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Some trends in sampling modern living (stained) benthic foraminifera in fjord, shelf and deep sea: Atlantic Ocean and adjacent seas

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INTRODUCTION

The author is undertaking a regional study of the living (stained) benthic foraminiferal faunas of the Atlantic Ocean and adjacent seas (Barents Sea, Gulf of Mexico, Mediterranean). Quantitative and qualitative data on assemblages have been compiled on more than 2000 samples for the 0–1 cm sediment interval. Most areas have been sampled on a single occasion; replicates and repeated sampling for temporal studies are treated as individual samples. The results will be used to define patterns of distribution of standing crop and biodiversity and to relate them to potential causes. These data have come from the literature spanning the period from the introduction of the rose Bengal method of staining foraminifera (as an indicator of life at the time of collection; Walton, 1952) until December 2013. Every effort has been made to include all relevant data.

A by-product of this dataset is that it is possible to recognize trends in the dates and seasons of sampling and the choice of size fraction. The three broad environments considered here are: shelf (<200 m), deep sea (>200 m) and fjord (depths range down to >800 m). Dates of sampling have been grouped into decades. Seasons of sampling are defined for N and S hemispheres: winter (N: December–February; S: June–August); spring (N: March–May; S: September–November); summer (N: June–August: S: December–February) and autumn (N: September–November; S: March–May). Where authors have not given a precise date for each sample, and the dates of the sampling campaign span two seasons, the earlier season has been used. In some cases there are no data on season and these are recorded as unknown. The data presented here are summarized in Tables 1–6 in which the highest values are given in bold. Most of the features are self-evident so only the main points are described below.

RESULTS

Criteria for accepting sample data: (1) the rose Bengal staining method has been used to characterize forms living at the time of collection; (2) numerical data on species abundance for 0–1 cm surface sediment. In cases where the data refer to samples with a thickness of >1 cm, these have been ignored. Where there are no published data tables (as in some older literature) the samples could not be included. All the data relate to field-sampling rather than experiments.

Table 1. Number of samples and percentage of the dataset.

	Water depth (m)	Number	Percentage
Fjord	variable	346	14
Shelf	0–200	**1136**	**47**
Deep sea	>200	941	39
Total		2423	

Table 2. Number and percentage of samples by size fraction studied.

		Shelf	Deep sea	Fjord	Total
		Number			
Fraction	>63	**713**	**313**	**197**	**1223**
	>74	220	0	0	220
	>100	39	85	21	145
	>125	99	**334**	128	561
	>150	28	82	0	110
	>250	37	127	0	164
	Total	1136	941	346	2423
		Percentage			
Fraction	>63	**63**	**33**	**57**	**50**
	>74	19	0	0	9
	>100	3	9	6	6
	>125	9	**35**	37	23
	>150	2	9	0	5
	>250	3	13	0	7

Number of samples: 2423 (Table 1).

Size fraction studied: >63, >74, >100, >125, >150 and >250 µm. Few studies have used the >74, >100, >150 or >250 µm fractions (Table 2). Overall, the predominant fraction is >63 µm but there are clear differences by environment. Whereas shelf and fjord samples are mainly >63 µm, for the deep sea there are slightly more >125 µm analyses.

Decade of sampling: the majority of >63 µm samples were taken in the 1960s to 1990s, whereas for the deep sea and fjords it was the 1990s (Table 3). After an initial burst in the 1950s, the >74 µm samples size fraction has not been much studied. Relatively few samples >100 µm have been studied and then primarily since the 1990s. The >125 µm fraction was the main choice for the deep sea in the 1980–1990s and >150 and >250 µm less often. Overall, the 1990s was the peak decade for sampling (876 samples, Table 3, right-hand column; Fig. 1). Since then there has been a dramatic decline, with only 237 samples since 2000.

Season: for single sampling the most popular sampling season is summer (Table 4) and the least popular is winter (in high latitudes winter sampling may not be technically feasible because of adverse climatic conditions). The relatively high figure for >63 µm winter sampling is mainly from the tropical Gulf of Guinea where seasonality is of minor importance. Only a small proportion of these studies involve repetitive seasonal collection of material and this has been mainly in fjords.

Water depth: the hypsographic curve (Fig. 2) shows the distribution of ocean area by depth. There is a heavy sampling bias

Table 3. Number and percentage of samples by size fraction and decade.

Fraction	>63 µm			>74 µm			>100 µm			>125 µm			>150 µm			>250 µm			Totals			
Number																						
Decade	Shelf	Deep sea	Fjord	Shelf	Deep sea	Fjord	Shelf	Deep sea	Fjord	Shelf	Deep sea	Fjord	Shelf	Deep sea	Fjord	Shelf	Deep sea	Fjord	Shelf	Deep sea	Fjord	Grand total
1950-59	0	0	0	**175**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	175	0	0	175
1960-69	**229**	14	0	2	0	0	4	0	0	0	14	0	0	0	0	0	0	0	**235**	28	0	263
1970-79	186	59	0	39	0	0	0	0	0	13	9	0	0	0	0	0	0	0	**238**	68	0	306
1980-89	89	34	0	4	0	0	0	0	0	20	**164**	**112**	4	12	0	**35**	**92**	0	152	302	112	566
1990-99	158	**193**	**197**	0	0	0	**32**	23	**21**	27	**146**	8	1	**33**	0	2	35	0	220	**430**	**226**	**876**
2000-09	51	13	0	0	0	0	1	**49**	0	**39**	1	8	**23**	**37**	0	0	0	0	114	100	8	222
2010-13	0	0	0	0	0	0	2	13	0	0	0	0	0	0	0	0	0	0	2	13	0	15
Total	713	313	197	220	0	0	39	85	21	99	334	128	28	82	0	37	127	0	1136	941	346	2423

Fraction	>63 µm			>74 µm			>100 µm			>125 µm			>150 µm			>250 µm			All samples			
Percentage																						
Decade	Shelf	Deep sea	Fjord	Shelf	Deep sea	Fjord	Shelf	Deep sea	Fjord	Shelf	Deep sea	Fjord	Shelf	Deep sea	Fjord	Shelf	Deep sea	Fjord	Shelf	Deep sea	Fjord	Grand total
1950-59	0	0	0	**80**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	8
1960-69	**32**	4	0	1	0	0	10	0	0	0	4	0	0	0	0	0	0	0	**21**	3	0	12
1970-79	26	19	0	18	0	0	0	0	0	13	3	0	0	0	0	0	0	0	**22**	8	0	14
1980-89	12	11	0	2	0	0	0	0	0	20	**49**	**88**	14	15	0	**95**	**72**	0	11	26	32	19
1990-99	22	**62**	**100**	0	0	0	**82**	27	**100**	27	**44**	6	4	**40**	0	5	28	0	20	**49**	**65**	**37**
2000-09	7	4	0	0	0	0	3	**58**	0	**39**	0	6	**82**	**45**	0	0	0	0	10	12	2	10
2010-13	0	0	0	0	0	0	5	15	0	0	0	0	0	0	0	0	0	0	0	2	0	1

Table 4. Number and percentage of samples by season of sampling.

Fraction	>63 µm			>74 µm			>100 µm			>125 µm			>150 µm			>250 µm			
Number																			
Season	Shelf	Deep sea	Fjord	Shelf	Deep sea	Fjord	Shelf	Deep sea	Fjord	Shelf	Deep sea	Fjord	Shelf	Deep sea	Fjord	Shelf	Deep sea	Fjord	Total
Unknown	44	19	**51**	0	0	0	6	0	0	13	24	1	0	0	0	4	**94**	0	256
Winter	95	**92**	35	16	0	0	0	0	0	0	27	25	2	4	0	**31**	16	0	343
Spring	**180**	72	4	10	0	0	0	0	0	0	50	**39**	1	20	0	2	17	0	395
Summer	**198**	66	34	**183**	0	0	**32**	**78**	2	**86**	**155**	**40**	**24**	**36**	0	0	0	0	**934**
Autumn	**196**	64	**73**	11	0	0	1	7	**19**	0	78	23	1	22	0	0	0	0	495
Total	713	313	197	220	0	0	39	85	21	99	334	128	28	82	0	37	127	0	2423
Percentage																			
Unknown	6	6	**26**	0	0	0	15	0	0	13	7	1	0	0	0	11	**74**	0	11
Winter	13	**29**	18	7	0	0	0	0	0	0	8	20	7	5	0	**84**	13	0	14
Spring	**25**	23	2	5	0	0	0	0	0	0	15	**30**	4	24	0	5	13	0	16
Summer	**28**	21	17	**83**	0	0	**82**	**92**	10	**87**	**46**	**31**	**86**	**44**	0	0	0	0	**39**
Autumn	**27**	20	**37**	5	0	0	3	8	**90**	0	23	18	4	27	0	0	0	0	20

towards shallower water depths, with 56% of the samples from the shelf. Inner shelf (0–100 m) samples dominate (Table 5). For the deep sea most samples are from the upper continental slope (30% from 200–2000 m) and there is a rapid decline in the number of samples with increasing water depth, with only 4% deeper than 4000 m. Figure 3 shows the number of samples studied per 1% area of the Atlantic Ocean at different water depths (data in Table 6).

Table 5. Number of samples by size fraction and water depth for shelf and deep sea together with the total number and percentage total.

Depth (m)	Number						Total	
	>63 µm	>74 µm	>100 µm	>125 µm	>150 µm	>250 µm	Number	Percentage
0–100	**600**	**217**	34	61	26	30	**968**	**47**
101–200	131	3	5	38	2	7	186	9
201–1000	180	0	**85**	**83**	**45**	**48**	441	21
1001–2000	52	0	0	79	23	37	191	9
2001–3000	32	0	0	63	12	25	132	6
3001–4000	13	0	0	53	2	16	84	4
4001–5000	16	0	0	42	0	1	59	3
>5000	0	0	0	14	0	0	14	1
Unknown	2	0	0	0	0	0	2	0
Sum	1026	220	124	433	110	164	2077	100

Table 6. Number of samples per 1% area (903 700 km²) of the Atlantic Ocean and adjacent seas.

Depth (m)	Percentage area of ocean	Samples	
		Samples	Per 1% area
0–200	5.5	**1154**	**210**
200–1000	5.6	441	80
1000–2000	4.8	191	35
2000–3000	9.1	132	24
3000–4000	21.7	84	15
4000–5000	**32.5**	59	11
>5000	20.9	14	3
Unknown		2	

Data on the areas of the different depth zones from Smith & Sandwell (1997).

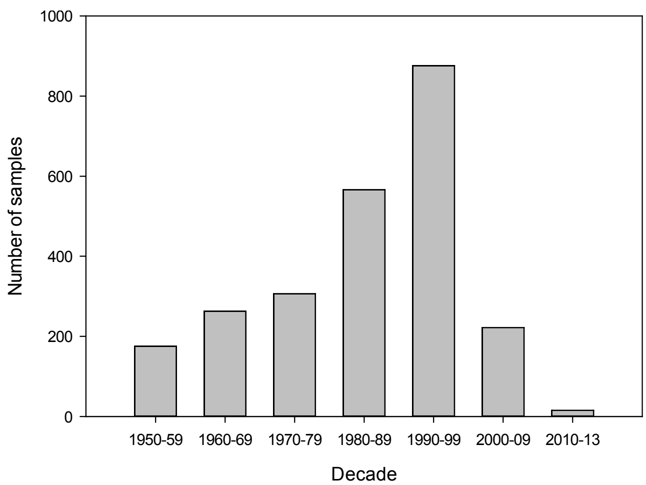

Fig. 1. Number of samples per decade.

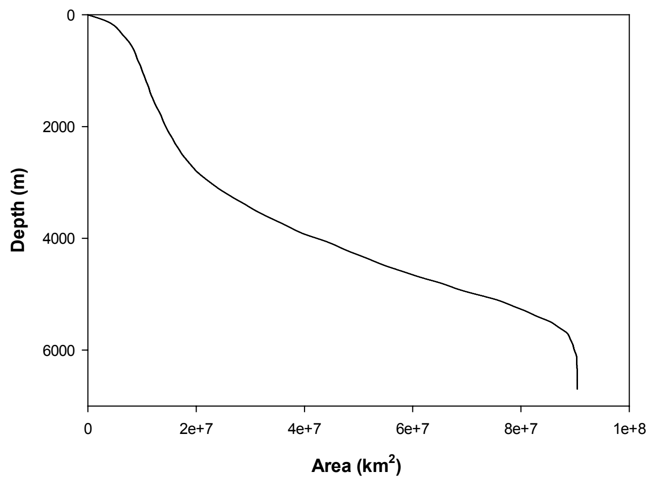

Fig. 2. Hypsographic curve of the Atlantic Ocean, Mediterranean and Gulf of Mexico (based on 1° gridded data from Smith & Sandwell, 1997).

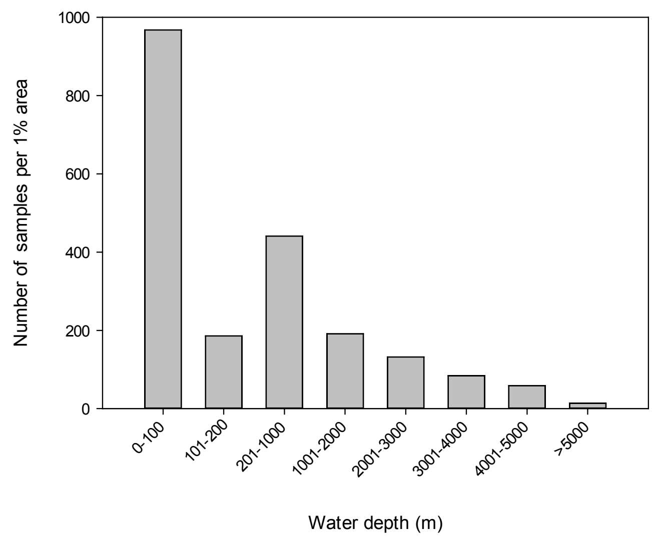

Fig. 3. Number of samples per 1% of the Atlantic Ocean area.

DISCUSSION AND CONCLUSIONS

These data quantify observations that have long been evident: that there has been no consistent choice of size fraction, with >63 and >125 being the most widely used (Schönfeld, 2012) and that there has been a bias towards sampling shallower regions. They also show that there have been notable changes in sampling through time, with the peak decade being the 1990s.

The dramatic decrease in sampling since 2000 may be a short-term blip or the start of a major trend, perhaps reflecting a greater emphasis on experimental and geochemical approaches. In Germany, during the 1990s the research fleet was new and it was easier to get ship's time for deep-sea sampling. Now there is more competition from palaeoclimatic and geochemical consortia and less involvement by individual micropalaeontologists. Furthermore, only a small proportion of deep-sea surface sediment samples so far collected have been processed for foraminiferal analysis; many are housed in cold stores awaiting attention (Joachim Schönfeld, pers. comm., March 2014).

In relation to its area, the deep sea has been grossly under sampled, especially below 1000 m. The practicalities of sampling the deep sea include the need for an ocean-going ship, deep-sea winches capable of sampling great depths, and the slow rate of sample recovery from great depths. In the laboratory, it takes a long time to pick living forms from the overwhelming abundance of planktonic tests in samples taken above the calcite compendium depth (CCD). All these factors add to the cost of undertaking such studies.

It is hoped that these data will aid those planning future sampling expeditions and provide supporting material to justify applications for funding as part of programmes investigating major scientific questions, such as deep-sea diversity, biogeography and the relationships between benthic foraminifera and other micro-/macrofauna in benthic ecological processes.

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