | | | | | | | | | | | | | | | | | | | |
| G. scitula | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. siphonifera | | | | | | | | | | | | | 1 | | | | | | | | | | 1 | | | | | |
| G. tenella | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. tumida | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. truncatulinoides d. | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. truncatulinoides s. | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. ungulata | | | 4 | | 11 | | 13 | | 8 | | 3 | | 10 | | 15 | | 3 | | 13 | | 9 | | 4 | | | | 8 | |
| G. uvula | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| H. pelagica | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| N. dutertrei | | | 3 | | | | 4 | 2 | 3 | | 2 | | 2 | | 3 | | 4 | | 7 | | 4 | | 3 | | | | 7 | |
| N. incompta | 1 | | | | | | | | | | | | 1 | | 1 | | | | | | 1 | | | | | | | |
| O. universa | | | | | | | | | | | | | 1 | | | | | | | | | | | | | | | |
| P. obliquiloculata | | | | | | | | | | | 1 | | | 1 | 1 | 1 | | | 1 | | 3 | | | | 1 | | 2 | 1 |
| S. dehiscens | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| T. parkerae | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| T. quinqueloba | | | | | | | | | | | | | | | | | | | | | | | | | 1 | | | |
| unidentified/juveniles | | | | | | | | | | | | | | | | | | | | | | | | | | | 1 | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Bolivina variabilis* | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Meroplanktonic species | 17 | | 11 | | 4 | | 2 | | 7 | | 2 | | 6 | | 2 | | 1 | | 6 | | 7 | | | | 2 | | 4 | |

\* = ½ Split; ws = with sac-like chamber; d. = dextral/s. = sinistral; cb = cytoplasm bearing (alive)/wc = without cytoplasm (empty test)

**Table A.3:** Foraminiferal census data. Plankton samples

| | 16 cb | 16 wc | 17 cb | 17 wc | 18 cb | 18 wc | 19 cb | 19 wc | 1 cb | 1 wc | 2 cb | 2 wc | 3 cb | 3 wc | 4 cb | 4 wc | 5 cb | 5 wc | 6 cb | 6 wc | 7 cb | 7 wc | 8 cb | 8 wc | 9 cb | 9 wc | 10 cb | 10 wc |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Cruise** | M94 | | M94 | | M94 | | M94 | | M95 | | M95 | | M95 | | M95 | | M95 | | M95 | | M95 | | M95 | | M95 | | M95 | |
| **Date** | 21.03.2013 | | 22.03.2013 | | 22.03.2013 | | 23.03.2013 | | 01.04.2013 | | 02.04.2013 | | 02.04.2013 | | 03.04.2013 | | 03.04.2013 | | 05.04.2013 | | 06.04.2013 | | 06.04.2013 | | 07.04.2013 | | 07.04.2013 | |
| **Station** | 16 | | 17 | | 18 | | 19 | | 1 | | 2 | | 3 | | 4 | | 5 | | 6 | | 7 | | 8 | | 9 | | 10 | |
| **Device** | PF | | PF | | PF | | PF | | PF | | PF | | PF | | PF | | PF | | PF | | PF | | PF | | PF | | PF | |
| **Sampling interval (m)** | 3.5 | | 3.5 | | 3.5 | | 3.5 | | 3.5 | | 3.5 | | 3.5 | | 3.5 | | 3.5 | | 3.5 | | 3.5 | | 3.5 | | 3.5 | | 3.5 | |
| **Size-class (µm)** | >100 | | >100 | | >100 | | >100 | | >100 | | >100 | | >100 | | >100 | | >100 | | >100 | | >100 | | >100 | | >100 | | >100 | |
| **Planktonic species** | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc |
| *C. nitida* | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *D. anfracta* | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *G. bulloides* | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *G. calida* | 7 | | 4 | | 4 | | 6 | | 6 | | | | 1 | | | | 1 | | 3 | | 3 | | 5 | | 4 | | 8 | 1 |
| *G. conglobatus* | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *G. crassaformis* | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *G. elongatus* | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *G. falconensis* | | | | | | | | | | | | | 1 | | | | | | | | | | 1 | | | | | |
| *G. glutinata* | 6 | | 6 | 2 | 5 | 2 | 3 | | 19 | 1 | 10 | | 4 | 2 | 1 | | 2 | | | | 8 | | 14 | | 12 | | 12 | |
| *G. hirsuta* | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *T. humilis* | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *T. iota* | 1 | | | | | | | | 1 | | | | | | | | | | 2 | | | | | | | | | |
| *G. menardii* | | | 3 | | 4 | | 1 | | | | | | | | | | | | | | | | | | | | | |
| *G. minuta* | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *G. ruber (p/w)* | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *G. ruber pink* | 5 | | 1 | | | | | | 8 | 1 | 4 | | 10 | | | | | | 2 | | 1 | | 10 | | 1 | | 5 | 1 |
| *G. ruber white* | 2 | | | 1 | | | | | 10 | 1 | 2 | | 8 | 1 | 3 | | 3 | | 4 | | 8 | | 12 | | 14 | | 5 | |
| *G. rubescens* | | | 2 | 1 | 4 | | 1 | | 6 | | | | 4 | 1 | | | | | 8 | | 5 | | 2 | | 3 | 1 | 3 | 1 |
| *G. sacculifer* | 2 | | 1 | | 1 | | 3 | | 8 | | 3 | | 18 | | 5 | | 3 | | 9 | 1 | 13 | | 9 | | 5 | | 16 | |
| *G. sacculifer* (ws) | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *G. scitula* | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *G. siphonifera* | | | | | | | 2 | | | | | | | | | | | | | | | | | | | | | |
| *G. tenella* | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *G. tumida* | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *G. truncatulinoides* d. | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *G. truncatulinoides* s. | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *G. ungulata* | 3 | | 8 | | 2 | | 2 | | 2 | | | | | | | | | | | | | | | 1 | 2 | | 2 | |
| *G. uvula* | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *H. pelagica* | | | | | 1 | | | | | | | | | | | | | | 1 | | | | | | | | | |
| *N. dutertrei* | 3 | | 8 | | 1 | | 2 | | 6 | 3 | 1 | | 3 | | | | 1 | | 2 | | 5 | | 3 | | 9 | | 4 | |
| *N. incompta* | 1 | | 3 | | | | | | | | | | | | 2 | | | | | | | | | | | | | |
| *O. universa* | | | | | | | | | | | | | | | | | 1 | | | | 2 | | | | | 1 | | |
| *P. obliquiloculata* | 1 | | | | | | | | | | | | | | 2 | | 1 | | | | 2 | | | | | | | |
| *S. dehiscens* | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *T. parkerae* | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *T. quinqueloba* | | | | | | | | | 1 | | | | 4 | | | | 1 | | 1 | | 3 | | | | | 1 | | |
| unidentified/juveniles | | | | 1 | 3 | | | 1 | 3 | | 1 | | 5 | | | | | | 5 | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Bolivina variabilis* | | | | | | | | | 3 | | 3 | | 2 | | 1 | | 3 | | 25 | | 7 | | 4 | | 3 | | 12 | |
| Meroplanktonic species | | | 40 | | 11 | | 4 | | 7 | | 10 | | 17 | | 8 | | 3 | | 18 | | 24 | | 22 | | 19 | | 12 | |

\* = ½ Split; ws = with sac-like chamber; d. = dextral/s. = sinistral; cb = cytoplasm bearing (alive)/wc = without cytoplasm (empty test)

**Table A.3:** Foraminiferal census data. Plankton samples

| Cruise | M95 | | M95 | | M95 | | M95 | | M95 | | M95 | | M95 | | M95 | | M95 | | M95 | | M95 | | M95 | | M95 | | M95 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date | 08.04.2013 | | 10.04.2013 | | 10.04.2013 | | 11.04.2013 | | 12.04.2013 | | 12.04.2013 | | 13.04.2013 | | 14.04.2013 | | 14.04.2013 | | 15.04.2013 | | 15.04.2013 | | 16.04.2013 | | 17.04.2013 | | 18.04.2013 | |
| Station | 11 | | 13 | | 14 | | 16 | | 17 | | 18 | | 19 | | 20 | | 21 | | 22 | | 23 | | 25 | | 26 | | 27 | |
| Device | PF | | PF | | PF | | PF | | PF | | PF | | PF | | PF | | PF | | PF | | PF | | PF | | PF | | PF | |
| Sampling interval (m) | 3.5 | | 3.5 | | 3.5 | | 3.5 | | 3.5 | | 3.5 | | 3.5 | | 3.5 | | 3.5 | | 3.5 | | 3.5 | | 3.5 | | 3.5 | | 3.5 | |
| Size-class (µm) | >100 | | >100 | | >100 | | >100 | | >100 | | >100 | | >100 | | >100 | | >100 | | >100 | | >100 | | >100 | | >100 | | >100 | |
| **Planktonic species** | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc |
| C. nitida | | | | | | | | | | | | | 1 | | | | | | | | | | | | | | | |
| D. anfracta | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. bulloides | | | | | | | | 2 | | | 1 | | | | | | | | 2 | | | | | | | | | |
| G. calida | | | 7 | | 3 | | 4 | | 3 | | 5 | | 9 | | | | | | | | | | 1 | | 4 | | | |
| G. conglobatus | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. crassaformis | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. elongatus | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. falconensis | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. glutinata | 11 | | 33 | | 11 | | 25 | | 12 | | 13 | 1 | 11 | | 6 | | | | 2 | | 2 | | 9 | 1 | 7 | 1 | 11 | |
| G. hirsuta | | | | 6 | | | | | | | | | | | 1 | | | | | | | | 1 | | | 1 | | |
| T. humilis | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| T. iota | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. menardii | 3 | | | | | | 2 | | 3 | | 4 | | 5 | | | | | | 2 | | 1 | | | | 1 | | 4 | 2 |
| G. minuta | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. ruber (p/w) | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. ruber pink | 2 | | 7 | 2 | 3 | | 2 | 2 | 1 | | 3 | | 5 | | 1 | | | | 1 | | | | 6 | | 1 | | | |
| G. ruber white | 7 | | 11 | | 2 | | 4 | 1 | 2 | | 7 | | 2 | | 3 | | 1 | | 3 | | | | 4 | | 1 | | | |
| G. rubescens | | | 7 | | | | 4 | 1 | 1 | | 2 | | 1 | | 1 | | | | 2 | | | | 3 | | | | 1 | |
| G. sacculifer | 4 | | 7 | | | | 3 | 1 | 2 | | 10 | | 15 | | 1 | | 1 | | 1 | | 2 | | 3 | | 2 | | | |
| G. sacculifer (ws) | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. scitula | | | | | | | | | | | | | | | | | | | | | | | 1 | | | | | |
| G. siphonifera | | | | | | | | | | | | | 4 | | | | | | | | | | | | | | | |
| G. tenella | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. tumida | | | | | | | | | | | | | | | | | | | 1 | | 1 | | | | | | | |
| G. truncatulinoides d. | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. truncatulinoides s. | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. ungulata | 7 | | 7 | 2 | 2 | | 11 | | | | 1 | | 1 | | 3 | | 5 | | 3 | | | | 1 | | 6 | | 1 | |
| G. uvula | | | | | | | | | | | | | | | 1 | | | | | | | | | | | | | |
| H. pelagica | | | | | | | | | | | | | | | | | | | | | | | | | | | 1 | 1 |
| N. dutertrei | 4 | | 5 | 3 | 2 | | 5 | 3 | 1 | 3 | 3 | | 9 | 2 | 4 | 1 | | | 4 | 1 | 1 | | 2 | | 8 | 1 | 5 | 1 |
| N. incompta | 2 | | | | | | 1 | 4 | 1 | | | | | | | | | | | 1 | | | | | | | | |
| O. universa | 1 | | | | | | | | 1 | | | | | | | | | | | | | | | | | | | |
| P. obliquiloculata | | | | 1 | 1 | | | | | | 1 | | | | | | | | | | | | | | | | 1 | |
| S. dehiscens | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| T. parkerae | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| T. quinqueloba | | | | | 1 | | 2 | | | | | | | | | | | | | | | | 1 | | | | 1 | |
| unidentified/juveniles | | | | | 1 | | | | | | | | | | | | | | | | | | | | | | | 1 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Bolivina variabilis* | 4 | | 16 | | 6 | | 7 | | 20 | | 23 | | 15 | | 29 | | 38 | | 64 | | 36 | | 33 | | 83 | | 99 | |
| Meroplanktonic species | 22 | | 90 | | 26 | | 92 | | 120 | | 149 | | 220 | | 283 | 5 | 390 | | 520 | | 444 | | 482 | | 805 | | 1124 | |

\* = ½ Split; ws = with sac-like chamber; d. = dextral/s. = sinistral; cb = cytoplasm bearing (alive)/wc = without cytoplasm (empty test)

**Table A.3:** Foraminiferal census data. Plankton samples

| Cruise | M95 | | M95 | |
|---|---|---|---|---|
| Date | 18.04.2013 | | 19.04.2013 | |
| Station | 28 | | 29 | |
| Device | PF | | PF | |
| Sampling interval (m) | 3.5 | | 3.5 | |
| Size-class (μm) | >100 | | >100 | |
| **Planktonic species** | cb | wc | cb | wc |
| *C. nitida* | | | | |
| *D. anfracta* | | | | |
| *G. bulloides* | | | | |
| *G. calida* | 3 | | 1 | |
| *G. conglobatus* | | | | |
| *G. crassaformis* | | | | |
| *G. elongatus* | | | | |
| *G. falconensis* | | | | |
| *G. glutinata* | 2 | | 16 | 6 |
| *G. hirsuta* | | | | |
| *T. humilis* | | | | |
| *T. iota* | | | | |
| *G. menardii* | 1 | | 6 | |
| *G. minuta* | | | | |
| *G. ruber* (p/w) | 4 | | | |
| *G. ruber* pink | 3 | | | |
| *G. ruber* white | 3 | | 1 | |
| *G. sacculifer* | 2 | | 2 | |
| *G. sacculifer* (ws) | | | | |
| *G. scitula* | | | | |
| *G. siphonifera* | | | | |
| *G. tenella* | | | | |
| *G. tumida* | | | | |
| *G. truncatulinoides* d. | | | | |
| *G. truncatulinoides* s. | | | | |
| *G. ungulata* | 1 | | | |
| *G. uvula* | | | | |
| *H. pelagica* | | | 1 | |
| *N. dutertrei* | | | 5 | 2 |
| *N. incompta* | | | | |
| *O. universa* | | | | |
| *P. obliquiloculata* | | | 2 | |
| *S. dehiscens* | | | | |
| *T. parkerae* | | | | |
| *T. quinqueloba* | | | | |
| unidentified/juveniles | | | | 2 |
| *Bolivina variabilis* | 22 | | 100 | |
| Meroplanktonic species | 244 | | 1647 | |

\* = ½ Split; ws = with sac-like chamber; d. = dextral/s. = sinistral; cb = cytoplasm bearing (alive)/wc = without cytoplasm (empty test)

**Table A.3:** Foraminiferal census data. Plankton samples

| Cruise | M78/1 | | M78/1 | | M78/1 | | M78/1 | | M78/1 | | M78/1 | | M78/1 | | M78/1 | | M78/1 | | M78/1 | | M78/1 | | M78/1 | | M78/1 | | M78/1 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date | 26.02.2009 | | 26.02.2009 | | 26.02.2009 | | 26.02.2009 | | 26.02.2009 | | 26.02.2009 | | 26.02.2009 | | 27.02.2009 | | 27.02.2009 | | 27.02.2009 | | 27.02.2009 | | 27.02.2009 | | 27.02.2009 | | 27.02.2009 | |
| Station | 164-6 | | 164-6 | | 164-6 | | 164-6 | | 164-6 | | 164-6 | | 164-6 | | 164-7 | | 164-7 | | 164-7 | | 164-7 | | 164-7 | | 164-7 | | 164-7 | |
| Device | PP | | PP | | PP | | PP | | PP | | PP | | PP | | PP | | PP | | PP | | PP | | PP | | PP | | PP | |
| Sampling interval (m) | 160 | | 160 | | 160 | | 160 | | 160 | | 160 | | 160 | | 80 | | 80 | | 80 | | 80 | | 80 | | 80 | | 80 | |
| Size-class (μm) | >500 | | 400-500 | | 300-400 | | 250-300 | | 150-250 | | 125-150 | | 100-125 | | >500 | | 400-500 | | 300-400 | | 250-300 | | 150-250 | | 125-150 | | 100-125 | |
| Planktonic species | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc |
| C. nitida | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| D. anfracta | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. bulloides | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. calida | | | | | | | | | | | | | 1 | | | | | | | | | | | | | | 5 | |
| G. conglobatus | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. crassaformis | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. elongatus | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. falconensis | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. glutinata | | | | | | | | | | | | | | | | | | | | | | | 1 | | | | 15 | |
| G. hirsuta | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| T. humilis | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| T. iota | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. menardii | | | | | | | | | | | | | | | | | | | | | | | 1 | | | | | |
| G. minuta | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. ruber (p/w) | | | | | | | | | 1 | 1 | | | | | | | | | | | 4 | | 7 | | 3 | | 3 | |
| G. ruber pink | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. ruber white | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. rubescens | | | | | | | | | 1 | | | | | | | | | | | | | | | | 2 | | 8 | |
| G. sacculifer | | | | | | | | | 1 | | | | | | | | | | 1 | | | | 7 | | 2 | | 4 | |
| G. sacculifer (ws) | | | | | | | | | | | 1 | | | | | | | | | | | | | | | | | |
| G. scitula | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. siphonifera | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. tenella | | | | | | | | | 1 | | | | | | | | | | | | | | | | | | | |
| G. tumida | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. truncatulinoides d. | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. truncatulinoides s. | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. ungulata | | | | | | | | | | | | | 1 | | | | | | | | | | 6 | | 7 | | 8 | |
| G. uvula | | | | | | | | | 3 | | | | | | | | | | | | | | | | | | | |
| H. pelagica | | | | | | | | | | | | | | | | | | | 1 | | 2 | | 2 | | | | | |
| N. dutertrei | | | | | | | | | | | | | | | | | | | | | | | | | | | 1 | |
| N. incompta | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| O. universa | | | | | | | | | | | | | | | 1 | | | | | | | | | | | | | |
| P. obliquiloculata | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| S. dehiscens | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| T. parkerae | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| T. quinqueloba | | | | | | | | | | | | | | | | | | | | | | | | | 1 | | | |
| unidentified/juveniles | | | | | | | | | | | | | | | | | | | | | | | | | | | 14 | |

\* = ½ Split; ws = with sac-like chamber; d. = dextral/s. = sinistral; cb = cytoplasm bearing (alive)/wc = without cytoplasm (empty test)

**Table A.3:** Foraminiferal census data. Plankton samples

| | 191-5 >500 cb | 191-5 >500 wc | 191-5 400-500 cb | 191-5 400-500 wc | 191-5 300-400 cb | 191-5 300-400 wc | 191-5 250-300 cb | 191-5 250-300 wc | 191-5 150-250 cb | 191-5 150-250 wc | 191-5 125-150 cb | 191-5 125-150 wc | 191-5 100-125 cb | 191-5 100-125 wc | 247-2* >500 cb | 247-2* >500 wc | 247-2* 400-500 cb | 247-2* 400-500 wc | 247-2* 300-400 cb | 247-2* 300-400 wc | 247-2* 250-300 cb | 247-2* 250-300 wc | 247-2* 150-250 cb | 247-2* 150-250 wc | 247-2* 125-150 cb | 247-2* 125-150 wc | 247-2* 100-125 cb | 247-2* 100-125 wc |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Cruise** | M78/1 | | M78/1 | | M78/1 | | M78/1 | | M78/1 | | M78/1 | | M78/1 | | M78/1 | | M78/1 | | M78/1 | | M78/1 | | M78/1 | | M78/1 | | M78/1 | |
| **Date** | 06.03.2009 | | 06.03.2009 | | 06.03.2009 | | 06.03.2009 | | 06.03.2009 | | 06.03.2009 | | 06.03.2009 | | 25.03.2009 | | 25.03.2009 | | 25.03.2009 | | 25.03.2009 | | 25.03.2009 | | 25.03.2009 | | 25.03.2009 | |
| **Station** | 191-5 | | 191-5 | | 191-5 | | 191-5 | | 191-5 | | 191-5 | | 191-5 | | 247-2* | | 247-2* | | 247-2* | | 247-2* | | 247-2* | | 247-2* | | 247-2* | |
| **Device** | PP | | PP | | PP | | PP | | PP | | PP | | PP | | PP | | PP | | PP | | PP | | PP | | PP | | PP | |
| **Sampling interval (m)** | 140 | | 140 | | 140 | | 140 | | 140 | | 140 | | 140 | | 41 | | 41 | | 41 | | 41 | | 41 | | 41 | | 41 | |
| **Size-class (µm)** | >500 | | 400-500 | | 300-400 | | 250-300 | | 150-250 | | 125-150 | | 100-125 | | >500 | | 400-500 | | 300-400 | | 250-300 | | 150-250 | | 125-150 | | 100-125 | |
| | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc |
| **Planktonic species** | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| C. nitida | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| D. anfracta | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. bulloides | | | | | | | 1 | | 1 | 1 | | 3 | | 2 | | | | | | | | | | | | | | |
| G. calida | | | | | | | | | 2 | 1 | | | | | | | | | 1 | | | | | | | | | |
| G. conglobatus | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. crassaformis | | | | | 1 | | | | | | | | | | | | | | | | | | | | | | | |
| G. elongatus | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. falconensis | | | | | | | | | | | | | 3 | | | | | | | | | | | | | | | |
| G. glutinata | | | | | | | 1 | | 1 | | 4 | | 4 | | | | | | | | | | | | | | | |
| G. hirsuta | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| T. humilis | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| T. iota | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. menardii | | | | | | | | | 1 | | 1 | | 1 | | | | | | | | | | | | | | | |
| G. minuta | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. ruber (p/w) | | | | | | | | | | | 1 | | | | | | | | | | | | | | | | | |
| G. ruber pink | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. ruber white | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. rubescens | | | | | | | | | | | | 1 | 3 | 3 | | | | | | | | | | | | | | |
| G. sacculifer | | | | | | | | | | | | | 1 | 1 | | | | | 2 | | | | | | | | | |
| G. sacculifer (ws) | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. scitula | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. siphonifera | | | | | | | | | | | | | | | 3 | | 1 | | 3 | | 1 | | | | | | | |
| G. tenella | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. tumida | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. truncatulinoides d. | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. truncatulinoides s. | | | | | 1 | | 1 | | | | | | | | | | | | | | | | | | | | | |
| G. ungulata | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G. uvula | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| H. pelagica | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| N. dutertrei | | | | | | | | | 1 | | | | 1 | | 1 | | | | | | | | | | | | | |
| N. incompta | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| O. universa | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| P. obliquiloculata | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| S. dehiscens | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| T. parkerae | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| T. quinqueloba | | | | | | | | | | | | | | 2 | | | | | | | | | | | | | | 2 |
| unidentified/juveniles | | | | | | | 1 | | 3 | | 3 | | 4 | | | | | | | | | | | | | | | |

\* = ½ Split; ws = with sac-like chamber; d. = dextral/s. = sinistral; cb = cytoplasm bearing (alive)/wc = without cytoplasm (empty test)

**Table A.3:** Foraminiferal census data. Plankton samples

| Cruise | M78/1 | | M78/1 | | M78/1 | | M78/1 | | M78/1 | | M78/1 | | M78/1 | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Date | 25.03.2009 | | 25.03.2009 | | 25.03.2009 | | 25.03.2009 | | 25.03.2009 | | 25.03.2009 | | 25.03.2009 | |
| Station | 247-2* | | 247-2* | | 247-2* | | 247-2* | | 247-2* | | 247-2* | | 247-2* | |
| Device | PP | | PP | | PP | | PP | | PP | | PP | | PP | |
| Sampling interval (m) | 42 | | 42 | | 42 | | 42 | | 42 | | 42 | | 42 | |
| Size-class (µm) | >500 | | 400-500 | | 300-400 | | 250-300 | | 150-250 | | 125-150 | | 100-125 | |
| Planktonic species | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc | cb | wc |
| C. nitida | | | | | | | | | | | | | | |
| D. anfracta | | | | | | | | | | | | | | |
| G. bulloides | | | | | | | | | | | | | | |
| G. calida | | | 1 | | | | | 1 | | | | | | |
| G. conglobatus | | | | | | | | | | | | | | |
| G. crassaformis | | | | | | | | | | | | | | |
| G. elongatus | | | | | | | | | | | | | | |
| G. falconensis | | | | | | | | | | | | | | |
| G. glutinata | | | | | | | | | 1 | | | | | |
| G. hirsuta | | | | | | | | | | | | | | |
| T. humilis | | | | | | | | | | | | | | |
| T. iota | | | | | | | | | | | | | | |
| G. menardii | | | | | | | | | 1 | | | | | |
| G. minuta | | | | | | | | | | | | | | |
| G. ruber (p/w) | | | | | | | | | | | | | | |
| G. ruber pink | | | | | | | | | | | | | | |
| G. ruber white | | | | | | | | | | | | | | |
| G. rubescens | | | | | | | | | | | | | | |
| G. sacculifer | | | | | | | | | | | | | | |
| G. sacculifer (ws) | | | | | | | | | | | | | | |
| G. scitula | | | | | | | | | | | | | | |
| G. siphonifera | | | 1 | 1 | | 1 | | | | | | | | |
| G. tenella | | | | | | | | | | | | | | |
| G. tumida | | | | | | | | | | | | | | |
| G. truncatulinoides d. | | | | | | | | | | | | | | |
| G. truncatulinoides s. | | | | | | | | | | | | | | |
| G. ungulata | | | | | | | | | | | | | | |
| G. uvula | | | | | | | | | | | | | | |
| H. pelagica | | | | | | | | | | | | | | |
| N. dutertrei | | | | | | | | | | | | | | |
| N. incompta | | | | | | | | | | | | | | |
| O. universa | | | | | | | | | | | | | | |
| P. obliquiloculata | | | | | | | | | | | | | | |
| S. dehiscens | | | | | | | | | | | | | | |
| T. parkerae | | | | | | | | | | | | | | |
| T. quinqueloba | | | | | | | | | | | 1 | | | |
| unidentified/juveniles | | | | | | | | | | | | | | |

* = ½ Split; ws = with sac-like chamber; d. = dextral/s. = sinistral; cb = cytoplasm bearing (alive)/wc = without cytoplasm (empty test)

**Table A.3:** Foraminiferal census data. Sediment samples

| Cruise | SO164 | SO164 | SO164 | SO164 | SO164 | SO164 | SO164 | SO164 | SO164 | SO164 | SO164 | SO164 | SO164 | SO164 | SO164 | SO164 | SO164 | SO164 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date | 27.05.02 | 27.05.02 | 27.05.02 | 27.05.02 | 27.05.02 | 27.05.02 | 27.05.02 | 07.06.02 | 07.06.02 | 07.06.02 | 07.06.02 | 07.06.02 | 07.06.02 | 07.06.02 | 09.06.02 | 09.06.02 | 09.06.02 | 09.06.02 |
| Station | 02-3 | 02-3 | 02-3 | 02-3 | 02-3 | 02-3 | 02-3 | 22-2 | 22-2 | 22-2 | 22-2 | 22-2 | 22-2 | 22-2 | 24-3 | 24-3 | 24-3 | 24-3 |
| Device | MUC | MUC | MUC | MUC | MUC | MUC | MUC | MUC | MUC | MUC | MUC | MUC | MUC | MUC | MUC | MUC | MUC | MUC |
| Split | 1/32 | 1/32 | 1/32 | 1/32 | 1/32 | 1/32 | 1/32 | 1/512 | 1/512 | 1/512 | 1/512 | 1/512 | 1/512 | 1/512 | 1/512 | 1/512 | 1/512 | 1/512 |
| Dry sediment weigth (g) | 1.66 | 1.66 | 1.66 | 1.66 | 1.66 | 1.66 | 1.66 | 7.3 | 7.3 | 7.3 | 7.3 | 7.3 | 7.3 | 7.3 | 7.6 | 7.6 | 7.6 | 7.6 |
| Size-class (μm) | >500 | 400–500 | 300–400 | 250–300 | 150–250 | 125–150 | 100–125 | >500 | 400–500 | 300–400 | 250–300 | 150–250 | 125–150 | 100–125 | >500 | 400–500 | 300–400 | 250–300 |
| C. nitida | | | | | | | | | | | | | | | | | 1 | |
| D. anfracta | | | | | | 1 | 1 | | | | | | | | | | | |
| G. bulloides | | | | 3 | | 1 | 1 | | | | | | | | | | | |
| G. calida | | 1 | | 2 | 7 | 7 | 1 | 1 | | | 5 | 2 | 6 | 4 | | | | |
| G. conglobatus | | 1 | | | | | | | | | | | | | | | | |
| G. crassaformis | | | | | | | | | 3 | | 4 | 3 | | | | 1 | | |
| G. elongatus | | 2 | | 1 | | | | | | | 9 | 5 | | | | | 1 | 5 |
| G. falconensis | | | 1 | | 2 | | | | | | | | | | | | 1 | |
| G. glutinata | | | 1 | 22 | 75 | 148 | | | | | | 38 | 18 | 77 | | | | |
| G. inflata | | | | | | | | | | | | | | | | | | |
| G. menardii | 2 | | 1 | 3 | 4 | 3 | | 6 | 3 | | 2 | 2 | | 5 | | 1 | 1 | |
| G. minuta | | | | | | | | | | | | | | | 3 | | | |
| G. ruber pink | 2 | 6 | 2 | 15 | 5 | 6 | | | 4 | 12 | 13 | 15 | 1 | | | 3 | 17 | 30 |
| G. ruber white | | 3 | 12 | 42 | 16 | 5 | | | 2 | 3 | 1 | 51 | 17 | 3 | | 1 | 5 | 9 |
| G. rubescens | | | 1 | 7 | 24 | 26 | | | | | | | 10 | 11 | | | | |
| G. sacculifer | 7 | 5 | 3 | 5 | 11 | 17 | | | 1 | 22 | 12 | 19 | 7 | 3 | | 3 | 13 | 1 |
| G. sacculifer (ws) | 1 | 4 | 1 | | | | | | 5 | 5 | | | | | 1 | 5 | 8 | |
| G. scitula | | | | 2 | 1 | 3 | | | | | | 4 | 4 | | | | | |
| G. siphonifera | | | | 1 | | 1 | | | 4 | 4 | | 2 | | | | 1 | 5 | 4 |
| G. tenella | | | | | | | | | | | | | | | | | | |
| G. tumida | 1 | | | | | | | 1 | | 3 | | | | | | | | |
| G. truncatulinoides d. | | | | | | | | 2 | | 2 | | | | | | | | |
| G. truncatulinoides s. | | | | | | | | | | 1 | | | | | | | | |
| G. ungulata | | | | | | | | | 2 | | | 4 | | 3 | | | | |
| G. uvula | | | | | | | | | | | | | | | | | | |
| H. pelagica | | | | | | | | | | | | | | | 1 | | | |
| N. dutertrei | 1 | 4 | | | 1 | | | 7 | 9 | 11 | 6 | | 6 | | 1 | 2 | 2 | 3 |
| N. incompta | | | | | | | | | | | 2 | | 2 | | | | | 1 |
| O. universa | 1 | | | | | | | | 2 | | | | | | 1 | 2 | | |
| P. obliquiloculata | | | | | | | | 2 | 2 | | | | | | 1 | 3 | | |
| S. dehiscens | | | | | | | | 2 | | | | | | | | | | |
| T. parkerae | | | | | | | | 2 | | | | | | | | | | |
| T. quinqueloba | | | | | 3 | 22 | | | | | | | | 4 | | | | |
| unidentified | | | | 1 | | | | | 2 | 2 | | 2 | | | | | | |

ws = with sac-like chamber; d. = dextral/s. = sinistral

**Table A.3:** Foraminiferal census data. Sediment samples

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Cruise** | M78/1 | M78/1 | M78/1 | M78/1 | M78/1 | M78/1 | M78/1 | M78/1 | M78/1 | M78/1 | M78/1 | M78/1 | M78/1 | M78/1 | SO164 | SO164 | SO164 |
| **Date** | 19.03.09 | 19.03.09 | 19.03.09 | 19.03.09 | 19.03.09 | 19.03.09 | 19.03.09 | 10.03.09 | 10.03.09 | 10.03.09 | 10.03.09 | 10.03.09 | 10.03.09 | 10.03.09 | 09.06.02 | 09.06.02 | 09.06.02 |
| **Station** | 222-8 | 222-8 | 222-8 | 222-8 | 222-8 | 222-8 | 222-8 | 212-1 | 212-1 | 212-1 | 212-1 | 212-1 | 212-1 | 212-1 | 24-3 | 24-3 | 24-3 |
| **Device** | GKG | GKG | GKG | GKG | GKG | GKG | GKG | MUC | MUC | MUC | MUC | MUC | MUC | MUC | MUC | MUC | MUC |
| **Split** | 1/128 | 1/128 | 1/128 | 1/128 | 1/128 | 1/128 | 1/128 | 1/512 | 1/512 | 1/512 | 1/512 | 1/512 | 1/512 | 1/512 | 1/512 | 1/512 | 1/512 |
| **Dry sediment weight (g)** | 2.54 | 2.54 | 2.54 | 2.54 | 2.54 | 2.54 | 2.54 | 8.9 | 8.9 | 8.9 | 8.9 | 8.9 | 8.9 | 8.9 | 7.6 | 7.6 | 7.6 |
| **Size-class (μm)** | 100–125 | 125–150 | 150–250 | 250–300 | 300–400 | 400–500 | >500 | 100–125 | 125–150 | 150–250 | 250–300 | 300–400 | 400–500 | >500 | 100–125 | 125–150 | 150–250 |
| C. nitida | | | | | | | | | | 1 | 1 | | | | | | 1 |
| D. anfracta | | | | | | | | | | | | | | | | | |
| G. bulloides | | 7 | 13 | | | | | | | 3 | 3 | | | 1 | | | |
| G. calida | | | 23 | | 1 | | | | 5 | 12 | 3 | 7 | 1 | 1 | 1 | 7 | 5 |
| G. conglobatus | | | | | | | | | | | | 1 | | | | | |
| G. crassaformis | | | 6 | | 9 | | | | 1 | 3 | 1 | 6 | | | | 2 | 2 |
| G. elongatus | | | 7 | | | | | | | 33 | 9 | 2 | | | | | 3 |
| G. falconensis | | 3 | | | | | | | | 3 | 1 | 3 | | | | | |
| G. glutinata | 44 | 12 | 32 | | | | | 19 | 3 | 23 | | | | | 92 | 57 | 34 |
| G. inflata | | | | | | | | | | | | | | | | | |
| G. menardii | 4 | | | 4 | | | | | 1 | | 1 | 1 | 4 | 5 | 1 | 1 | 1 |
| G. minuta | | | | | | | | | | | 3 | 2 | | | | | |
| G. ruber pink | 5 | | 13 | 3 | | | | 2 | 3 | 20 | 29 | 16 | 2 | | 8 | 5 | 21 |
| G. ruber white | | | 24 | 4 | 5 | | | 1 | 5 | 39 | 20 | 7 | 1 | | 3 | 12 | 48 |
| G. rubescens | | | | | | | | 6 | 7 | 5 | 4 | | | | 11 | 11 | 3 |
| G. sacculifer | 4 | 8 | 28 | 4 | | | | 2 | 3 | 19 | 23 | 13 | 6 | 3 | | 3 | 9 |
| G. sacculifer (ws) | | | | 5 | 4 | | | | | 1 | 5 | 13 | 8 | 3 | | | 1 |
| G. scitula | | | | | | | | | | 1 | | | | | | | 1 |
| G. siphonifera | | | | | | | | | | | | 2 | 1 | 1 | | 3 | 4 |
| G. tenella | | | | | | | | | | | 1 | | | | 1 | | |
| G. tumida | | | | | | | | | | | | | | 1 | | | |
| G. truncatulinoides d. | | | | | | | | | 1 | 1 | 3 | 1 | 1 | | | | |
| G. truncatulinoides s. | | | | | | | | | | | 1 | | | | | | |
| G. ungulata | | | | | | | | | | | | 3 | | | | | |
| G. uvula | | | | | | | | | | | | | | | | | |
| H. pelagica | | | | | | | | | | | | | | | | | |
| N. dutertrei | | | 5 | 6 | 3 | 8 | | | 1 | 2 | 2 | 20 | 10 | | 1 | 4 | 13 |
| N. incompta | | | 4 | | | | | | | 3 | 3 | 2 | | | | | |
| O. universa | | | | | | | 5 | | | | 1 | 4 | 2 | 2 | | | |
| P. obliquiloculata | | | | | | | | | | | | 4 | 3 | 1 | | | |
| S. dehiscens | | | | | | | | | | | | | | | | | |
| T. parkerae | | | | | | | | | | | | | | | | | |
| T. quinqueloba | 15 | | | | | | | 3 | | | | | | | 12 | 2 | |
| unidentified | | | | | | | | | | | | | | | | | 3 |

ws = with sac-like chamber; d. = dextral/s. = sinistral

**Table A.4:** Output of the multivariate multiple regression analyses using PAST software (Hammer et al., 2001).

Results for the MSN samples (14 species)

|  | $R^2$ | F | df1 | df2 | p |
|---|---|---|---|---|---|
| Temperature | 0.81 | 3.2 | 14 | 10 | 0.03 |
| Salinity | 0.76 | 2.3 | 14 | 10 | 0.09 |

Results for the PF samples (27 species)

|  | $R^2$ | F | df1 | df2 | p |
|---|---|---|---|---|---|
| Temperature | 0.91 | 18.52 | 27 | 47 | 0.00 |
| Salinity | 0.36 | 0.99 | 27 | 47 | 0.48 |

**Table A.5:** Bray-Curtis similarity indices for MSN and sediment samples obtained from PAST software (Hammer et al., 2001). The numbers indicate the MSN station numbers during cruise M78/1. P=Plankton samples, S=Sediment samples

|  | 211 P | 211 S | 219 P | 219 S | 220 P | 220 S | 221 P | 221 S | 222 P | 222 S |
|---|---|---|---|---|---|---|---|---|---|---|
| 211 P | 1.00 | 0.66 | 0.58 | 0.46 | 0.58 | 0.62 | 0.54 | 0.54 | 0.64 | 0.55 |
| 211 S | 0.66 | 1.00 | 0.52 | 0.53 | 0.49 | 0.77 | 0.52 | 0.65 | 0.62 | 0.66 |
| 219 P | 0.58 | 0.52 | 1.00 | 0.41 | 0.89 | 0.55 | 0.62 | 0.44 | 0.66 | 0.51 |
| 219 S | 0.46 | 0.53 | 0.41 | 1.00 | 0.47 | 0.71 | 0.72 | 0.77 | 0.61 | 0.66 |
| 220 P | 0.58 | 0.49 | 0.89 | 0.47 | 1.00 | 0.58 | 0.63 | 0.48 | 0.71 | 0.54 |
| 220 S | 0.62 | 0.77 | 0.55 | 0.71 | 0.58 | 1.00 | 0.68 | 0.80 | 0.74 | 0.77 |
| 221 P | 0.54 | 0.52 | 0.62 | 0.72 | 0.63 | 0.68 | 1.00 | 0.66 | 0.73 | 0.67 |
| 221 S | 0.54 | 0.65 | 0.44 | 0.77 | 0.48 | 0.80 | 0.66 | 1.00 | 0.65 | 0.66 |
| 222 P | 0.64 | 0.62 | 0.66 | 0.61 | 0.71 | 0.74 | 0.73 | 0.65 | 1.00 | 0.74 |
| 222 S | 0.55 | 0.66 | 0.51 | 0.66 | 0.54 | 0.77 | 0.67 | 0.66 | 0.74 | 1.00 |

**Table A.6:** Data (average values) of the Thermosalinograph during cruises M78/1, M94 and M95.

| Cruise | Station Nr. | Temperature (°C) | Salinity (psu) | Cruise | Station Nr. | Temperature (°C) | Salinity (psu) |
|---|---|---|---|---|---|---|---|
| M78/1 | 1  | 26.65 | 35.93 | M94 | 13 | 26.64 | 35.95 |
| M78/1 | 2  | 25.60 | 36.00 | M94 | 14 | 26.89 | 35.88 |
| M78/1 | 3  | 26.87 | 35.54 | M94 | 15 | 26.63 | 35.93 |
| M78/1 | 4  | 26.60 | 35.80 | M94 | 16 | 26.75 | 35.96 |
| M78/1 | 5  | 26.00 | 35.70 | M94 | 17 | 26.72 | 35.96 |
| M78/1 | 6  | 25.50 | 35.70 | M94 | 18 | 26.94 | 35.93 |
| M78/1 | 7  | 24.94 | 35.93 | M94 | 19 | 26.72 | 35.89 |
| M78/1 | 10 | 20.00 | 36.30 | M95 | 1  | 26.84 | 36.39 |
| M78/1 | 11 | 20.00 | 36.40 | M95 | 2  | 25.42 | 36.22 |
| M78/1 | 14 | 19.90 | 36.40 | M95 | 3  | 25.66 | 36.19 |
| M78/1 | 15 | 20.00 | 36.40 | M95 | 4  | 25.64 | 36.12 |
| M78/1 | 16 | 20.10 | 36.40 | M95 | 5  | 25.86 | 36.59 |
| M78/1 | 17 | 20.00 | 36.40 | M95 | 6  | 26.13 | 36.49 |
| M78/1 | 18 | 20.00 | 36.50 | M95 | 7  | 25.75 | 36.14 |
| M78/1 | 19 | 20.50 | 36.40 | M95 | 8  | 25.85 | 36.19 |
| M78/1 | 20 | 20.00 | 36.40 | M95 | 9  | 25.58 | 36.14 |
| M78/1 | 21 | 20.20 | 36.40 | M95 | 10 | 25.86 | 36.96 |
| M78/1 | 23 | 24.40 | 35.90 | M95 | 11 | 25.61 | 36.13 |
| M78/1 | 24 | 24.20 | 35.90 | M95 | 13 | 25.67 | 36.14 |
| M78/1 | 33 | 24.40 | 35.70 | M95 | 14 | 26.19 | 36.12 |
| M78/1 | 34 | 26.00 | 35.20 | M95 | 16 | 25.98 | 36.17 |
| M78/1 | 35 | 25.90 | 35.20 | M95 | 17 | 25.90 | 36.12 |
| M78/1 | 36 | 26.16 | 33.46 | M95 | 18 | 26.25 | 36.17 |
| M78/1 | 37 | 26.30 | 31.10 | M95 | 19 | 26.54 | 36.63 |
| M78/1 | 39 | 25.30 | 33.50 | M95 | 20 | 26.21 | 36.18 |
| M78/1 | 40 | 25.90 | 35.30 | M95 | 21 | 26.48 | 36.19 |
| M78/1 | 41 | 26.70 | 34.60 | M95 | 22 | 26.33 | 36.12 |
| M78/1 | 42 | 26.40 | 34.80 | M95 | 23 | 26.55 | 36.12 |
| M78/1 | 43 | 26.70 | 34.90 | M95 | 25 | 26.94 | 36.14 |
| M78/1 | 44 | 26.90 | 34.90 | M95 | 26 | 26.95 | 36.27 |
| M78/1 | 45 | 27.00 | 34.50 | M95 | 27 | 26.80 | 36.89 |
| M78/1 | 47 | 27.20 | 34.60 | M95 | 28 | 26.86 | 36.28 |
| M94 | 2  | 27.18 | 35.75 | M95 | 29 | 27.12 | 36.82 |
| M94 | 3  | 27.49 | 35.99 |  |  |  |  |
| M94 | 4  | 26.94 | 35.94 |  |  |  |  |
| M94 | 5  | 27.32 | 35.59 |  |  |  |  |
| M94 | 6  | 27.13 | 35.62 |  |  |  |  |
| M94 | 7  | 27.22 | 35.57 |  |  |  |  |
| M94 | 8  | 26.54 | 35.88 |  |  |  |  |
| M94 | 9  | 26.64 | 35.86 |  |  |  |  |
| M94 | 10 | 26.58 | 35.92 |  |  |  |  |
| M94 | 11 | 26.70 | 35.92 |  |  |  |  |

# APPENDIX B

## Supplementary information of Chapter 3

**Table B.1:** Stable oxygen isotope values ($\delta^{18}O_{calcite}$) of foraminiferal calcite from plankton tows and surface sediments. 1 indicates $\delta^{18}O_{calcite}$ from Steph et al. (2009); # indicates stations of cruise SO164.

| Species | Station | Sampling interval (m) | Size-fraction (μm) | Number of specimens/sample | $\delta^{18}O_{calcite}$ (‰ VPDB) |
|---|---|---|---|---|---|
| *G. sacculifer* | 211-6 | 0–60 | >500 | 3 | -1.56 |
| | 211-6 | | | | -1.49 |
| | 211-6 | | | | -1.44 |
| | 211-6 | | | | -1.50 |
| | 211-5 | | | | -1.41 |
| | 211-5 | | | | -1.49 |
| | 211-5 | | | | -1.51 |
| | 211-5 | | | | -1.61 |
| | 211-6 | | | | -1.45 |
| | 211-5 | | 400–500 | 7 | -1.34 |
| | 211-6 | | 300–400 | 6 | -1.59 |
| | 211-6 | 60–100 | >500 | 3 | -1.06 |
| | 211-5 | | | | -1.40 |
| | 211-6 | | | | -1.39 |
| | 211-5 | | | | -1.30 |
| | 211-5 | | 400–500 | 3 | -1.34 |
| | 211-5 | 100–200 | >500 | 3 | -1.26 |
| | 212-1 | Sediment | 355–400 | 30 | -1.02 |
| | 212-1 | | | | -1.37 |
| | 212-1 | | | | -0.95 |
| | 212-1 | | | | -1.43 |
| | 219-7 | 0–60 | >500 | 3 | -1.71 |
| | 219-7 | | | | -1.68 |
| | 219-7 | | | | -1.60 |
| | 219-7 | | | | -1.71 |
| | 219-7 | | | | -1.73 |
| | 219-7 | | 400–500 | 5 | -1.34 |
| | 219-8 | | | 6 | -1.79 |
| | 219-8 | | | 6 | -1.76 |
| | 219-8 | | | 5 | -1.77 |
| | 219-7 | | | 5 | -1.69 |
| | 219-8 | | | 5 | -1.55 |
| | 219-7 | | 300–400 | 10 | -1.56 |
| | 219-7 | | | | -1.55 |
| | 219-8 | | | | -1.71 |
| | 219-8 | | | | -1.89 |
| | 219-7 | 60–125 | >500 | 3 | -1.76 |
| | 219-7 | | | | -1.67 |
| | 219-8 | | | | -1.37 |
| | 219-7 | | | | -1.71 |
| | 219-7 | | | | -1.69 |

**Table B.1:** Continued.

| Species | Station | Sampling interval (m) | Size-fraction (μm) | Number of specimens/sample | $\delta^{18}O_{calcite}$ (‰ VPDB) |
|---|---|---|---|---|---|
| *G. sacculifer* | 219-7 | 60–125 | 400–500 | 5 | -1.39 |
| | 219-7 | | 300–400 | 10 | -1.59 |
| | 219-7 | 125–180 | >500 | 3 | -1.55 |
| | 02-3# | Sediment[1] | 355-400 | | -1.39 |
| | 220-8 | 0–70 | >500 | 3 | -1.65 |
| | 220-9 | | | 5 | -1.88 |
| | 220-9 | | | 5 | -1.97 |
| | 220-9 | | | 5 | -1.92 |
| | 220-9 | | | 5 | -1.93 |
| | 220-8 | | | 5 | -1.88 |
| | 220-8 | | | 5 | -1.79 |
| | 220-8 | | | 5 | -1.65 |
| | 220-9 | | 400–500 | 9 | -1.76 |
| | 220-9 | | | 9 | -1.56 |
| | 220-9 | | | 12 | -1.73 |
| | 220-8 | 70–100 | >500 | 3 | -1.65 |
| | 220-8 | | 400–500 | 5 | -1.47 |
| | 22-2# | Sediment[1] | 355-400 | | -1.25 |
| | 221-8 | 0–40 | >500 | 3 | -1.79 |
| | 221-8 | | 400–500 | 5 | -1.83 |
| | 221-7 | | | 7 | -2.07 |
| | 221-8 | | | 8 | -1.99 |
| | 221-8 | | | 7 | -1.96 |
| | 221-8 | | 300–400 | 9 | -1.94 |
| | 221-8 | | | 9 | -1.99 |
| | 221-8 | | | 9 | -1.98 |
| | 221-8 | | | 9 | -2.03 |
| | 221-8 | | | 7 | -2.08 |
| | 221-8 | | | 7 | -1.96 |
| | 221-7 | 40–60 | 400–500 | 5 | -1.66 |
| | 221-8 | | 300–400 | 6 | -1.66 |
| | 221-8 | 60–150 | 400–500 | 5 | -1.59 |
| | 24-3# | Sediment[1] | 355-400 | | -1.5 |
| | 222-7 | 0–40 | >500 | 3 | -1.52 |
| | 222-6 | | 400–500 | 5 | -1.29 |
| | 222-7 | | 300–400 | 7 | -1.94 |
| | 222-6 | 40–80 | 300–400 | 5 | -1.68 |
| | 222-8 | Sediment | 355-400 | 30 | -1.59 |
| *O. universa* | 211-6 | 0–60 | >500 | 10 | -1.33 |
| | 211-5 | | | 5 | -1.58 |
| | 211-5 | | | 5 | -1.54 |
| | 211-6 | | | 8 | -1.24 |
| | 211-5 | 60–100 | >500 | 5 | -1.23 |
| | 211-5 | | | 5 | -1.20 |
| | 211-6 | | | 5 | -1.39 |
| | 211-6 | | | 10 | -1.24 |
| | 211-6 | 100–200 | >500 | 7 | -0.85 |

**Table B.1:** Continued.

| Species | Station | Sampling interval (m) | Size-fraction (μm) | Number of specimens/sample | $\delta^{18}O_{calcite}$ (‰ VPDB) |
|---|---|---|---|---|---|
| *O. universa* | 212-1 | Sediment | 355–400 | 10 | -0.73 |
| | 220-9 | 0–70 | >500 | 6 | -1.55 |
| | 22-2# | Sediment | 355–400 | 18 | -1.33 |
| | 22-2# | | | | -1.14 |
| | 221-8 | 0–40 | >500 | 10 | -1.82 |
| | 221-7 | | | 9 | -1.84 |
| | 221-8 | 40–60 | >500 | 7 | -1.6 |
| | 221-7 | 60–150 | >500 | 5 | -1.42 |
| | 24-3# | Sediment | 355–400 | 18 | -1.21 |
| | 24-3# | | | | -1.88 |
| | 24-3# | | | | -1.40 |
| *N. dutertrei* | 221-8 | 0–40 | 400–500 | 3 | -1.28 |
| | 221-8 | | 300–400 | 5 | -1.63 |
| | 221-7 | | 250–300 | 6 | -1.65 |
| | 221-7 | | | 5 | -1.81 |
| | 221-8 | | | 6 | -1.25 |
| | 221-8 | | | 6 | -1.77 |
| | 221-8 | 40–60 | 400–500 | 2 | -1.35 |
| | 221-7 | | 300–400 | 3 | -1.58 |
| | 221-7 | | 250–300 | 6 | -2.12 |
| | 221-8 | 60–150 | 400–500 | 2 | -1.28 |
| | 221-8 | | 300–400 | 3 | -1.39 |
| | 221-7 | | 250–300 | 6 | -1.44 |
| | 24-3# | Sediment[1] | 355–400 | | -0.53 |
| | 222-7 | 0–40 | 300–400 | 5 | -1.27 |
| | 222-8 | Sediment | 355–400 | 13 | -0.26 |
| *P. obliquiloculata* | 211-5 | 0–60 | 300–400 | 3 | -0.83 |
| | 212-1 | Sediment | 355–400 | 18 | -0.14 |
| | 212-1 | | | | -0.11 |
| | 212-1 | | | | -0.16 |
| | 219-8 | 60–125 | 300–400 | 3 | -1.15 |
| | 02-3# | Sediment | 355–400 | 12 | -0.87 |
| | 220-8 | 0–70 | 300–400 | 3 | -1.24 |
| | 220-8 | 110–150 | 300–400 | 3 | -0.98 |
| | 22-2# | Sediment | 355–400 | 12 | -0.65 |
| | 22-2# | | | | -0.91 |
| | 22-2# | | | | -0.67 |
| | 221-7 | 0–40 | 300–400 | 3 | -1.48 |
| | 221-8 | | | | -0.23 |
| | 221-8 | | | | -1.47 |
| | 221-8 | 40–60 | 300–400 | 3 | -1.41 |
| | 221-8 | 60–150 | 300–400 | 3 | -1.01 |
| | 221-7 | | | | -0.74 |
| | 221-7 | | | | -1.68 |
| | 24-3# | Sediment | 355–400 | 11 | -0.99 |
| | 24-3# | | | | 0.05 |

**Table B.1:** Continued.

| Species | Station | Sampling interval (m) | Size-fraction (µm) | Number of specimens/sample | $\delta^{18}O_{calcite}$ (‰ VPDB) |
|---|---|---|---|---|---|
| *P. obliquiloculata* | 222-6 | 0–40 | 300–400 | 3 | -1.22 |
| *G. menardii* | 211-6 | 60–100 | 300–400 | 3 | -1.01 |
| | 211-6 | 100–200 | 300–400 | 5 | -0.16 |
| | 212-1<br>212-1<br>212-1 | Sediment | 355–400 | 8 | -0.46<br>-0.85<br>-1.25 |
| | 221-8 | 60–150 | 300–400 | 5 | -1.17 |
| | 221-8 | 150–210 | 400–500 | 2 | -0.87 |
| | 24-3# | Sediment[1] | 355–400 | | -0.24 |
| *G. ungulata* | 211-5<br>211-6<br>211-6<br>211-5 | 0–60 | 400–500 | 4 | -1.08<br>-0.98<br>-0.67<br>-0.70 |
| | 211-6<br>211-5<br>211-5<br>211-6 | | 300–400 | 5<br>4<br>4<br>4 | -1.03<br>-1.14<br>-0.71<br>-0.92 |
| | 211-5<br>211-5<br>211-6<br>211-6<br>211-6 | | 250–300 | 7 | -0.99<br>-1.09<br>-1.06<br>-0.90<br>-0.99 |
| | 211-6<br>211-5<br>211-6 | 60–100 | 300–400 | 5<br>5<br>6 | -0.90<br>-0.88<br>-1.07 |
| | 211-6 | 100–200 | 400–500 | 3 | -0.27 |
| | 211-5<br>211-5<br>211-6 | | 300–400 | 5<br>5<br>4 | -0.20<br>-0.42<br>-0.14 |
| | 212-1<br>212-1<br>212-1<br>212-1 | Sediment | 355–400 | 12 | 0.30<br>-1.20<br>-0.95<br>-0.83 |
| *G. truncatulinoides* dextral | 211-6 | 100–200 | 300–400 | 4 | -0.10 |
| | 211-6 | 200–300 | 300–400 | 2 | 0.89 |
| | 212-1<br>212-1<br>212-1 | Sediment | 355–400 | 7 | 1.35<br>1.29<br>0.95 |
| | 219-7 | 220–400 | 300–400 | 2 | 0.18 |
| | 02-3# | Sediment[1] | 355–400 | | 0.98 |
| | 220-8 | 150–220 | 300–400 | 2 | 0.20 |
| | 22-2# | Sediment[1] | 355–400 | | 0.8 |
| | 221-7 | 150–210 | 300–400 | 4 | 0.01 |
| | 221-7 | 210–300 | 300–400 | 3 | 0.52 |
| | 24-3# | Sediment[1] | 355–400 | | 1.54 |
| *G. tumida* | 219-8 | 180–220 | 400–500 | 2 | -0.88 |
| | 219-8 | 220–400 | 400–500 | 3 | -0.28 |
| | 02-3# | Sediment[1] | 355–400 | | -0.11 |

**Table B.2:** Mg/Ca ratios of foraminiferal calcite measured on bulk foraminiferal samples (ICP-OES) and on single chambers (LA-ICP-MS) from plankton tows and surface sediments. For the LA-ICP-MS measurements, average values (± standard deviation) of all chambers from single specimens are calculated. 2 indicates Mg/Ca ratios from Regenberg et al. (2006), *with dissolution correction (published in Regenberg et al., 2009); # stations of cruise SO164.

| Species | Station | Sampling interval (m) | Size fraction (µm) | Number ind. /sample | Mg/Ca (mmol mol$^{-1}$) ICP-OES | Number of chambers /ind. | Mg/Ca (mmol mol$^{-1}$) LA-ICP-MS |
|---|---|---|---|---|---|---|---|
| *G. sacculifer* | 211-6 | 0–60 | >500 | 12 | 3.95 | | |
| | 211-6 | | | 12 | 3.08 | | |
| | 211-6 | | | 12 | 3.49 | | |
| | 211-6 | | | 12 | 3.26 | | |
| | 211-6 | | | 12 | 3.35 | | |
| | 211-5 | | | 12 | 3.64 | 3 /tri83 | 3.27 ± 0.24 |
| | 211-5 | | | 12 | 3.46 | | |
| | 211-5 | | | 12 | 3.37 | | |
| | 211-5 | | | 12 | 3.26 | | |
| | 211-5 | | | 12 | 3.53 | | |
| | 211-5 | | | 12 | 3.37 | | |
| | 211-6 | | | 12 | 3.6 | | |
| | 211-6 | | | 12 | 3.44 | | |
| | 211-6 | | 400–500 | 42 | 3.51 | | |
| | 211-5/211-6 | | 300–400 | 64 | 3.72 | | |
| | 211-5 | 60–100 | >500 | 12 | 3.44 | 3 /tri85 | 3.95 ± 0.8 |
| | 211-6 | | | 12 | 3.63 | | |
| | 211-6 | | 400–500 | 10 | 3.94 | | |
| | 211-5 | 100–200 | >500 | – | – | 3 /tri87 | 2.48 ± 0.57 |
| | 212-1 | Sediment | 355–400 | 30 | 4.44 | | |
| | 212-1 | | | | 4.17 | | |
| | 212-1 | | | | 4.39 | | |
| | 212-1 | | | | 4.39 | | |
| | 219-7 | 0–60 | >500 | 16 | 3.9 | | |
| | 219-8 | | | | 4.24 | 3 /tri6 | 3.11 ± 0.7 |
| | 219-8 | | | | 4.16 | 3 /tri7 | 3.87 ± 0.2 |
| | 219-7 | | 400–500 | 40 | 4.37 | | |
| | 219-7/219-8 | | 300–400 | 70 | 4.29 | | |
| | 219-8 | 60–125 | >500 | 17 | 4.30 | 3 /tri8 | 3.18 ± 0.62 |
| | 219-7/219-8 | | 400–500 | 24 | 4.22 | | |
| | 219-7/219-8 | | 300–400 | 54 | 4.37 | | |
| | 219-8 | 220–400 | >500 | – | – | 3 /tri12 | 3.86 ± 0.7 |
| | 02-3# | Sediment² | 355–400 | | 4.2 | | |
| | 220-9 | 0–70 | >500 | 10 | 3.87 | 3 /tri2 | 3.72 ± 0.44 |
| | 220-8 | | | 11 | 4.15 | 3 /tri99 | 2.82 ± 0.56 |
| | 220-9 | | | 10 | 4.15 | | |
| | 220-8 | | | 12 | 4.2 | | |
| | 220-8 | | | 12 | 4.14 | | |
| | 220-9 | | | 11 | 4.36 | | |
| | 220-9 | | | 12 | 4.08 | | |
| | 220-8 | | | 11 | 4.0 | | |
| | 220-8 | | 400–500 | 38 | 4.20 | | |
| | 220-8 | | 300–400 | 80 | 3.90 | | |
| | 220-8 | 70–110 | >500 | – | – | 3 /tri100 | 3.12 ± 1.00 |
| | 220-9 | 150–220 | 250–300 | – | – | 2 /tri4 | 3.7 ± 0.02 |
| | 22-2# | Sediment² | 355–400 | | 3.71/4.45* | | |

**Table B.2:** Continued.

| Species | Station | Sampling interval (m) | Size fraction (µm) | Number ind. /sample | Mg/Ca (mmol mol⁻¹) ICP-OES | Number of chambers /ind. | Mg/Ca (mmol mol⁻¹) LA-ICP-MS |
|---|---|---|---|---|---|---|---|
| *G. sacculifer* | 221-8 | 0–40 | >500 | 20 | 4.00 | | |
| | 221-7 | | | | | 3 /tri101 | 4.3 ± 0.25 |
| | 221-7 | | 400–500 | 50 | 4.01 | | |
| | 221-7 | | 300–400 | 86 | 3.91 | | |
| | 221-7 | 40–60 | >500 | - | - | 3 /tri19 | 3.3 ± 0.53 |
| | 221-8 | | 400–500 | 15 | 4.02 | - | |
| | 221-7/221-8 | | 300–400 | 54 | 4.06 | - | |
| | 221-7 | 60–150 | >500 | - | - | 3 /tri20 | 3.8 ± 0.35 |
| | 24-3# | Sediment² | 355–400 | | 4.23 | | |
| | 222-6 | 0–40 | >500 | - | - | 3 /tri110 | 4.0 ± 0.14 |
| | 222-7 | | 400–500 | 12 | 4.55 | | |
| | 222-6 | | 300–400 | 30 | 4.13 | | |
| | 222-7 | 40–80 | 400–500 | - | - | 3 /tri111 | 4.0 ± 0.3 |
| | 222-7 | 80–120 | >500 | - | - | 3 /tri23 | 3.27 ± 0.65 |
| | 222-8 | Sediment | 355–400 | 30 | 3.84 | | |
| *N. dutertrei* | PF 12 | 3.5 | 365 | - | - | 3 /dut116 | 2.7 ± 0.74 |
| | 02-3# | Sediment² | 355–400 | | 2.58/2.86* | | |
| | 22-2# | Sediment² | 355–400 | | 1.84/3.15* | | |
| | 221-7 | 0–40 | 300–400 | | | 3 /dut104 | 1.73 ± 0.38 |
| | 221-7/221-8 | | | 50 | 2.97 | | |
| | 221-7/221-8 | 40–60 | 300–400 | 19 | 4.21 | | |
| | 24-3# | Sediment² | 355–400 | | 2.63 | | |
| | 222-6 | 0–40 | 300–400 | - | - | 3 /dut112 | 2.99 ± 0.77 |
| *G. ungulata* | PF 7 | 3.5 | 425 | - | - | 3 /ung113 | 2.35 ± 0.35 |
| | PF 12 | | 450 | - | - | 3 /ung117 | 2.55 ± 0.15 |
| | 211-5 | 0–60 | >500 | - | - | 2 /ung28 | 3.19 ± 0.32 |
| | 211-5/221-6 | | 400–500 | 14 | 3.39 | | |
| | 211-5/221-6 | | 300–400 | 28 | 3.32 | | |
| | 211-5 | 60–100 | >500 | - | - | 3 /ung29 | 3.22 ± 0.41 |
| | 211-5/211-6 | | 400–500 | 14 | 3.19 | | |
| | 211-5/211-6 | | 300–400 | 22 | 3.33 | | |
| | 211-5 | 100–200 | >500 | - | - | 3 /ung30 | 3.1 ± 0.06 |
| | 211-5/211-6 | | 400–500 | 17 | 3.48 | | |
| | 211-5/211-6 | | 300–400 | 20 | 3.17 | | |
| *O. universa* | 211-6 | 0–60 | >500 | - | - | 3 /uni36 | 10.3 ± 0.33 |
| | 211-6 | 60–100 | >500 | - | - | 3 /uni37 | 10.09 ± 0.54 |
| | 219-8 | 0–60 | >500 | - | - | 3 /uni39 | 9.08 ± 0.95 |
| | 219-7 | 60–125 | >500 | - | - | 3 /uni40 | 7.13 ± 0.68 |
| | 219-7 | 180–220 | >500 | - | - | 3 /uni41 | 8.31 ± 1.5 |
| | 220-8 | 0–70 | >500 | - | - | 3 /uni42 | 8.16 ± 0.50 |
| | 220-8 | 110–150 | >500 | - | - | 3 /uni44 | 7.05 ± 0.18 |
| | 221-8 | 0–40 | >500 | - | - | 3 /uni106 | 7.28 ± 0.06 |
| | 221-8 | 40–60 | >500 | - | - | 3 /uni46 | 8.09 ± 0.4 |
| | 221-8 | 60–150 | >500 | - | - | 3 /uni47 | 9.79 ± 0.4 |
| | 222-7 | 0–40 | >500 | - | - | 3 /uni48 | 6.55 ± 0.16 |
| | 222-7 | 120–180 | >500 | - | - | 3 /uni50 | 5.3 ± 0.08 |

**Table B.2:** Continued.

| Species | Station | Sampling interval (m) | Size fraction (μm) | Mg/Ca (mmol mol$^{-1}$) ICP-OES | Number of chambers /ind. | Mg/Ca (mmol mol$^{-1}$) LA-ICP-MS |
|---|---|---|---|---|---|---|
| *G. menardii* | PF 19 | 3.5 | 355 | – | 3 /men118 | 1.76 ± 0.31 |
| | 211-5 | 100–200 | 300–400 | – | 3 /men91 | 3.45 ± 0.27 |
| | 211-5 | | 300–400 | – | 3 /men92 | 2.62 ± 0.95 |
| | 211-5 | 200–300 | >500 | – | 3 /men31 | 2.8 ± 0.5 |
| | 02-3# | Sediment² | 355–400 | 3.49/3.52* | | |
| | 220-8 | 0–70 | 400–500 | – | 3 /men26 | 2.21 ± 0.17 |
| | 22-2# | Sediment² | 355–400 | 2.20/3.31* | | |
| | 221-7 | 0–40 | 400–500 | – | 3 /men32 | 3.18 ± 0.19 |
| | 221-8 | 60–150 | 400–500 | – | 3 /men105 | 3.36 ± 0.52 |
| | 221-7 | 150–210 | >500 | – | 3 /men34 | 3.24 ± 0.42 |
| | 221-8 | 210–300 | >500 | – | 3 /men35 | 3.69 ± 0.49 |
| | 24-3# | Sediment² | 400–500 | 2.98 | | |
| | 222-6 | 0–40 | 400–500 | – | 3 /men27 | 3.92 ± 0.31 |
| *G. truncatulinoides* | PF 11 | 3.5 | 325 | – | 4 /tdex115 | 3.22 ± 1.56 |
| dextral | 211-5 | 100–200 | 300–400 | – | 3 /tdex90 | 3.0 ± 0.55 |
| | 22-2# | Sediment² | 355-400 | 1.62/2.76* | | |
| | 221-8 | 150–210 | 300–400 | – | 4 /tdex108 | 1.66 ± 0.19 |
| | 221-8 | 210–300 | 400–500 | – | 4 /tdex109 | 2.84 ± 0.53 |
| | 24-3# | Sediment² | 400-500 | 2.28 | | |
| *G. tumida* | 219-8 | 60–125 | >500 | – | 3 /tum61 | 2.45 ± 0.13 |
| | 219-8 | 125–180 | >500 | – | 3 /tum62 | 1.6 ± 0.38 |
| | 219-7 | 180–220 | >500 | – | 3 /tum63 | 2.25 ± 0.35 |
| | 219-7 | 220–400 | >500 | – | 3 /tum64 | 1.57 ± 0.62 |
| | 02-3# | Sediment² | 400–500 | 2.43 | | |
| | 22-2# | Sediment² | 355–400 | 1.95/2.93* | | |
| *P. obliquiloculata* | 221-8 | 0–40 | 400–500 | – | 2 /obli77 | 2.54 ± 0.09 |
| | 221-7 | 40–60 | 400–500 | – | 2 /obli78 | 2.55 ± 0.31 |
| | 222-7 | 0–40 | 300–400 | – | 3 /obli80 | 3.44 ± 1.01 |
| | 222-7 | 40–80 | 300–400 | – | 3 /obli81 | 2.43 ± 0.51 |
| | 222-6 | 80–120 | 300–400 | – | 3 /obli82 | 3.3 ± 0.32 |

**Table B.3:** Stable isotope values in seawater ($\delta^{18}O_{seawater}$), measured temperature (°C) and salinity (psu) during RV Meteor cruise M78/1 (Schönfeld et al., 2011, by courtesy of C. Dullo and S. Flögel).

| Station | Sampling depth (m) | $\delta^{18}O_{seawater}$ (‰ VSMOW) | Temperature (°C) | Salinity (psu) |
|---------|------|------|------|------|
| 210-13 | 40 | 0.98 | 24.8 | 36.0 |
| 210-13 | 85 | 1.02 | 24.2 | 36.2 |
| 210-13 | 100 | 1.01 | 24.0 | 36.8 |
| 210-13 | 150 | 1.05 | 21.0 | 36.4 |
| 210-13 | 190 | 0.92 | 19.2 | 36.4 |
| 210-13 | 275 | 0.75 | 15.9 | 36.1 |
| 210-13 | 400 | 0.45 | 11.8 | 35.4 |
| 219-1 | 50 | 0.96 | 26.1 | 35.9 |
| 219-1 | 100 | 0.94 | 26.1 | 36.0 |
| 219-1 | 220 | 0.96 | 19.5 | 36.6 |
| 219-1 | 600 | 0.27 | 8.5 | 34.9 |
| 220-1 | 10 | 0.97 | 26.2 | 35.7 |
| 220-1 | 61 | 1.02 | 26.1 | 35.7 |
| 220-1 | 91 | 1.21 | 26.1 | 36.8 |
| 220-2 | 136 | 1.17 | 22.1 | 36.8 |
| 220-2 | 196 | 1.04 | 18.4 | 36.5 |
| 220-2 | 485 | 0.3 | 9.3 | 35.0 |
| 221-1 | 10 | 0.97 | 26.4 | 35.5 |
| 221-1 | 30 | 1.01 | 26.4 | 35.5 |
| 221-1 | 60 | 1.21 | 26.5 | 36.6 |
| 221-2 | 100 | 1.28 | 24.0 | 37.2 |
| 221-2 | 150 | 1.11 | 20.2 | 36.8 |
| 221-2 | 200 | 0.99 | 17.7 | 36.4 |
| 221-2 | 500 | 0.31 | 8.9 | 34.9 |
| 222-1 | 10 | 1.0 | 26.5 | 35.7 |
| 222-1 | 30 | 1.0 | 26.6 | 35.7 |
| 222-1 | 55 | 1.12 | 22.7 | 36.7 |
| 222-1 | 75 | 1.11 | 21.8 | 36.8 |
| 222-1 | 140 | 1.04 | 18.3 | 36.5 |
| 222-1 | 229 | 0.74 | 14.4 | 35.7 |

**Table B.4:** Spearman rank correlation obtained from PAST (Hammer et al., 2001).

| Species | $\delta^{18}O_{calcite}$ Two tailed probability | $\delta^{18}O_{calcite}$ Correlation value |
|---------|------|------|
| *G. sacculifer* | 0.00 | 0.34 |
| *G. ungulata* | 0.28 | 0.25 |
| *G. menardii* | 0.9 | -0.1 |
| *N. dutertrei* | 0.04 | 0.57 |
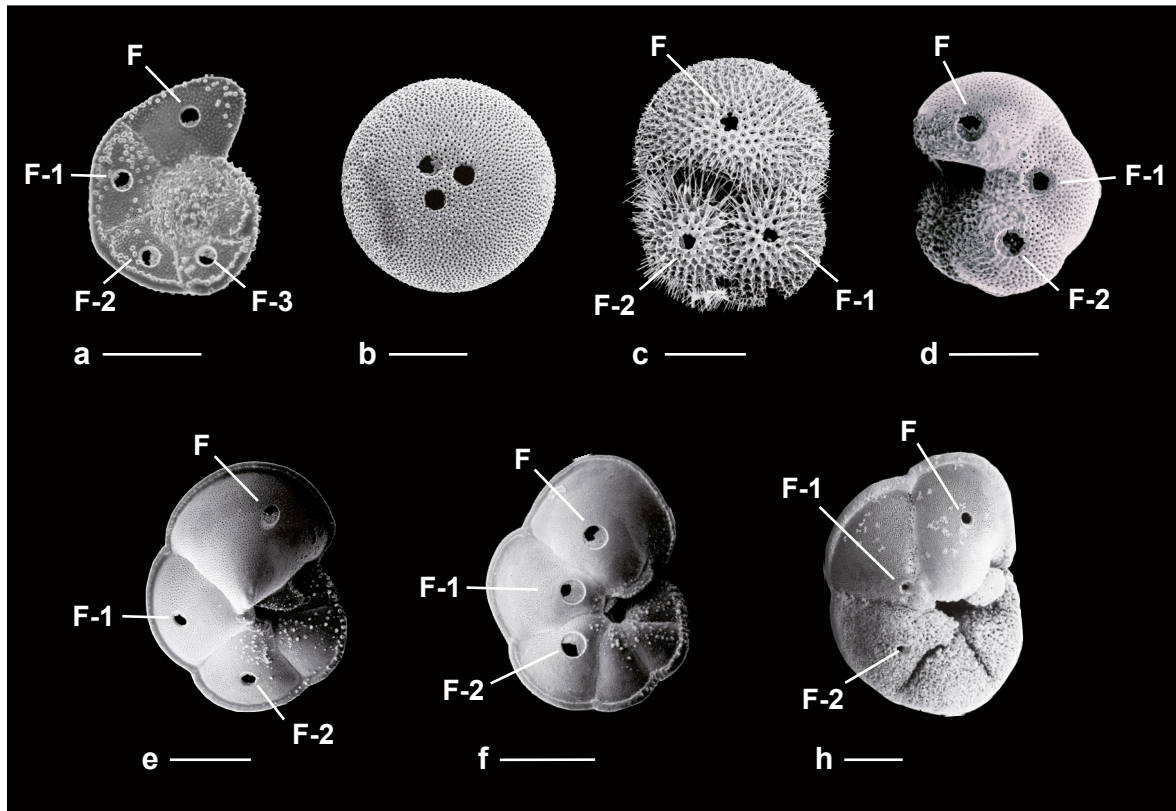
**Plate B.1:** Scanning electron micrographs (SEM)

(a) *G. truncatulinoides* dextral (from station 221-8 in 150-210 m water depth)

(b) *O. universa* (from station 221-8 in 60-150 m water depth)

(c) *G. sacculifer* (from station 211-5 in 0-60 m water depth)

(d) *P. obliquiloculata* (from station 221-7 in 40-60 m water depth)

(e) *G. ungulata* (from station 211-5 in 0-60 m water depth)

(f) *G. menardii* (from station 221-7 in 0-40 m water depth)

(g) *G. tumida* (from station 219-7 in 220-400 m water depth)


Scale: 200 µm; The holes point to the spots from laser ablations in chamber F to F-3.

# APPENDIX C

## Mg/Ca LA-ICP-MS profiles
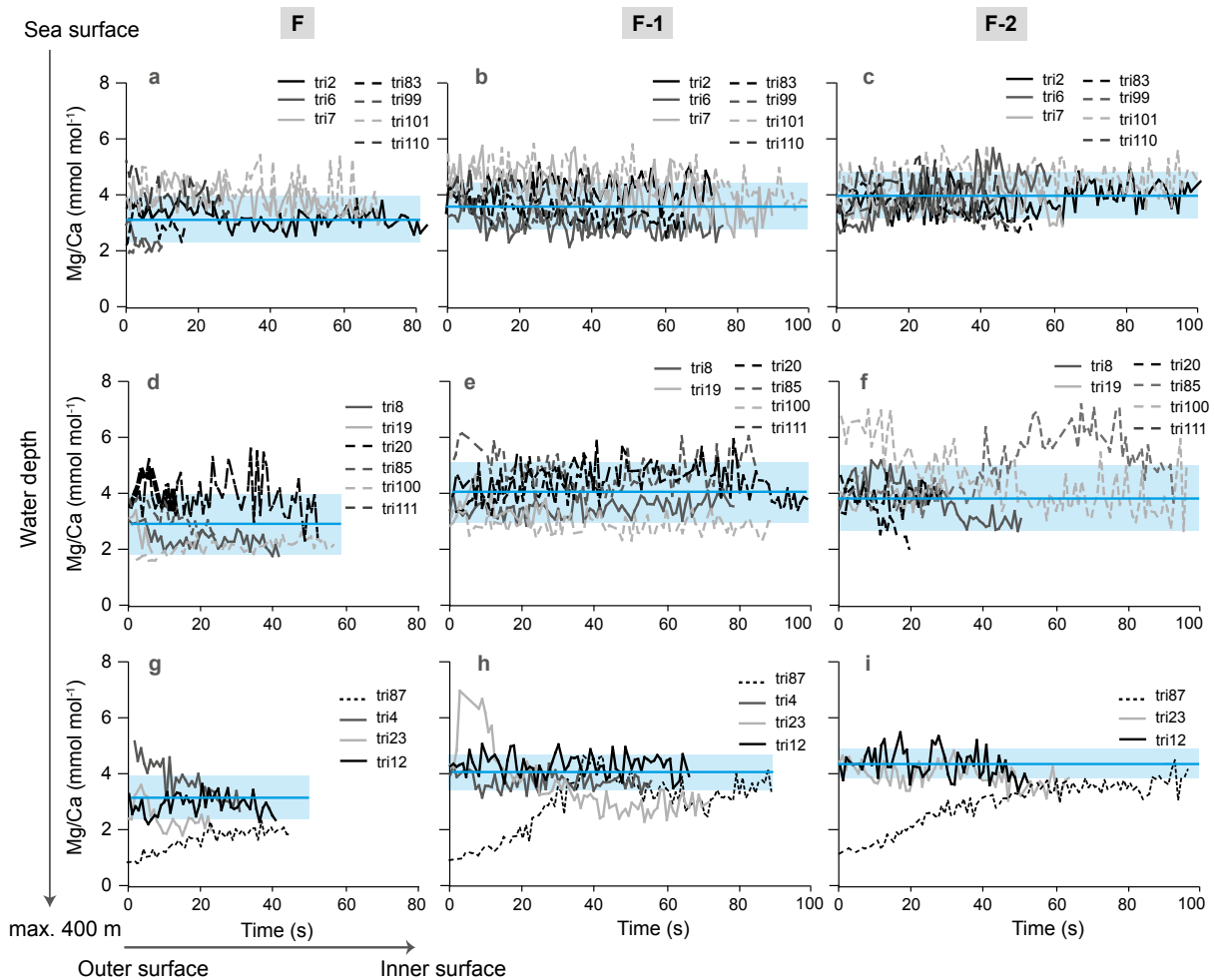


**Figure C.1:** Laser ablation ICP-MS profiles of Mg/Ca through *G. sacculifer*. Single chambers (F, F-1 and F-2) were measured from the outside of the test towards the inside (left to right). Single individuals were collected at different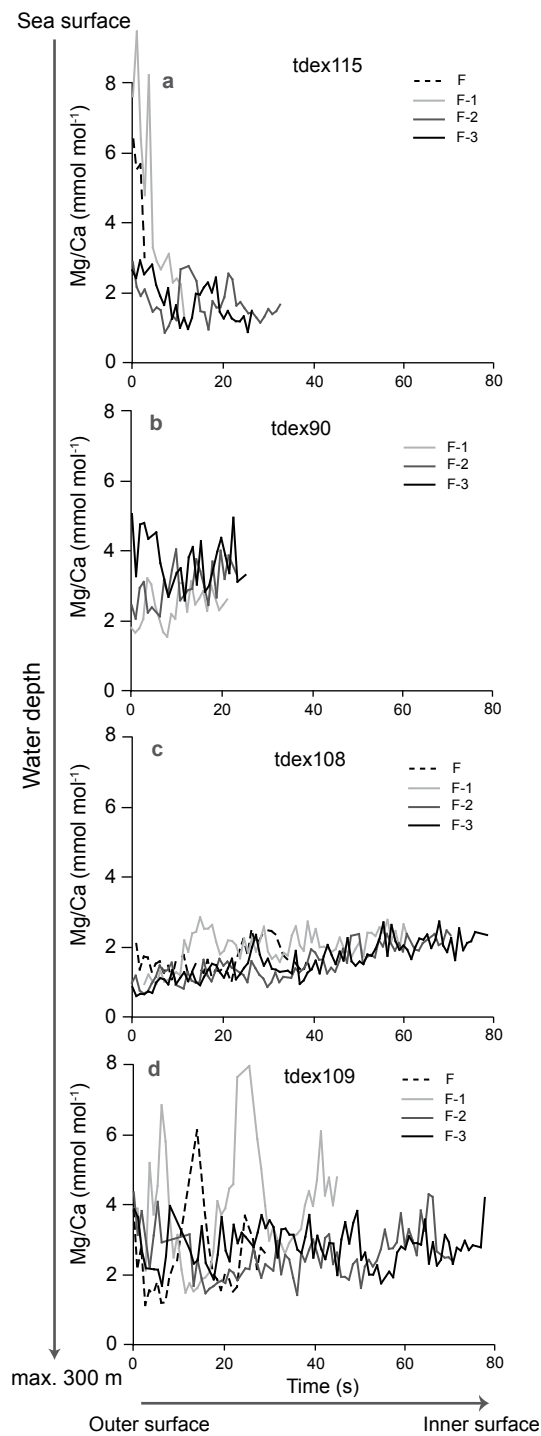 stations and water depth intervals (cf. Appendix B). Blue lines: Average Mg/Ca ratios (blue bars indicate the ± standard deviation).
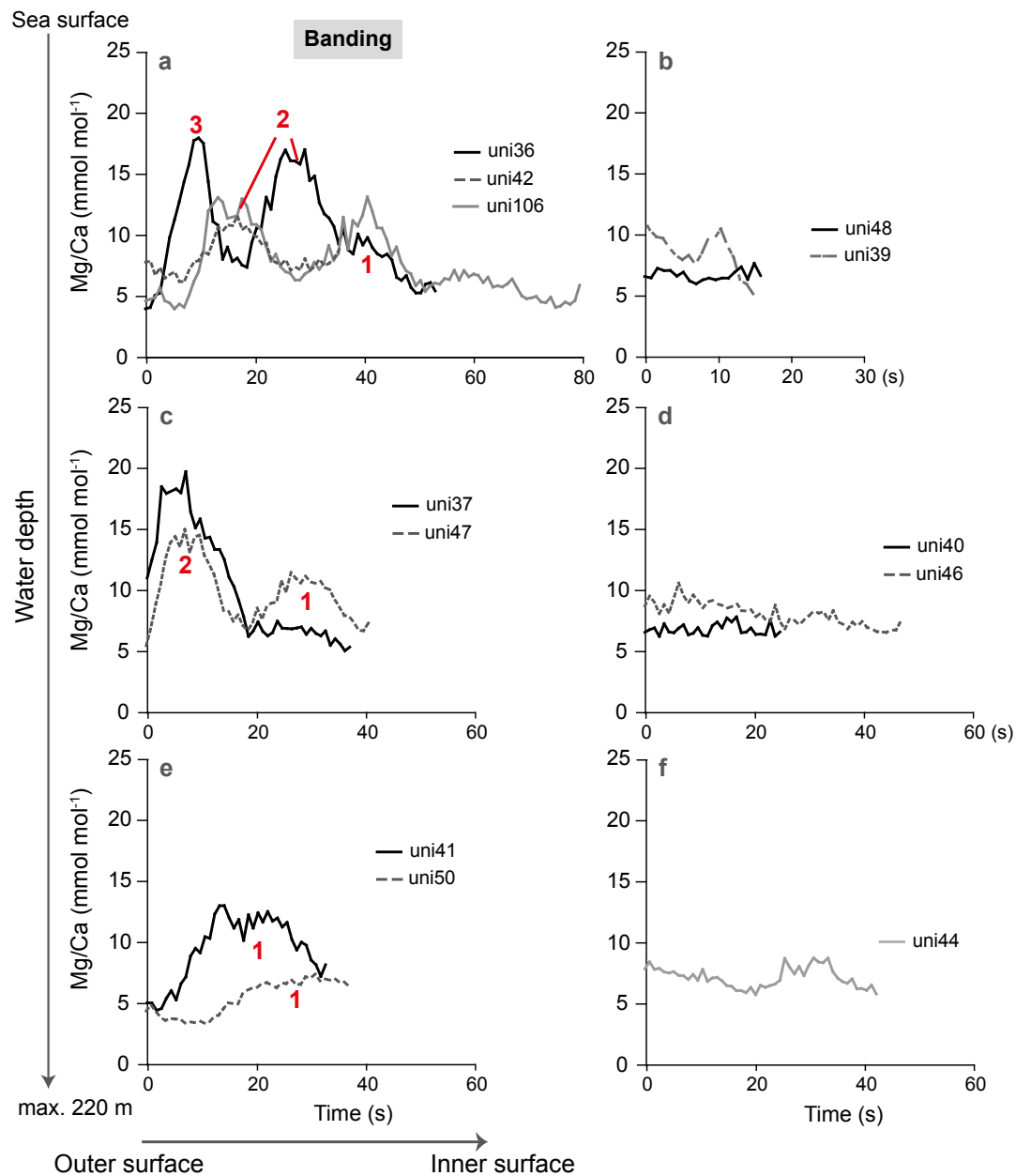
**Figure C.2:** Laser ablation ICP-MS profiles of Mg/Ca (average values) through *O. universa*. Spherical chambers were measured three times from the outside of the test towards the inside (left to right). Single individuals were collected at different stations and water depth intervals (cf. Appendix B). Note: Red numbers indicate diurnal cycles of high and low $Mg^{2+}$ bands as described in Eggins et al. (2004) and Spero et al. (2015).
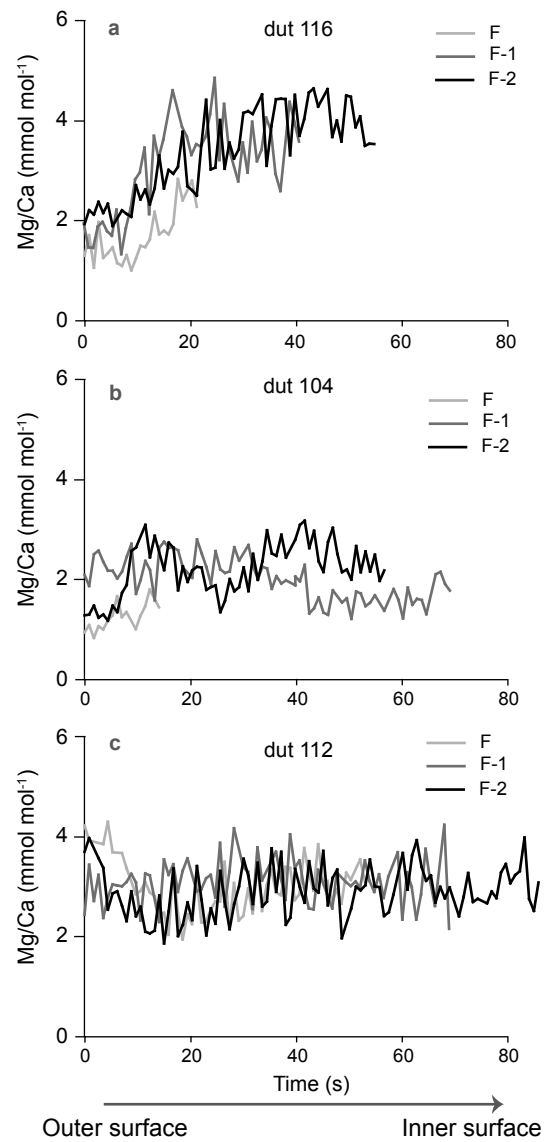
**Figure C.3:** Laser ablation ICP-MS profiles of Mg/Ca through *N. dutertrei*. Single chambers (F, F-1 and F-2) were measured from the outside of the test towards the inside (left to right). Single individuals were collected at different stations and water depth intervals (cf. Appendix B).
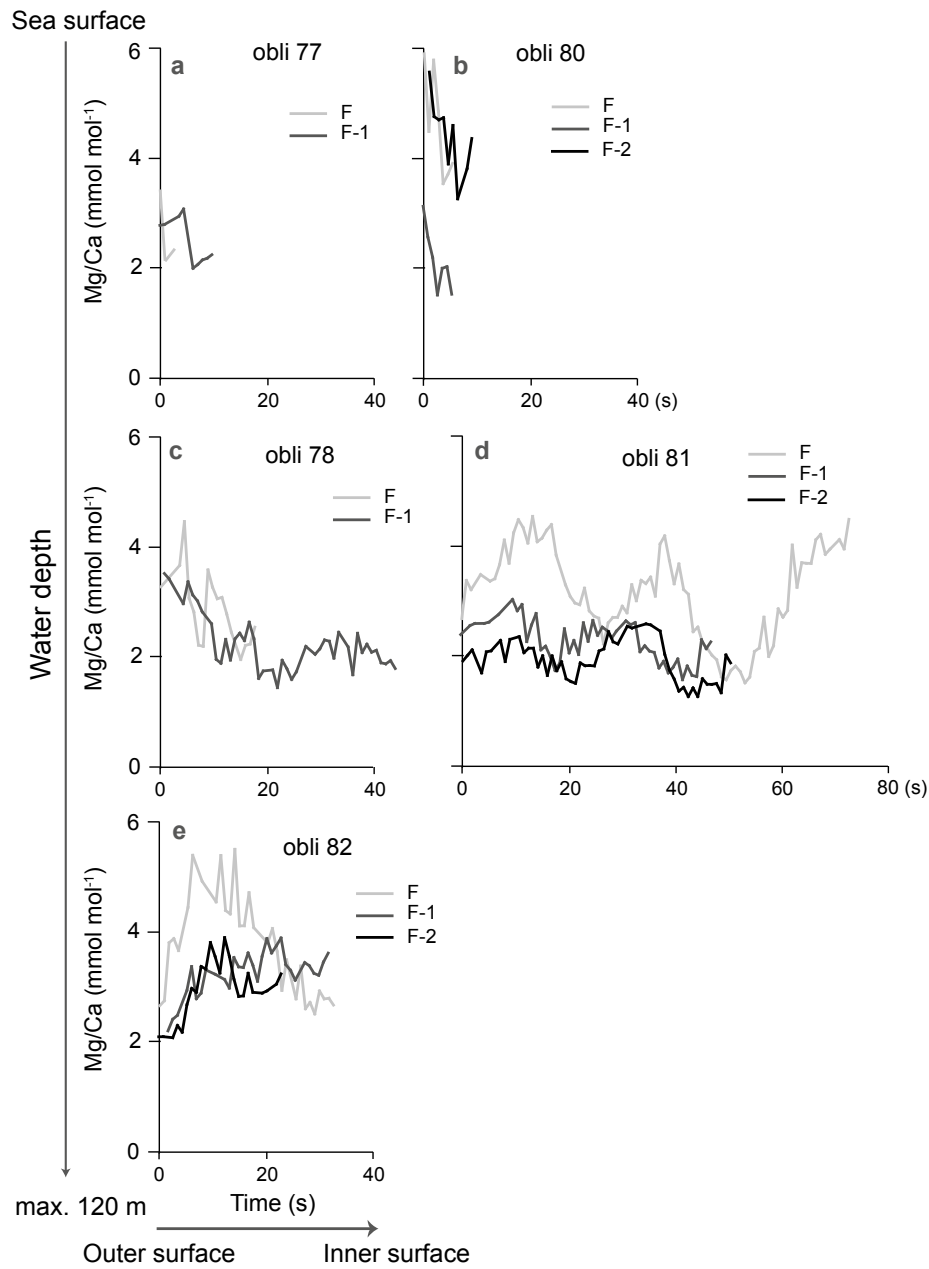
**Figure C.4:** Laser ablation ICP-MS profiles of Mg/Ca through *P. obliquiloculata*. Single chambers (F, F-1 and F-2) were measured from the outside of the test towards the inside (left to right). Single individuals were collected at different stations and water depth intervals (cf. Appendix B).
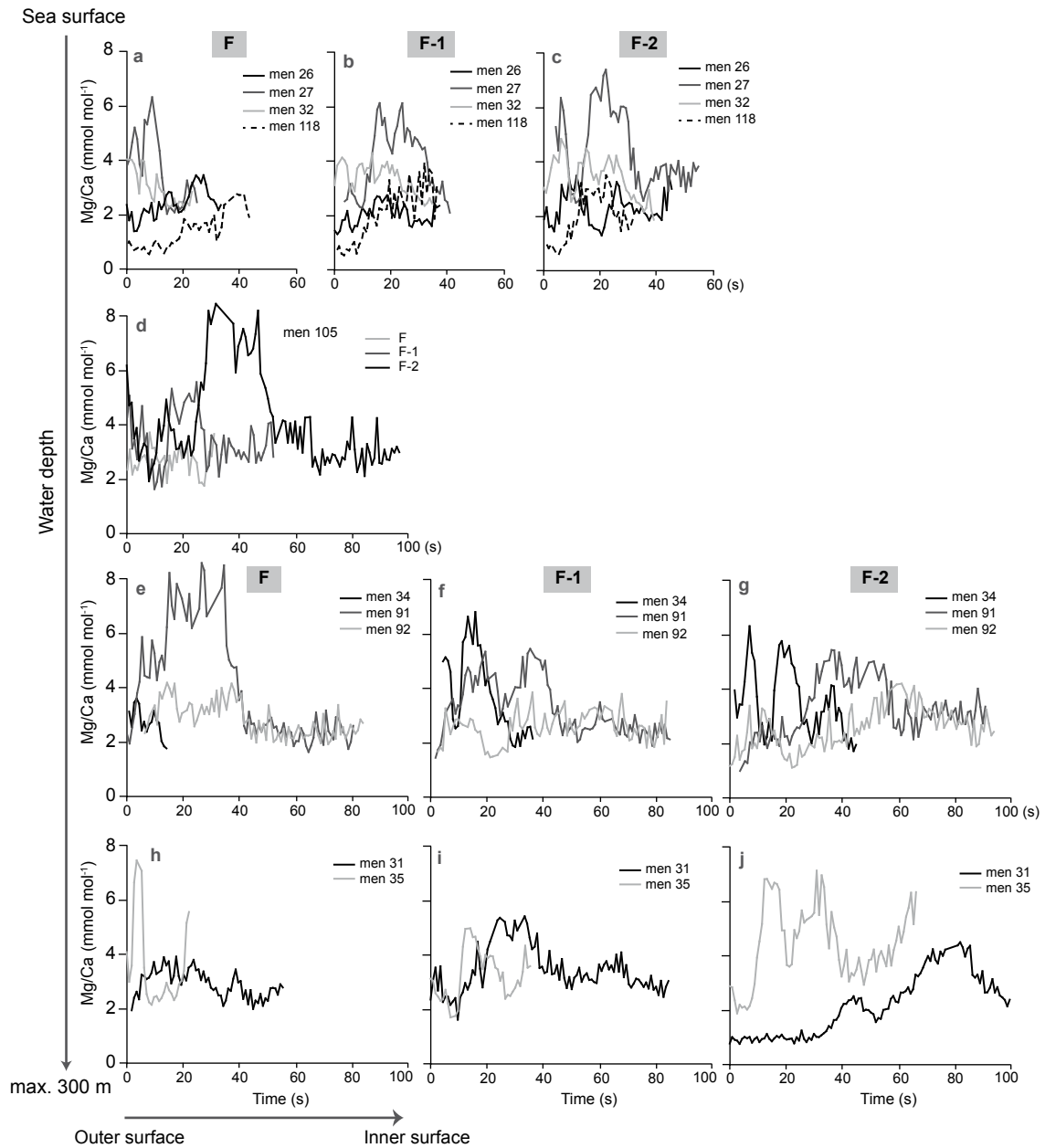
**Figure C.5:** Laser ablation ICP-MS profiles of Mg/Ca through *G. menardii*. Single chambers (F, F-1 and F-2) were measured from the outside of the test towards the inside (left to right). Single individuals were collected at different stations and water depth intervals (cf. Appendix B).
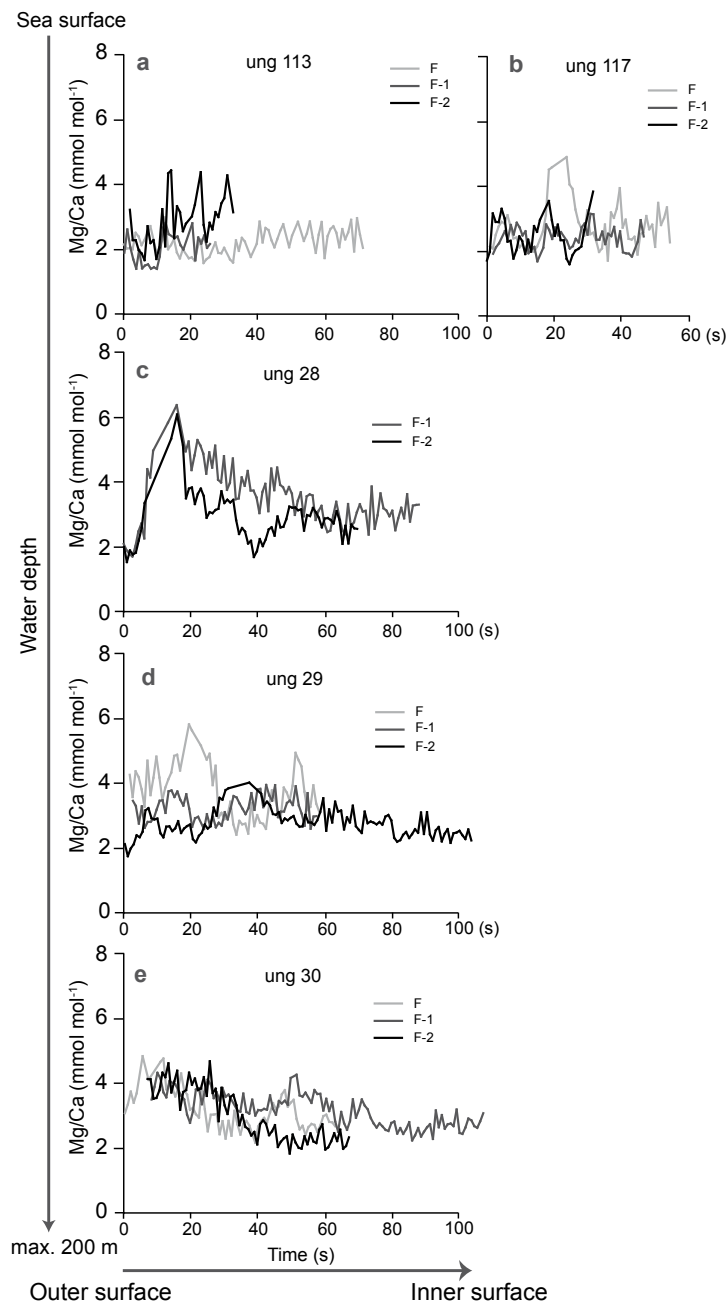
**Figure C.6:** Laser ablation ICP-MS profiles of Mg/Ca through *G. ungulata*. Single chambers (F, F-1 and F-2) were measured from the outside of the test towards the inside (left to right). Single individuals were collected at different stations and water depth intervals (cf. Appendix B).

**Figure C.7:** Laser ablation ICP-MS profiles of Mg/Ca through *G. truncatulinoides* dextral. Single chambers (F, F-1 and F-2) were measured from the outside of the test towards the inside (left to right). Single individuals were collected at different stations and water depth intervals (cf. Appendix B).
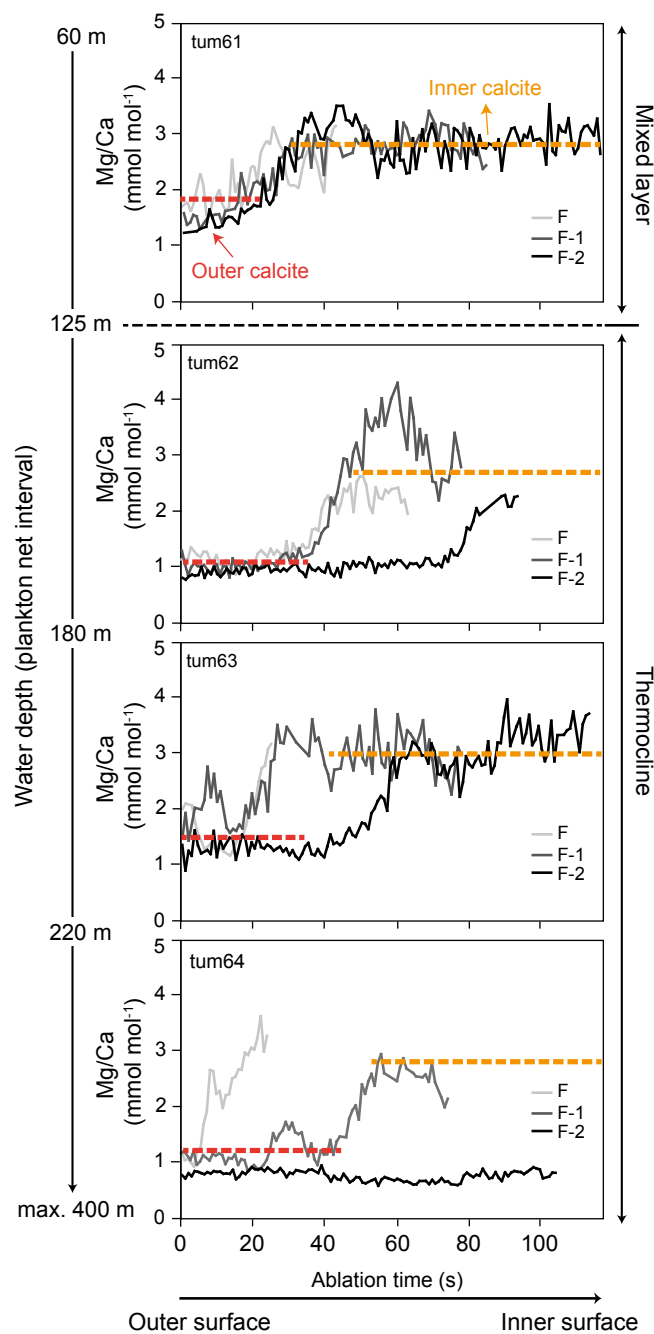
**Figure C.8:** Laser ablation ICP-MS profiles of Mg/Ca through *G. tumida*. Single chambers (F, F-1 and F-2) were measured from the outside of the test towards the inside (left to right). Single individuals were collected at different stations and water depth intervals (cf. Appendix B).

Note: Red and yellow dashed lines indicate the average Mg/Ca ratios of the "outer" Mg-poor and "inner" Mg-rich calcite. Two calcite phases are characteristic for *G. tumida* and described in previous studies (e.g. Brown and Elderfield, 1996; Nouet and Bassinot, 2007). Only Mg-poor calcite was measured in the slight crystallized chamber F-2 of specimen tum64 (collected in 220-400 m water depth).

# APPENDIX D

## Supplementary information of Chapter 4

**Table D.1:** Salinity and temperature measurements during the sampling period in autumn 2012.

| | | Salinity (psu) | | | Temperature (°C) | | |
|---|---|---|---|---|---|---|---|
| Date | Water depth (m) | Station 1 | Station 2 | Station 3 | Station 1 | Station 2 | Station 3 |
| **22.10.12** | 0 | 33.7 | 34.1 | - | 29.4 | 28.5 | - |
| | 10 | 33.8 | 34.2 | - | 29.4 | 28.4 | - |
| | 20 | 33.8 | 34.2 | - | 29.4 | 28.3 | - |
| | 25 | 33.8 | 34.2 | - | 29.4 | 28.3 | - |
| **29.10.12** | 0 | 33.7 | 33.7 | 33.7 | 29.1 | 29.2 | 29.5 |
| | 10 | 33.7 | 33.7 | 33.7 | 29.2 | 29.2 | 29.2 |
| | 20 | 33.8 | 33.8 | - | 29.2 | 29.2 | - |
| | 25 | 33.9 | 33.8 | - | 29.2 | 29.2 | - |
| **02.11.12** | 0 | 33.7 | 33.7 | 33.6 | 29.1 | 29.2 | 29.4 |
| | 10 | 33.7 | 33.7 | 33.7 | 29.1 | 29.4 | 29.5 |
| | 20 | 33.7 | 33.7 | - | 29.2 | 29.4 | - |
| | 25 | 33.8 | 33.8 | - | 29.2 | 29.4 | - |
| **05.11.12** | 0 | 33.7 | 33.7 | - | 29.3 | 29.2 | - |
| | 10 | 33.7 | 33.7 | - | 29.3 | 29.3 | - |
| | 20 | 33.8 | 33.7 | - | 29.4 | 29.2 | - |
| | 25 | 33.8 | 33.7 | - | 29.3 | 29.2 | - |

**Table D.2:** Stable oxygen isotopes of surface waters during the sampling period in autumn 2012.

| Date | Station | $\delta^{18}O_{seawater}$ (‰VSMOW) |
|---|---|---|
| 22.10.12 | Station 1 | 0.76 |
| | Station 2 | 0.79 |
| 29.10.12 | Station 1 | 0.8 |
| | Station 2 | 0.78 |
| 02.11.12 | Station 1 | 0.8 |
| | Station 2 | 0.82 |
| | Station 3 | 0.8 |
| 05.11.12 | Station 1 | 0.91 |
| | Station 2 | 0.9 |

**Table D.3:** Census data of planktonic and benthic foraminifera from plankton net hauls off Puerto Rico during autumn 2012. ws= *Globigerinoides sacculifer* with sac-like chamber.

| Date | 22.10. | 22.10. | 22.10. | 22.10. | 29.10. | 29.10. | 29.10. | 29.10. | 29.10. | 02.11. | 02.11. | 02.11. | 02.11. | 02.11. | 05.11. | 05.11. | 05.11. | 05.11. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Station | 1 | 1 | 2 | 2 | 1 | 1 | 2 | 2 | 3 | 1 | 1 | 2 | 2 | 3 | 1 | 1 | 2 | 2 |
| Sampling depth (m) | 0-60 | 60-100 | 0-60 | 60-100 | 0-60 | 60-100 | 0-60 | 60-100 | 5 | 0-60 | 60-100 | 0-60 | 60-100 | 5 | 0-60 | 60-100 | 0-60 | 60-100 |
| Water volume (m⁻³) | 2.56 | 1.71 | 2.56 | 1.71 | 2.56 | 1.71 | 2.56 | 1.71 | 52.35 | 2.56 | 1.71 | 2.56 | 1.71 | 52.35 | 2.56 | 1.71 | 2.56 | 1.71 |
| *Globigerinoides ruber* white | 8 | – | 7 | 1 | 2 | 2 | 3 | – | 3 | 13 | 1 | 14 | – | 2 | 4 | 3 | 2 | 1 |
| *Globigerinoides ruber* pink | 125 | 2 | 127 | 17 | 16 | 17 | 24 | 8 | 44 | 59 | 22 | 43 | 27 | 7 | 62 | 20 | 60 | 19 |
| *Globigerinoides sacculifer* | 137 | 6 | 112 | 15 | 18 | 12 | 14 | 7 | 27 | 105 | 31 | 40 | 48 | 1 | 56 | 23 | 38 | 28 |
| *Globigerinoides sacculifer* (ws) | 1 | – | – | – | 6 | – | 1 | – | – | 2 | 7 | 5 | 4 | – | 5 | 3 | 2 | – |
| *Hastigerina pelagica* | – | – | 1 | – | – | 1 | – | – | – | – | 1 | 2 | 3 | – | – | – | – | – |
| *Globigerina bulloides* | – | – | 1 | – | – | – | – | – | 1 | – | – | – | – | – | – | – | 1 | – |
| *Globigerinella calida* | 1 | 1 | 2 | 2 | 3 | – | 1 | 3 | – | 1 | 7 | – | 3 | – | 2 | 4 | 1 | 5 |
| *Globigerinella siphonifera* | – | – | 1 | 2 | – | 1 | – | 3 | – | – | 4 | 5 | 8 | – | – | 3 | 2 | 1 |
| *Globoturborotalita rubescens* | 19 | 3 | 11 | 3 | 2 | 1 | – | – | – | 4 | – | 2 | 1 | 1 | 1 | – | 2 | 1 |
| *Orbulina universa* | – | – | – | – | – | 2 | – | – | – | 3 | 1 | 2 | 4 | 1 | 1 | 5 | 1 | 2 |
| *Turborotalita quinqueloba* | – | 1 | – | – | – | – | 1 | – | 1 | – | – | – | – | – | 1 | – | 6 | – |
| *Globorotalia menardii* | 1 | – | 2 | 1 | – | 4 | – | 1 | 1 | 1 | 4 | – | 8 | – | 1 | 1 | 1 | 1 |
| *Neogloboquadrina dutertrei* | 10 | – | 2 | 3 | 3 | 2 | – | – | 1 | 4 | 2 | 3 | 8 | – | – | 2 | 4 | 4 |
| *Pulleniatina obliquiloculata* | – | – | – | – | – | – | – | – | – | – | – | – | 1 | – | – | – | – | – |
| *Globigerinita glutinata* | 35 | – | 25 | 4 | 1 | 2 | 3 | 3 | – | 6 | – | 4 | 6 | – | 16 | 1 | 7 | 1 |
| *Candeina nitida* | – | – | 2 | – | – | – | – | – | – | – | 1 | – | – | – | – | – | – | 3 |
| juvenile planktonic species | – | – | – | 2 | 2 | 2 | 5 | 6 | – | – | – | – | – | – | – | – | – | – |
| *Asterigerina carinata* | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| *Bolivina minima* | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| *Bolivina paula* | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| *Bolivina striatula* | – | – | – | – | – | – | – | – | 1 | – | – | – | – | – | – | – | – | – |
| *Bolivina variabilis* | – | – | 7 | 1 | 15 | 4 | 25 | 6 | 65 | – | 1 | 17 | 3 | 11 | – | – | 31 | 3 |
| *Cibicidoides pachyderma* | – | – | – | 1 | 1 | 1 | 1 | 1 | – | – | – | 3 | – | – | – | – | – | – |
| *Cornuspira involvens* | – | – | – | – | 1 | – | – | – | 1 | – | – | – | – | – | – | – | – | – |
| *Tretomphalus bulloides* | – | – | 2 | 1 | – | 1 | – | – | – | – | – | 2 | – | 8 | – | – | 1 | – |
| *Trifarina bella* | – | – | 1 | 33 | – | 2 | – | 7 | 1 | – | 1 | – | – | – | – | – | 1 | 1 |
| other benthic species | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Total planktonic species | 337 | 13 | 293 | 50 | 53 | 46 | 52 | 31 | 78 | 198 | 81 | 120 | 121 | 12 | 149 | 65 | 127 | 66 |
| Total benthic species | 0 | 0 | 10 | 36 | 17 | 8 | 26 | 14 | 68 | 0 | 2 | 22 | 3 | 19 | 0 | 0 | 33 | 4 |

**Table D.4:** Bray Curtis similarity indices obtained from PAST (Hammer et al., 2001).

|  | 22.10.12 | 29.10.12 | 02.11.12 | 05.11.12 |
|---|---|---|---|---|
| 22.10.12 | 1.00 | 0.36 | 0.71 | 0.65 |
| 29.10.12 | 0.36 | 1.00 | 0.48 | 0.59 |
| 02.11.12 | 0.71 | 0.48 | 1.00 | 0.81 |
| 05.11.12 | 0.65 | 0.59 | 0.81 | 1.00 |

**Table D.5:** Stable isotope values in calcite tests of *G. ruber* (pink) during sampling period in autumn 2012.

| Date | Station | Sampling depth (m) | $\delta^{18}O_{calcite}$ (VPDB ‰) | $\delta^{13}C_{calcite}$ (VPDB ‰) |
|---|---|---|---|---|
| 22.10.12 | Station 1 | 0-60 | -2.59 | 0.62 |
|  | Station 2 | 0-60 | -2.52 | 0.66 |
|  |  | 60-100 | -2.44 | 0.44 |
| 29.10.12 | Station 1 | 0-60 | -2.38 | 0.24 |
|  |  | 60-100 | -2.41 | 0.59 |
|  | Station 2 | 0-60 | -2.63 | 0.29 |
|  |  | 60-100 | -2.33 | 0.49 |
|  | Station 3 | 5 | -2.96 | -0.40 |
| 02.11.12 | Station 2 | 0-60 | -2.62 | 0.41 |
|  |  | 60-100 | -2.12 | 0.78 |
| 05.11.12 | Station 1 | 0-60 | -2.66 | 0.42 |
|  | Station 2 | 0-60 | -2.60 | 0.80 |
|  |  | 60-100 | -2.70 | 0.96 |

**Table D.6:** Foraminiferal census data of **Schmuker 2000b** from plankton net samples off the coast of Puerto Rico, which are used for this study (Fig. 4.5B). + = specimens of *Globorotalia menardii*, *G. tumida* and *G. ungulata*; ws= *Globigerinoides sacculifer* with sac-like chamber.

| Station | I | | II | | III | | IV | |
|---|---|---|---|---|---|---|---|---|
| Longitude (°W) | 67°01.1 | | 67°25.0 | | 67°25.0 | | 67°30.0 | |
| Latitude (°N) | 17°82.0 | | 17°85.5 | | 17°87.5 | | 17°88.5 | |

| Date | Station | Depth (m) | G. ruber pink | G. ruber white | G. sacculifer | G. sacculifer (ws) | G. menardii+ | G. calida | G. siphonifera | O. universa | N. dutertrei | Total planktonic species |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 19.09.1994 | IV | 0–120 | 275 | 169 | 104 | 2 | 41 | 3 | 9 | 6 | 11 | 629 |
| 19.09.1994 | III | 0–120 | 327 | 296 | 106 | | 56 | 12 | 10 | 4 | 32 | 865 |
| 19.09.1994 | II | 0–120 | 105 | 120 | 14 | | 25 | 5 | 5 | | 13 | 300 |
| 22.09.1994 | IV | 0–120 | 131 | 130 | 58 | 5 | 45 | 8 | 3 | 21 | 25 | 442 |
| 22.09.1994 | III | 0–120 | 78 | 77 | 33 | 3 | 42 | 8 | | 10 | 13 | 269 |
| 26.09.1994 | IV | 0–120 | 194 | 193 | 77 | 2 | 27 | 17 | 10 | 9 | 19 | 558 |
| 26.09.1994 | III | 0–120 | 92 | 107 | 34 | | 17 | 3 | 1 | 5 | 8 | 275 |
| 26.09.1994 | II | 0–120 | 118 | 137 | 24 | | 9 | 4 | 4 | | 9 | 310 |
| 29.09.1994 | IV | 0–120 | 290 | 289 | 67 | | 7 | 14 | 15 | 14 | 24 | 727 |
| 29.09.1994 | III | 0–120 | 534 | 629 | 155 | 2 | 17 | 25 | 25 | 17 | 20 | 1455 |
| 29.09.1994 | II | 0–120 | 349 | 347 | 96 | 1 | 10 | 11 | 15 | 9 | 16 | 872 |
| 11.10.1994 | IV | 0–120 | 120 | 78 | 53 | | 38 | 16 | 28 | 19 | 4 | 370 |
| 11.10.1994 | III | 0–120 | 186 | 164 | 69 | | 31 | 10 | 10 | 10 | 6 | 494 |
| 11.10.1994 | II | 0–120 | 100 | 119 | 51 | | 18 | 8 | 8 | 8 | 11 | 329 |
| 11.10.1994 | I | 0–10 | 105 | 73 | 37 | | | 2 | | 1 | | 218 |
| 14.10.1994 | IV | 0–120 | 90 | 64 | 34 | | 183 | 10 | 18 | 13 | 18 | 446 |
| 14.10.1994 | III | 0–120 | 96 | 85 | 39 | 1 | 34 | 8 | 8 | 2 | 2 | 277 |
| 20.10.1994 | IV | 0–120 | 84 | 113 | 25 | | 49 | 45 | 5 | 9 | 6 | 343 |
| 20.10.1994 | III | 0–120 | 36 | 63 | 17 | | 21 | 19 | | 5 | 5 | 170 |
| 20.10.1994 | I | 0–10 | 44 | 69 | 21 | | 3 | 1 | | | | 139 |
| 24.10.1994 | IV | 0–120 | 170 | 197 | 47 | | 19 | 10 | | 4 | 4 | 456 |
| 24.10.1994 | III | 0–120 | 180 | 296 | 49 | | 24 | 16 | 4 | 3 | 9 | 597 |
| 24.10.1994 | II | 0–120 | 101 | 181 | 28 | 1 | 9 | 7 | | 1 | 6 | 341 |
| 24.10.1994 | I | 0–10 | 111 | 137 | 20 | | 2 | 1 | | 1 | 3 | 282 |
| 06.03.1995 | IV | 0–120 | 13 | 32 | 8 | | 24 | 40 | 9 | 29 | 14 | 200 |
| 06.03.1995 | III | 0–120 | 18 | 27 | 10 | | 23 | 51 | 8 | 29 | 11 | 210 |
| 05.03.1995 | II | 0–120 | 15 | 17 | 6 | | 37 | 52 | 12 | 24 | 15 | 204 |
| 09.03.1995 | IV | 0–120 | 110 | 367 | 30 | | 26 | 152 | 2 | 12 | 16 | 740 |
| 09.03.1995 | III | 0–120 | 126 | 391 | 65 | | 25 | 164 | 5 | 20 | 6 | 823 |
| 09.03.1995 | II | 0–120 | 72 | 147 | 24 | 1 | 29 | 110 | 10 | 24 | 10 | 437 |
| 09.03.1995 | I | 0–10 | 45 | 107 | 27 | | 19 | 139 | 4 | 4 | 8 | 364 |
| 13.03.1995 | IV | 0–120 | 79 | 73 | 57 | | 23 | 220 | 28 | 9 | 11 | 517 |
| 13.03.1995 | II | 0–120 | 44 | 94 | 15 | | 27 | 219 | 14 | 9 | 14 | 447 |
| 13.03.1995 | I | 0–10 | 45 | 146 | 19 | | 4 | 67 | 5 | | 1 | 290 |
| 15.03.1995 | IV | 0–120 | 106 | 104 | 60 | | 24 | 220 | 16 | 27 | 6 | 583 |
| 16.03.1995 | IV | 0–120 | 64 | 51 | 26 | | 19 | 285 | 12 | 12 | 9 | 490 |
| 16.03.1995 | III | 0–120 | 77 | 83 | 35 | 2 | 24 | 305 | 11 | 31 | 14 | 591 |
| 16.03.1995 | II | 0–120 | 51 | 68 | 45 | 1 | 15 | 195 | 10 | 26 | 20 | 438 |
| 16.03.1995 | I | 0–10 | 10 | 10 | 6 | | 1 | 35 | 1 | 1 | 1 | 67 |
| 19.03.1995 | III | 0–120 | 99 | 151 | 47 | | 40 | 272 | 33 | 8 | 23 | 694 |
| 21.03..1995 | IV | 0–120 | 61 | 57 | 25 | 3 | 13 | 377 | 2 | 23 | 11 | 612 |
| 21.03. 1995 | III | 0–120 | 17 | 8 | 8 | | 5 | 181 | 12 | 8 | 6 | 262 |
| 21.03.1995 | II | 0–120 | 14 | 17 | 2 | | 7 | 259 | 80 | 9 | 8 | 422 |
| 21.03.1995 | I | 0–10 | | 2 | | | 1 | 18 | 2 | | 1 | 28 |

**Table D.6:** Continued.

| Date | Station | Depth | *G. ruber* pink | *G. ruber* white | *G. sacculifer* | *G. sacculifer* (ws) | *G. menardii+* | *G. calida* | *G. siphonifera* | *O. universa* | *N. dutertrei* | Total planktonic species |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 24.03.1995 | IV | 0–120 | 13 | 3 | 6 | | 6 | 112 | 140 | 51 | 6 | 348 |
| 24.03.1995 | III | 0–120 | 3 | 7 | 6 | | 3 | 89 | 120 | 49 | 16 | 304 |
| 24.03.1995 | II | 0–120 | 17 | 72 | 8 | | 2 | 204 | 37 | 40 | 14 | 402 |
| 24.03.1995 | I | 0–10 | 9 | 47 | 2 | | 1 | 3 | | | 2 | 64 |
| 27.03.1995 | IV | 0–120 | 6 | 3 | 1 | | 3 | 79 | 14 | 21 | 4 | 155 |
| 27.03.1995 | III | 0–120 | 4 | 10 | 3 | | 1 | 152 | 21 | 37 | 2 | 242 |
| 27.03.1995 | II | 0–120 | 10 | 23 | 5 | | | 211 | | 39 | 2 | 308 |
| 27.03.1995 | I | 0–10 | 4 | 14 | 2 | | | 5 | | | | 25 |
| 31.03.1995 | IV | 0–120 | 24 | 22 | 1 | | 6 | 6 | 2 | 12 | 14 | 101 |
| 31.03.1995 | III | 0–120 | 6 | 5 | | | 2 | 10 | 2 | 2 | 1 | 38 |
| 31.03.1995 | II | 0–120 | 6 | 7 | 1 | | 1 | 4 | 5 | 3 | 2 | 38 |
| 31.03.1995 | I | 0–10 | 11 | 9 | 1 | | 1 | 3 | 2 | | | 28 |

**Table D.7:** Stable isotope values of **Schmuker 2000b** of *G. ruber*, which are used for this study (Fig. 4.6).

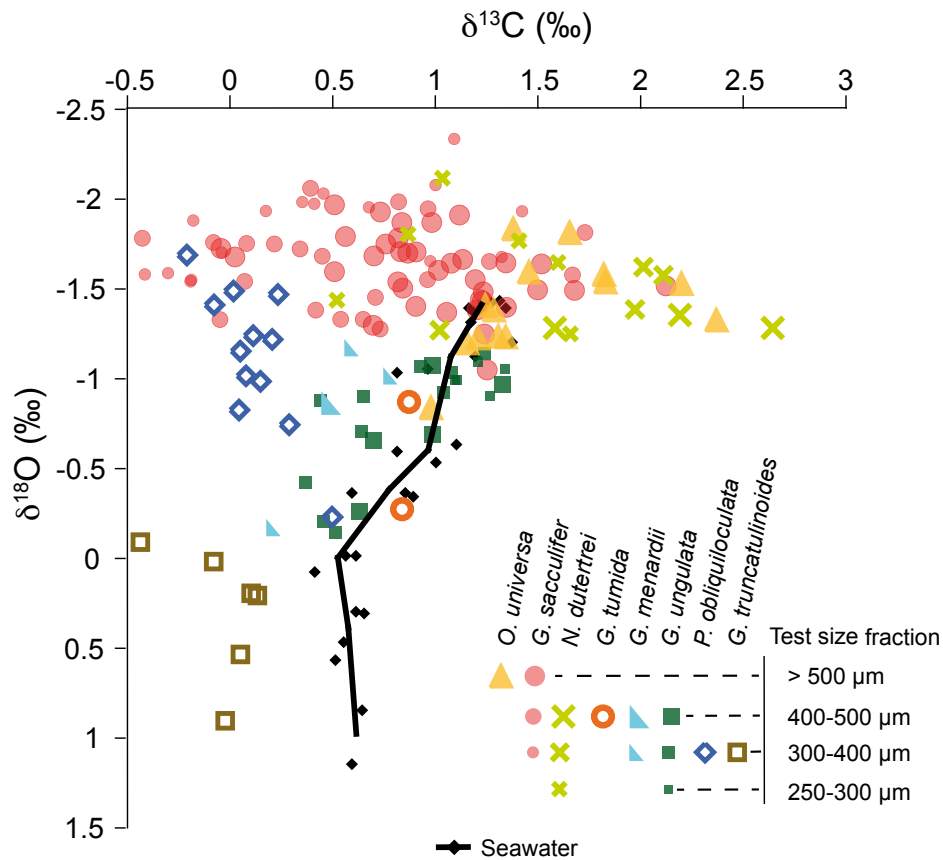| Date | Station | $\delta^{13}C_{calcite}$ (VPDB ‰) | $\delta^{18}O_{calcite}$ (VPDB ‰) |
|---|---|---|---|
| 29.09.1994 | III | -0.00 | -2.61 |
| 24.10.1994 | III | 0.27 | -2.50 |
| 24.03.1995 | II | 0.49 | -1.88 |
| 09.03.1995 | III | 0.35 | -1.98 |
| 09.03.1995 | II | 0.49 | -2.00 |
| 09.03.1995 | I | 0.49 | -2.09 |

# APPENDIX E

## Stable carbon isotopes ($\delta^{13}C$)



**Figure E.1:** Stable isotope values of living foraminifera ($\delta^{18}O_{calcite}$ and $\delta^{13}C_{calcite}$) and *in-situ* measured seawater ($\delta^{18}O_{equilibrium}$ and $\delta^{13}C_{DIC}$) (cf. Tab. E.1 and E.2; Chapter 3; Appendix B). Each symbol corresponds to a single species at a specific test-size. Black line indicates the average values of the ambient seawater.

Note: $\delta^{13}C_{calcite}$ was measured on the ThermoScientific MAT 253 mass spectrometer connected to an automatic carbonate preparation device Kiel CARBO IV at GEOMAR. The results were reported *versus* the National Bureau of Standards (NBS) 19, and the *in-house* standard (Solnhofen limestone) indicate a long-term analytic precision of <0.3‰ ($\pm 1\sigma$) (Tab. E.2). Dissolved inorganic carbon isotopes ($\delta^{13}C_{DIC}$) in seawater were measured at the laboratory of GeoZentrum Nordbayern (Erlangen) and analysed by a Gasbench II coupled to the Thermo Delta V Advantage Isotope Ratio Mass Spectrometer (IRMS). The data are reported in per mil (‰) *versus* VPDB and the analytic precision is better than 0.1‰ ($\pm 1\sigma$) (Tab. E.1).
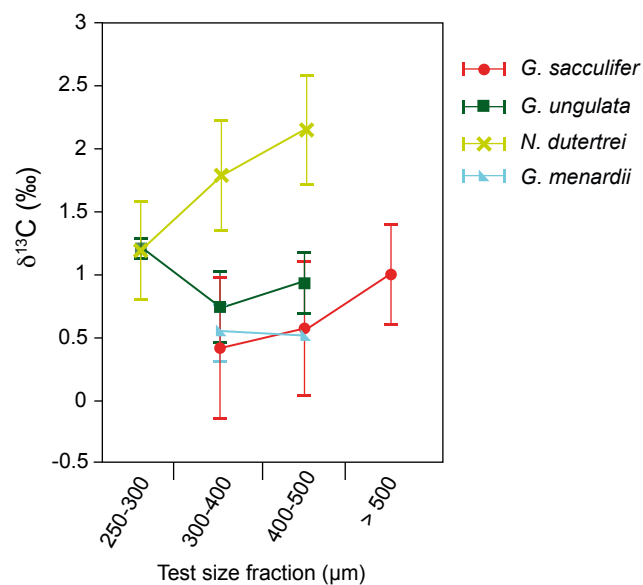
**Figure E.2:** Stable carbon isotopes (average $\delta^{13}C_{calcite}$ and $\pm$ standard deviations) compared to different test-size fractions of living planktonic foraminifera (only species with more than two test-size fractions are depicted).

**Table E.1:** Stable carbon isotope values in seawater ($\delta^{13}C_{DIC}$).

| Station | Sampling depth (m) | $\delta^{13}C_{DIC}$ (‰ VPDB) | Station | Sampling depth (m) | $\delta^{13}C_{DIC}$ (‰ VPDB) |
|---------|--------------------|-------------------------------|---------|--------------------|-------------------------------|
| 210-13 | 40 | 0.97 | 221-1 | 10 | 1.32 |
| 210-13 | 85 | 0.82 | 221-1 | 30 | 1.35 |
| 210-13 | 100 | 0.82 | 221-1 | 60 | 1.38 |
| 210-13 | 150 | 0.6 | 221-2 | 100 | 1.11 |
| 210-13 | 190 | 0.42 | 221-2 | 150 | 0.57 |
| 210-13 | 275 | 0.52 | 221-2 | 200 | 0.56 |
| 210-13 | 400 | 0.6 | 221-2 | 500 | 0.6 |
| 219-1 | 50 | 1.19 | 222-1 | 10 | 1.28 |
| 219-1 | 100 | 1.17 | 222-1 | 30 | 1.24 |
| 219-1 | 220 | 0.62 | 222-1 | 55 | 1.01 |
| 219-1 | 600 | 0.6 | 222-1 | 75 | 0.9 |
| 220-1 | 10 | 1.22 | 222-1 | 140 | 0.66 |
| 220-1 | 61 | 1.18 | 222-1 | 229 | 0.65 |
| 220-1 | 91 | 1.2 | | | |
| 220-2 | 136 | 0.86 | | | |
| 220-2 | 196 | 0.62 | | | |
| 220-2 | 485 | 0.6 | | | |

**Table E.2:** Stable carbon isotope values ($\delta^{13}C_{calcite}$) of foraminiferal calcite from plankton tows.

| Species | Station | Sampling interval (m) | Size-fraction (µm) | Number of specimens/sample | $\delta^{13}C_{calcite}$ (‰ VPDB) |
|---|---|---|---|---|---|
| *G. sacculifer* | 211-6 | 0–60 | >500 | 3 | 1.200 |
| | 211-6 | | | | 1.240 |
| | 211-6 | | | | 1.235 |
| | 211-6 | | | | 1.505 |
| | 211-5 | | | | 0.911 |
| | 211-5 | | | | 1.684 |
| | 211-5 | | | | 0.848 |
| | 211-5 | | | | 1.022 |
| | 211-6 | | | | 1.227 |
| | 211-5 | | 400–500 | 7 | 0.54 |
| | 211-6 | | 300–400 | 6 | -0.3 |
| | 211-6 | 60–100 | >500 | 3 | 1.259 |
| | 211-5 | | | | 1.353 |
| | 211-6 | | | | 1.209 |
| | 211-5 | | | | 0.703 |
| | 211-5 | | 400–500 | 3 | 0.65 |
| | 211-5 | 100–200 | >500 | 3 | 1.25 |
| | 219-7 | 0–60 | >500 | 3 | 0.913 |
| | 219-7 | | | | 0.030 |
| | 219-7 | | | | 0.515 |
| | 219-7 | | | | 0.837 |
| | 219-7 | | | | -0.038 |
| | 219-7 | | 400–500 | 5 | -0.052 |
| | 219-8 | | | 6 | -0.431 |
| | 219-8 | | | 6 | 0.213 |
| | 219-8 | | | 5 | -0.084 |
| | 219-7 | | | 5 | 0.446 |
| | 219-8 | | | 5 | 0.068 |
| | 219-7 | | 300–400 | 10 | -0.188 |
| | 219-7 | | | | -0.191 |
| | 219-8 | | | | -0.039 |
| | 219-8 | | | | -0.178 |
| | 219-7 | 60–125 | >500 | 3 | 0.765 |
| | 219-7 | | | | 1.140 |
| | 219-8 | | | | 1.062 |
| | 219-7 | | | | 0.872 |
| | 219-7 | | | | 0.708 |
| | 219-7 | 60–125 | 400–500 | 5 | 0.41 |
| | 219-7 | | 300–400 | 10 | -0.41 |
| | 219-7 | 125–180 | >500 | 3 | 0.82 |
| | 220-8 | 0–70 | >500 | 3 | 1.083 |
| | 220-9 | | | 5 | 0.990 |
| | 220-9 | | | 5 | 0.515 |
| | 220-9 | | | 5 | 1.124 |
| | 220-9 | | | 5 | 0.739 |
| | 220-8 | | | 5 | 0.844 |
| | 220-8 | | | 5 | 0.569 |
| | 220-8 | | | 5 | 1.350 |

**Table E.2:** Continued.

| Species | Station | Sampling interval (m) | Size-fraction (μm) | Number of specimens/sample | δ¹³C$_{calcite}$ (‰ VPDB) |
|---|---|---|---|---|---|
| *G. sacculifer* | 220-9 | 0–70 | 400–500 | 9 | 0.078 |
| | 220-9 | | | 9 | 0.959 |
| | 220-9 | | | 12 | 0.338 |
| | 220-8 | 70–100 | >500 | 3 | 1.52 |
| | 220-8 | | 400–500 | 5 | 0.70 |
| | 221-8 | 0–40 | >500 | 3 | 0.83 |
| | 221-8 | | 400–500 | 5 | 1.725 |
| | 221-7 | | | 7 | 0.389 |
| | 221-8 | | | 8 | 0.817 |
| | 221-8 | | | 7 | 0.961 |
| | 221-8 | | 300–400 | 9 | 0.177 |
| | 221-8 | | | 9 | 0.353 |
| | 221-8 | | | 9 | 0.412 |
| | 221-8 | | | 9 | 0.457 |
| | 221-8 | | | 7 | 1.002 |
| | 221-8 | | | 7 | 0.679 |
| | 221-7 | 40–60 | 400–500 | 5 | 1.26 |
| | 221-8 | | 300–400 | 6 | 0.98 |
| | 221-8 | 60–150 | 400–500 | 5 | 1.67 |
| | 222-7 | 0–40 | >500 | 3 | 2.13 |
| | 222-6 | | 400–500 | 5 | 0.73 |
| | 222-7 | | 300–400 | 7 | 1.42 |
| | 222-6 | 40–80 | 300–400 | 5 | 1.33 |
| *O. universa* | 211-6 | 0–60 | >500 | 10 | 2.378 |
| | 211-5 | | | 5 | 1.83 |
| | 211-5 | | | 5 | 2.208 |
| | 211-6 | | | 8 | 1.352 |
| | 211-5 | 60–100 | >500 | 5 | 1.218 |
| | 211-5 | | | 5 | 1.164 |
| | 211-6 | | | 5 | 1.295 |
| | 211-6 | | | 10 | 1.316 |
| | 211-6 | 100–200 | >500 | 7 | 0.99 |
| | 220-9 | 0–70 | >500 | 10 | 1.84 |
| | 221-8 | 0–40 | >500 | 10 | 1.633 |
| | 221-7 | | | 9 | 1.389 |
| | 221-8 | 40–60 | >500 | 7 | 1.47 |
| | 221-7 | 60–150 | >500 | 5 | 1.25 |
| *N. dutertrei* | 221-8 | 0–40 | 400–500 | 3 | 2.65 |
| | 221-8 | | 300–400 | 5 | 2.02 |
| | 221-7 | 0–40 | 250–300 | 6 | 1.609 |
| | 221-7 | | | 5 | 0.878 |
| | 221-8 | | | 6 | 1.67 |
| | 221-8 | | | 6 | 1.419 |
| | 221-8 | 40–60 | 400–500 | 2 | 2.12 |
| | 221-7 | | 300–400 | 3 | 2.2 |
| | 221-7 | | 250–300 | 6 | 1.05 |
| | 221-8 | 60–150 | 400–500 | 2 | 1.59 |
| | 221-8 | | 300–400 | 3 | 1.98 |
| | 221-7 | | 250–300 | 6 | 0.53 |

**Table E.2:** Continued.

| Species | Station | Sampling interval (m) | Size-fraction (μm) | Number of specimens/sample | $\delta^{13}C_{calcite}$ (‰ VPDB) |
|---|---|---|---|---|---|
| *N. dutertrei* | 222-7 | 0–40 | 300–400 | 5 | 1.03 |
| *P. obliquiloculata* | 211-5 | 0–60 | 300–400 | 3 | 0.05 |
| | 219-8 | 60–125 | 300–400 | 3 | 0.06 |
| | 220-8 | 0–70 | 300–400 | 3 | 0.12 |
| | 220-8 | 110–150 | 300–400 | 3 | 0.16 |
| | 221-7 | 0–40 | 300–400 | 3 | 0.027 |
| | 221-8 | | | | 0.507 |
| | 221-8 | | | | 0.243 |
| | 221-8 | 40–60 | 300–400 | 3 | -0.07 |
| | 221-8 | 60–150 | 300–400 | 3 | 0.087 |
| | 221-7 | | | | 0.298 |
| | 221-7 | | | | -0.201 |
| | 222-6 | 0–40 | 300–400 | 3 | 0.22 |
| *G. menardii* | 211-6 | 60–100 | 300–400 | 3 | 0.78 |
| | 211-6 | 100–200 | 300–400 | 5 | 0.21 |
| | 221-8 | 60–150 | 300–400 | 5 | 0.59 |
| | 221-8 | 150–210 | 400–500 | 2 | 0.49 |
| *G. ungulata* | 211-5 | 0–60 | 400–500 | 4 | 0.985 |
| | 211-6 | | | | 1.328 |
| | 211-6 | | | | 0.697 |
| | 211-5 | | | | 0.986 |
| | 211-6 | | 300–400 | 5 | 1.080 |
| | 211-5 | | | 4 | 1.241 |
| | 211-5 | | | 4 | 0.643 |
| | 211-6 | | | 4 | 1.042 |
| | 211-5 | | 250–300 | 7 | 1.104 |
| | 211-5 | | | | 1.210 |
| | 211-6 | | | | 1.338 |
| | 211-6 | | | | 1.265 |
| | 211-6 | | | | 1.093 |
| | 211-6 | 60–100 | 300–400 | 5 | 0.652 |
| | 211-5 | | | 5 | 0.441 |
| | 211-6 | | | 6 | 0.927 |
| | 211-6 | 100–200 | 400–500 | 3 | 0.63 |
| | 211-5 | | 300–400 | 5 | 0.458 |
| | 211-5 | | | 5 | 0.368 |
| | 211-6 | | | 4 | 0.516 |
| *G. truncatulinoides* dextral | 211-6 | 100–200 | 300–400 | 4 | -0.44 |
| | 211-6 | 200–300 | 300–400 | 2 | -0.02 |
| | 219-7 | 220–400 | 300–400 | 2 | 0.10 |
| | 220-8 | 150–220 | 300–400 | 2 | 0.14 |
| | 221-7 | 150–210 | 300–400 | 4 | -0.08 |
| | 221-7 | 210–300 | 300–400 | 3 | 0.05 |
| *G. tumida* | 219-8 | 180–220 | 400–500 | 2 | 0.87 |
| | 219-8 | 220–400 | 400–500 | 3 | 0.84 |

# APPENDIX F



**Plate 4**

**Plate 4 Optical microscope images**

| Species | Sample<br>Cruise: Station (Water depth m) |
|---|---|
| a: *Sphaeroidinella dehiscens* | M78/1: 219-7 (220-400 m) |
| b: *Pulleniatina obliquiloculata* | M95: 531 (60 -100 m) |
| c: *Orbulina universa*<br>    – without spines | M95: 487 (60 -100 m) |
| d: *Hastigerina pelagica* | M95: 531 (60 – 100 m) |
| e: *Globigerinoides sacculifer*<br>    – with sac-like chamber | Puerto Rico: 2 (60 -100 m) |
| f: *Globorotalia ungulata* | M94: 474 (20 - 40 m) |
| g: *Globorotalia menardii* | M95: 584 ( 0 - 20 m) |
| h-i: *Globorotalia tumida* | M78/1: 219-8 (220-400 m) |

Scale bar (a–i) = 100 µm
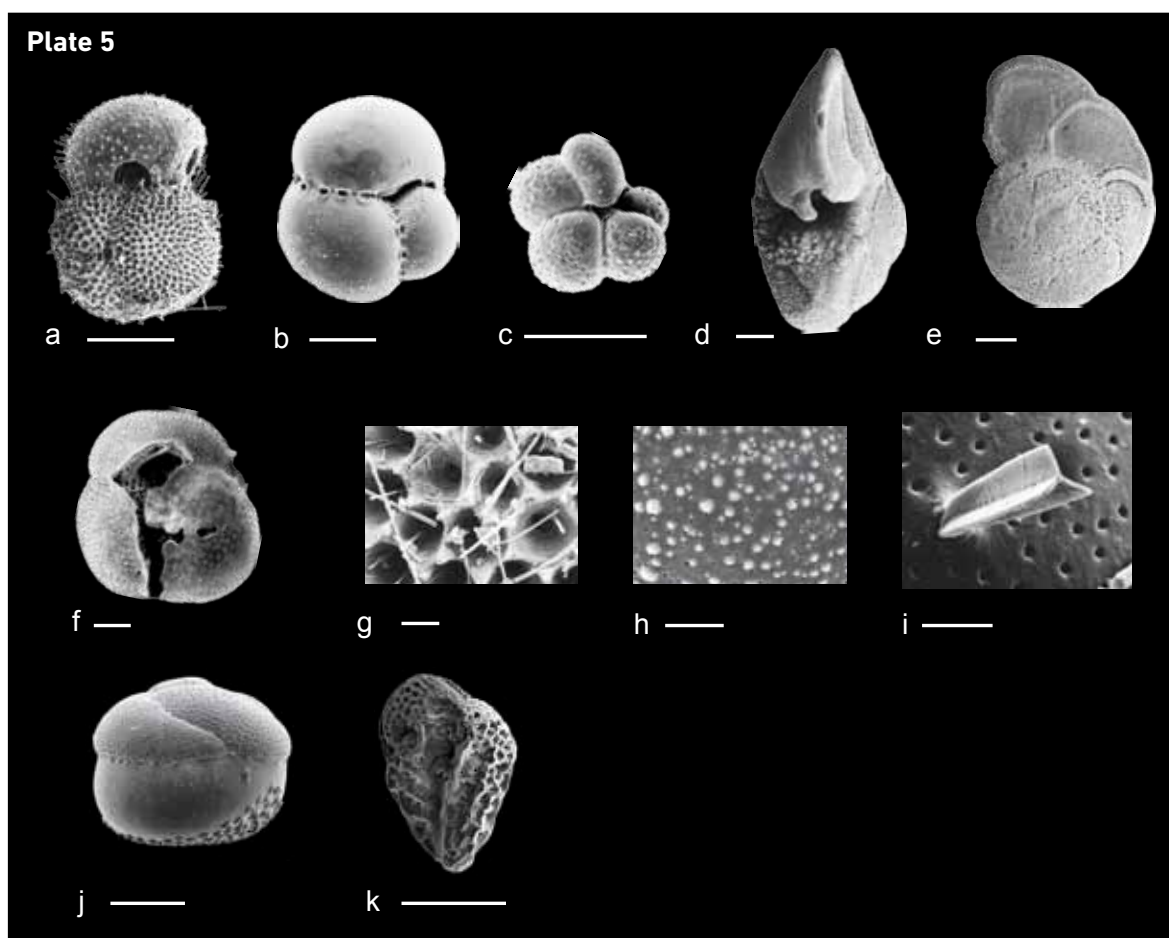
**Plate 5** Scanning electron micrographs (SEM)

| Species | Sample<br>Cruise: Station (Water depth m) |
| --- | --- |
| a: *Globigerinoides ruber* | M78/1: 221-8 (0-40 m) |
| b: *Candeina nitida* | M78/1: 221-8 (210-300 m) |
| c: *Turborotalita quinqueloba* | M78/1: 222-6 (120-180 m) |
| d: *Globorotalia tumida* | M78/1: 219-8 (220-400 m) |
| e: *Globorotalia tumida* | M78/1: 219-8 (220-400 m) |
| f: *Sphaeroidinella dehiscens* | M78/1: 211-5 (200-300 m) |
| g: *Globigerinoides sacculifer* – test surface | M78/1: 211-6 (0-60 m) |
| h: *Globigerinita glutinata* – test surface | M78/1: 221-8 (40-60 m) |
| i: Spine of *Hastigerina pelagica* | M78/1: 222-6 (180-300 m) |
| j: *Tretomphalus bulloides* | Puerto Rico: 3 (5 m) |
| k: *Bolivina variabilis* | Puerto Rico: 2 (0-60 m) |

Scale bar (a-f; j-k) = 100 µm
Scale bar (g-i) = 10 µm

**Appendix G**

**Ph.D. Publication and presentations**

**Peer reviewed publication (Published):**

Bahr, A., Schönfeld, J., Hoffmann, J., Voigt, S., Aurahs, R., Kučera, M., Flögel, S., **Jentzen, A**., Gerdes, A., 2013. Comparison of Ba/Ca and $\delta^{18}O_{WATER}$ as freshwater proxies: A multi-species core-top study on planktonic foraminifera from the vicinity of the Orinoco River mouth. Earth and Planetary Science Letters 383, 45–57.

*(Contribution: Census data of planktonic foraminifera. The data are also presented in Chapter 2)*

**Poster presentations:**

**Jentzen, A**., Schönfeld, J., Nürnberg, D. (2014) Distribution and Geochemical Composition of Living Planktonic Foraminifera in the Caribbean Sea; In: AGU Fall Meeting 2014, 15.-19.12.2014, San Francisco, USA.

**Jentzen, A**., Schönfeld, J., Kučera, M., Weiner, A., Nürnberg, D. (2014) Short and long-term dynamics of planktonic foraminiferal assemblages off Puerto Rico (Caribbean) - Impact of Hurricane „Sandy"; In: International Symposium on Foraminifera FORAMS 2014, 19.-24.01.2014, Concepcion, Chile.

**Jentzen, A**., Schönfeld, J., Kučera, M., Nürnberg, D., Weiner, A. (2013) Living planktonic foraminifera in the Caribbean Sea - a proxy validation study; In: 11. International Conference on Paleoceanography (ICP11) 2013, 01.-06.09.2013, Sitges - Barcelona, Spain.

**Cruise reports (not peer-reviewed):**

Betzler, C., Lindhorst, S., Lüdmann, T., Borstel V., F., Büld, M., Djamlan, E., Eberli, G., Eversheim, J., **Jentzen, A.**, Keizer, F., Ludwig, J., Möbius, J., Paulat, M., Reiche, S., Reijmer, J., Reolid, J., Schiebel, L., Schutter, I., Ulferts, L., Winter, S., Wolf, D., Wunsch, M., Rentsch, H., Raeke, A., 2014. CICARB-Current impact on the facies and stratigraphy of the Bahamas Carbonate Platform. Cruise No. M95 - March 29- April 25, 2013 - Kingston (Jamaica) - Pointe à Pitre (Guadeloupe). METEOR-Berichte, M95. 1-36.

Hübscher, C., Nürnberg, D., Al Hseinat, M., Alvarez Garcia, M., Erdem, Z., Gehre, N., **Jentzen, A**., Kavelage, C., Karas, C., Kimmel, B., Mildner, T., Ortiz, A.O., Parker, A.O., Petersen, A., Raeke, A., Reiche, S., Schmidt, M., Weiss, B., Wolf, D., 2014. Yucatan Throughflow - Cruise No. M94 - March 12 - March 26, 2013 – Balboa (Panama) - Kingston (Jamaica). METEOR-Berichte, M94. 1-32.

*(Contribution: Plankton net, zooplankton filtering and water sampling during cruises RV Meteor M94 and M95 in 2013)*

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