Research paper

Foram-AMBI: A sensitivity index based on benthic foraminiferal faunas from North-East Atlantic and Arctic fjords, continental shelves and slopes

Elisabeth Alve [a,*], Sergei Korsun [b], Joachim Schönfeld [c], Noortje Dijkstra [d], Elena Golikova [b], Silvia Hess [a], Katrine Husum [e], Giuliana Panieri [f]

[a] Department of Geosciences, University of Oslo, Box 1047 Blindern, 0316 Oslo, Norway
[b] Department of Invertebrate Zoology, Faculty of Biology, St. Petersburg State University, Universitetskaya nab. 7/9, 199034 St. Petersburg, Russia
[c] GEOMAR - Helmholtz-Centre for Ocean Research Kiel, Wischhofstr. 1-3, D-24148 Kiel, Germany
[d] Department of Geology, University of Tromsø, Dramsveien 201, 9037 Tromsø, Norway
[e] Norwegian Polar Institute, Box 6606 Langnes, 9296 Tromsø, Norway
[f] CAGE — Centre for Arctic Gas Hydrate, Environment and Climate, Department of Geology, UiT the Arctic University of Norway, Dramsveien 201, N-9037 Tromsø, Norway

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ABSTRACT

The present study follows up the FOraminiferal BIo-MOnitoring (FOBIMO) working group's aim to explore methods which will improve the usefulness of benthic foraminifera in environmental monitoring. An internationally well-established marine biotic index, AMBI, commonly applied to assess ecological quality status was adapted for use on benthic foraminifera. As required by the AMBI formula, species were assigned to one of five ecological groups according to their sensitivity/tolerance to conditions along an increasing stress gradient (here increasing organic matter enrichment). For the assignments, we used 19 published data sets on fully marine NE Atlantic and Arctic fjord, continental shelf, and slope assemblages for which total organic carbon (TOC) data were available. Assignments were based on the relative abundance of the different species along associated TOC gradients. Of the 128 assigned species, the majority was assigned to Groups I–III dominating in low to moderately organic enriched environments with a high to good ecological quality status. Groups IV and V, representing strongly organically enriched environments with a moderate to poor ecological quality status, had 1 and 2 species, respectively. The resulting foraminifera-based Foram-AMBI was calculated using the AMBI formula and tested on four independent foraminiferal data sets from the same geographical region. The validation included correlations of the Foram-AMBI with Shannon's diversity (H′log$_2$) as well as with the organic carbon content in the validation data sets. In two validation data sets from the Norwegian Skagerrak coast, a high proportion of the assemblages consisted of assigned species. The results showed a good correlation between the Foram-AMBI and both the TOC and Shannon's diversity H′log$_2$. In two more southern validation data sets all TOC values were low and the abundance of unassigned species was too high for the Foram-AMBI to provide trustworthy results.

The Foram-AMBI of the two validation data sets with high abundance of assigned species clearly reflected an increasing organic carbon-induced stress gradient. Hence, this first attempt to apply the AMBI formula on benthic foraminiferal data shows promising results. However, to improve the applicability of Foram-AMBI, there is a need to assign more species by obtaining data from studies along wide organic carbon pressure gradients, particularly from the southern North Sea and southwards.

1. Introduction

Following the publication of the European Water Framework Directive (WFD, 2000/60/EC), numerous biotic indices have been proposed to quantitatively characterise the ecological quality status (EcoQS) of marine soft-bottom habitats. Also, as part of the EU's wish to coordinate the approaches to implement the Marine Strategy Framework Directive (MSFD, 2008/56/EC) in the North-East Atlantic region there is a need to develop common quantitative indicators for ecological quality (e.g., Josefson et al., 2009; Borja et al., 2011). The development of the indices is mainly based on soft sediment benthic macroinvertebrate communities, the standard group of organisms used in conventional environmental monitoring. Of these indices, the most commonly used and widely accepted is the AZTI Marine Biotic Index, AMBI, which was introduced by Borja et al. (2000) based on the work of Glémarec and

* Corresponding author.
E-mail addresses: ealve@geo.uio.no (E. Alve), s_korsun@ocean.ru (S. Korsun), jschoenfeld@geomar.de (J. Schönfeld), noortje.dijkstra@uit.no (N. Dijkstra), e.golikova@bio.spbu.ru (E. Golikova), silvia.hess@geo.uio.no (S. Hess), katrine.husum@npolar.no (K. Husum), giuliana.panieri@uit.no (G. Panieri).

Hily (1981), Hily (1984), Glémarec (1986), and Grall and Glémarec (1997).

Another important group of marine organisms reflecting environmental conditions are benthic foraminifera. The usefulness of these protists as environmental indicators is due to their fast turnover rates, abundance, and high degree of specialisation (reviews in Alve, 1995; Scott et al., 2001; Nigam et al., 2006; Martínez-Colón et al., 2009). Their shells fossilise and, therefore, they can be used not only to define EcoQS for the present (Bouchet et al., 2012; Barras et al., 2014) but also provide time series back to reference conditions, e.g., prior to industrialisation (for discussion, see Alve et al., 2009; Dolven et al., 2013). The latter is in contrast to conventional biological monitoring which usually covers the past 20 years only (Borja et al., 2010).

So far, official and governmental soft-bottom benthic marine environmental bio-monitoring programmes aimed to characterise EcoQS have exclusively been based on macroinvertebrate surveys for which standardised methods are defined. Hence, the FOraminiferal BIoMOnitoring (FOBIMO) working group was initiated in 2011 with the aim to standardise methods for the specific use of benthic foraminifera in environmental monitoring. As part of this process, a suite of standard methods was proposed (Schönfeld et al., 2012). The next step was to test if established biotic indices commonly used on macrofauna also work for benthic foraminifera. Because of its wide use in traditional bio-monitoring, the FOBIMO working group agreed that the marine biotic index AMBI was a reasonable choice. Four sub-working groups were established of which our group was to focus on NE Atlantic and Arctic fjords, continental shelves, and slopes (Fig. 1). Consequently, the aims of the present study are to 1) assign benthic foraminiferal species recorded in this region to ecological groups according to the AMBI scheme, 2) calculate AMBI for independent foraminiferal data sets from the same geographical region, and 3) validate if the resultant index values correlate with environmental pressure gradients and other established biotic indices. In order to do so, we followed the criteria and procedures in Borja et al. (2000) as closely as possible. In order to distinguish the foraminifera-based index described here from

that based on macroinvertebrate communities, we introduce the name Foram-AMBI.

Being able to use the same index for both foraminifera and macroinvertebrates will make it possible to test if the two organism groups reflect ecological conditions similarly. If so, it will be possible to define EcoQS in present-day environments using Foram-AMBI. Compared to macrofauna sampling, collecting foraminifera entails less disturbance at the sites of investigation due to the smaller sampling gear used. Additionally, and following the application of fossil assemblages in Dolven et al. (2013), Foram-AMBI may allow the assessment of historical changes in EcoQS using an established classification system beyond time intervals for which macroinvertebrate time series exist. Another advantage using an established index based on foraminifera over the use of traditional macrofauna methods is that the foraminifera can provide information on EcoQS in habitats where low abundance of macroinvertebrates hampers their applicability (e.g., oxygen depleted basins and many bathyal environments).

2. Material and methods

2.1. Defining Foram-AMBI

AMBI is based on species' sensitivity/tolerance to an environmental stress gradient. Increased supply of organic material to the sea-floor, often as a result of cultural eutrophication, has been the most severe anthropogenic pressure on marine soft-bottom communities (e.g., Díaz and Rosenberg, 2008). Additionally, since organic matter enrichment is tightly coupled with enhanced oxygen consumption, increased supply of organic material is commonly linked to decreased dissolved oxygen concentrations in the sediment pore water and, in some instances, in the bottom water. Consequently, we used sedimentary organic carbon as a proxy parameter displaying the stress level imposed on the benthic communities. Total organic carbon (TOC) content of surface sediments is one of the most commonly reported environmental parameters in recent benthic foraminiferal studies. Therefore, TOC was
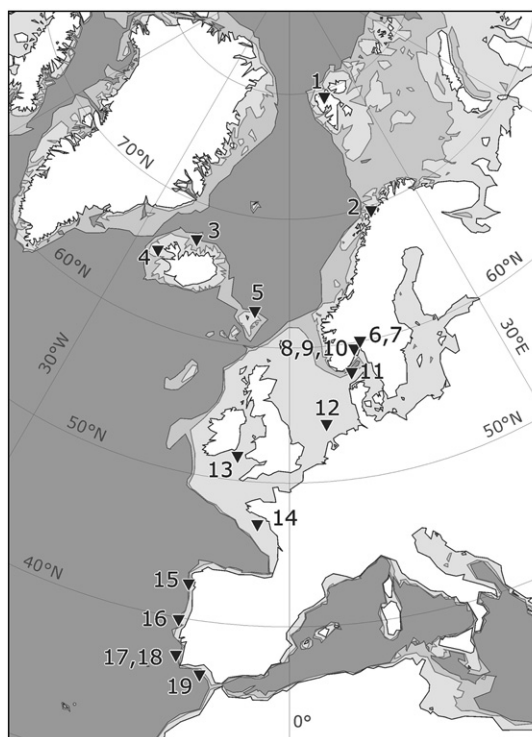
Authors and study area:

1. Hald and Korsun (1997); Svalbard fjords
2. Husum and Hald (2004); Malangen fjord, N Norway
3. Rytter et al. (2002); N Icelandic margin
4. Jennings et al. (2004); Icelandic shelf
5. Mackensen et al. (1985), Mackensen (1987); Iceland-Scotland Ridge and off SW Norway
6. Alve and Nagy (1986); Oslofjord, Norway
7. Hess et al. (2014); Oslofjord, Norway
8,9,10. Alve (2000); Frierfjord, Norway (fossil assemblages)
11. Alve and Murray (1997); Skagerrak, North Sea
12. Moodley (1990); S North Sea
13. Scott et al. (2003); Celtic Sea
14. Duchemin et al. (2005); Bay of Biscay
15. Diz and Frances (2008); Ria de Vigo, NW Spain
16. Koho et al. (2007); Nazaré canyon, Portugal
17. Schönfeld (1997); S Portugese margin
18. Schönfeld (2001); Portugese slope
19. Schönfeld (2002); Gulf of Cadiz, Spain

Fig. 1. Map showing the location of the data sets used for species assignments in the present study. Bathymetric contours show 200 m and 500 m, GEBCO.

chosen to scale species patterns of environmental sensitivity in the present study. In order to calculate AMBI, as many species as possible have to be assigned to one of five ecological groups depending on the species' sensitivity to increasing stress, here as inferred sensitivity to increasing TOC and associated biogeochemical modifications of the sediment habitat. This follows the concept of Glémarec and Hily (1981) with the underlying assumption of a structured gradient between a spatially confined source of excess particulate organic carbon and a nearly unaffected situation in unimpacted environments. The organic enrichment can be naturally or human induced.

The following characteristics, largely based on Grall and Glémarec (1997) and Borja et al. (2000), were used to assign benthic foraminiferal species to the five ecological groups (Fig. 2):

- Group I (G I). "Sensitive species" are sensitive to organic matter enrichment. Their abundance is highest under unimpacted conditions (at lowest TOC values) and drops to zero as organic matter concentration increases.
- Group II (G II). "Indifferent species" are indifferent to organic matter enrichment. They never dominate the assemblage. They occur in low abundance over a broad range of organic matter concentrations, but are absent at very high concentrations.
- Group III (G III). "Tolerant species" are tolerant to excess organic matter enrichment. They may occur at low TOC, their highest frequencies are stimulated by organic enrichment but they are absent at very high organic matter concentrations.
- Group IV (G IV). "2nd-order opportunistic species" show a clear positive response to organic matter enrichment with maximum abundance between the maxima of Groups III and V.
- Group V (G V). "1st-order opportunistic species" show a clear positive response to excess organic matter enrichment with maximum abundance at a higher stress level induced by organic load than species of Group IV. At even higher organic matter concentrations, no foraminifera are able to survive.

As opposed to the assignments of macroinvertebrates, trophic characteristics were not used in the assignments of the foraminiferal species
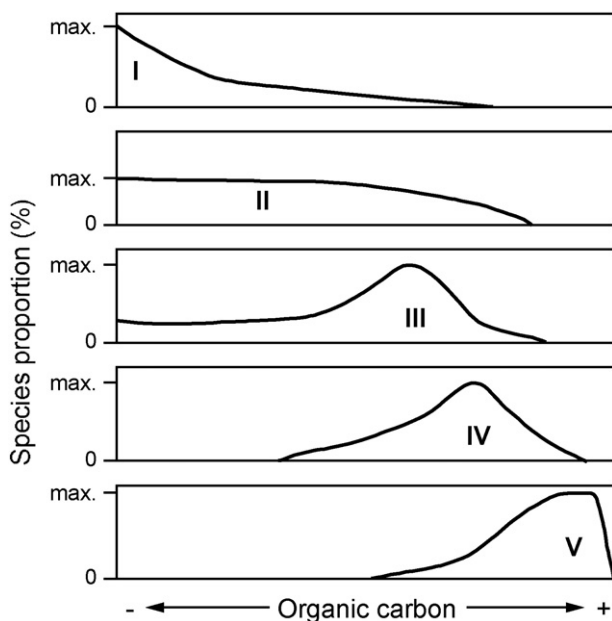
Fig. 2. Schematic showing the relative abundance pattern along the main environmental stress gradient (TOC) for benthic foraminiferal species assigned to the five ecological groups defined in the text. Max = maximum abundance (%) of a species in a specific data set. For full explanations, see the text.

due to current limited knowledge. The Foram-AMBI was calculated from the sum of relative abundances of all species in the different ecological groups using the Borja et al. (2000) formula:

$$AMBI = \{(0 \times \%G\ I) + (1.5 \times \%G\ II) + (3 \times \%G\ III) + (4.5 \times \%G\ IV) + (6 \times \%G\ V)\}/100$$

For samples where species that are not assigned make up >20% of the assemblage, the AMBI-values should be evaluated with care and if they make up >50%, AMBI should not be used (Borja and Muxika, 2005).

2.2. Data selection

The present study is based on published soft-bottom, living (stained) and fossil benthic foraminiferal assemblage data from North East Atlantic and Arctic fjords, continental shelves, and upper slopes (35° to 80°N and 60°W to 60°E, Fig. 1). The data sets were available as Microsoft Excel spreadsheets through Murray's (2006) online data base (www.cambridge.org/9780521828390; 'Resources') and by courtesy of the respective authors.

The following criteria had to be met for data sets on present-day assemblages to be used in the assignments: 1) foraminiferal counts and TOC values had to be from the same station. 2) The samples had to represent normal marine shelf to upper slope conditions with a maximum water depth of about 1200 m. In near coastal, stratified waters, the samples had to come from below the halocline with salinity more than about 30psu. 3) In order to exclude allochthonous faunal elements, only living (rose Bengal stained) assemblages were considered. 4) Each sample had to contain >50 stained specimens. 5) A data set had to include at least 4 samples meeting criteria 1–4. We omitted data with obvious errors (e.g., sum of relative abundance >100%, unrealistic shifts in species composition between samples from the same station, or unrealistically high frequency of stained specimens among sessile foraminifera such as *Cibicides lobatulus*). We also excluded data from areas where it was suspected that the samples contained redeposited coal. For such samples, the TOC values would not be meaningful in the context of the present study. Among all published papers on living (stained) foraminifera from the study region, only 19 data sets were found to meet the above-mentioned criteria. Of these, 16 were used for species assignments and three for subsequent validation of the results (Table 1). Most data sets were at the lower end of what can be an expected TOC range in fine-grained, coastal sediments. Therefore, four data sets on fossil assemblages from microtidal areas with negligible supply of allochthonous species, spanning wide TOC-ranges, were also included. Three of these data sets were used in the species assignments and the fourth was used for validation of the results (Table 1).

2.3. Preparation of data and species assignments

In preparation for the assignments, each data set was standardised to relative abundances. To obtain consistency between the data sets, "organic-walled allogromiids" (sensu Gooday, 2002) were omitted prior to the calculation of relative abundances. Each species was assigned to one of the five ecological groups based on their abundance pattern versus sedimentary TOC concentration. The abundance patterns were displayed using the scatter plot (X/Y) diagram function of Microsoft Excel™ and visually compared with the principal patterns as outlined above and in Fig. 2.

We assigned all species occurring in at least three samples and which made up >2% in at least one sample in each data set. These species assignments were summarised in a master table (Web Appendix Table 1). If the abundance pattern of a species could be assigned to more than one group, a conditional assignment was given. Species with such assignments were indicated by [ ] in the master table. A few species (e.g., *Bulimina marginata*) showed a high (>20%) abundance over a relatively wide range of TOC. Such species were able not only to

Table 1

Details of data sets used for species assignments and validation (VDS). Location of data sets is shown in Fig. 1. VDS = validation data sets; n.d. = no data. Water depth reflects range for the original study (max depth used in the present paper is 1200 m).

Data set	Local study area	Reference	Data source WA-nr[a]	Sampling equipment	Number of samples[b]	Water depth (m)	Sediment interval (cm)	Assemblages used	Foram size fraction (µm)	TOC (%)	Sand content (%)
1	Svalbard fjords	Hald and Korsun (1997)	WA-97	Box corer	34 (55)	65–360	surface 1–2	rB stained	>100	0.3–2.1	0.1–36.3
2	Malangen fjord, N Norway	Husum and Hald (2004)	WA-100	Box corer	13	88–445	0–2	rB stained	>100	0.65–2.10	4.3–88.0
3	N Icelandic margin	Rytter et al. (2002)	Paper and authors	Box corer and grab sampler	21 (46)	148–1552	0–1	rB stained	>125	0.41–2.05	0.51–78.75
4	Icelandic shelf	Jennings et al. (2004)	WA-191	Grab sampler	4 (32)	165–656	surface cm	rB stained	>106	2.07–2.73	1.65–6.82
5	Iceland-Scotland Ridge and off SW Norway	Mackensen et al. (1985); Mackensen (1987)	WA-192	Box corer	27 (78)	144–3940	surface 0.5–1.5	rB stained	>125	0.03–1.26	2–47
6	Oslofjord, Norway	Alve and Nagy (1986)	Paper and authors	Gravity corer	8 (64)	18–51	Top 1–2	rB stained	>125	1.4–3.6	<2
7	Oslofjord, Norway	Hess et al. (2014)	Paper and authors	Gravity corer	15	49–51	0–1	rB stained	>63	1.4–3.5	n.d. (mainly mud)
8	Frierfjord, Norway	Alve (2000); core 20–91	Paper and author	Gravity corer	9 (18)	72	15–43	Fossil assemblages	>125	0.36–4.71	n.d. (mainly mud)
9	Frierfjord, Norway	Alve (2000); core 48–91	Paper and author	Gravity corer	20 (21)	50	0–32	Fossil assemblages	>125	0.6–15.2	n.d. (mainly mud)
10	Frierfjord, Norway	Alve (2000); core 43–91	Paper and author	Gravity corer	12 (19)	93	22–51	Fossil assemblages	>125	0.62–4.24	n.d. (mainly mud)
11	Skagerrak, North Sea	Alve and Murray (1997)	WA-113	Multicorer	36	117–551	0–2	rB stained	>63	0.4–2.8	<10 except Danish slope with up to 80 (Bøe et al., 1996)
12	S North Sea	Moodley (1990)	Paper	Box corer	6 (8)	28–45	0–1	rB stained	>63	0.21–1.37	Sand (93–284 µm medium grain size)
13	Celtic Sea	Scott et al. (2003)	WA-119	Grab sampler	26 (52)	64–115	surface 0.5	rB stained	>63	0.13–1.17	17.1–96.9
14	Bay of Biscay	Duchemin et al. (2005)	Paper	Multicorer	4	100–130	0–1	rB stained	>63	0.13–0.26	>50–<70 (silty sand)
15	Ria de Vigo, NW Spain	Diz and Frances (2008)	Paper and authors	Box corer	13 (16)	22–42	0–1	rB stained	>63	2.0–4.5	n.d.
16	Nazaré canyon, Portugal	Koho et al. (2007)	Paper	Multicorer and box corer	6 (13)	151–3097	0–5	rB stained	>150	1.5–3.3	n.d.
17	S Portuguese margin	Schönfeld (1997)	WA-196	Box corer	16 (18)	246–2985	0–1	rB stained	>250	0.23–0.80	0.3–84.8
18	Portuguese slope	Schönfeld (2001)	WA-195	Multicorer	4 (3)	801–1919	0–1	rB stained	>150	0.33–0.76	n.d.
19	Gulf of Cadiz, Spain	Schönfeld (2002)	WA-194	Box corer and grab sampler	15 (27)	103–1917	0–1 and the surface of hard substrate	rB stained	>250	0.23–0.87	4–62
VDS 1	Norwegian Skagerrak coast	Bouchet al. (2012)	Paper and authors	Gravity corer	27 sta. each with 3 replicates	23–204	0–1	rB stained	>63	0.8–9.0	2–48
VDS 2	Oslofjord, Norway	Dolven et al. (2013)	Paper and authors	Gravity corer	59 (67)	55–160	0–61	Fossil assemblages	>63	1.33–6.05	n.d. (mainly mud)
VDS 3	S North Sea	de Nooijer et al. (2008)	Paper and authors	Box corer	11 sta. each with 2 replicates	25–50	0–1	rB stained	>63	0.12–0.7	>80 (fine sand)
VDS 4	Gulf of Cadiz, Spain	Mendes et al. (2012)	Paper and authors	Grab sampler, vibrocorer	51	11–116	0–1	rB stained	>63	[c]	n.d.

[a] Web Appendix tables in Murray (2006).

[b] No. of samples used in the present study (total no. of samples in cited study).

[c] TOC data not available, interpolated near-bottom suspension concentrations (mg/l) were used instead.

tolerate but even to benefit from high organic carbon levels. Hence, these species were assigned to the appropriately highest group. Because it is not obvious that all species belonging to the same genus respond in the same way to organic enrichment, unspecified species or species groups were not assigned. Ideally, species which had only one conditional assignment across all data sets should not have been considered in the final assignment. However, due to the way the AMBI formula is constructed, a species which is not assigned will automatically be merged with Group I species. Consequently, if there was a chance that such a species showed e.g., a Group III-pattern, it was considered more correct to assign it to Group III rather than not to assign it at all.

The assignments were undertaken in several steps. First, pairs of authors were responsible for assigning specific data sets. The assignments of the first investigator were cross checked by the second and vice versa. If the second investigator came to a different conclusion, this was discussed and consensus was reached. During a second step, all data sets were scrutinised again and the assignments were revised in a plenary meeting. During this revision, particular attention was paid in evaluating the assignments of species in each data set relative to a realistic maximum TOC range expected to occur from an unimpacted to a stressed environment, i.e., each data set was evaluated within a broader continuum. The master table was modified accordingly. If a species was assigned differently in different data sets, the pattern that was recognised in the majority of studies was taken as the final assignment.

In the master table, we kept the species names as given in the original studies. Some emendations were made in cases where species denominations provided by the authors differed from the generally used taxonomy, or where the plates of the respective papers revealed an obvious misidentification. In cases where we suspected that different names were used for the same species, we paid particular attention to assign them in the same way. This applied to e.g., *Globobulimina auriculata/turgida*, *Cassidulina laevigata/carinata*, *Cassidulina neoteretis/teretis*, *Adercotryma glomerata/wrighti*. In some cases, generic names for the same species varied between authors (e.g., *Brizalina/Bolivina skagerrakensis*, *Fontbotia/Cibicides wuellerstorfi*). In such cases, we selected one common generic name for each of these species, mainly following the World Register of Marine Species (WoRMS; Hayward et al., 2014). However, in a few cases where the WoRMS suggestion was exotic, e.g., *Veleroninoides*, we for the sake of easy perception kept the more commonly used generic name, in this example, *Cribrostomoides*.

2.4. Validation of Foram-AMBI

In order to validate if the Foram-AMBI reflected changes in environmental disturbance along a gradient of increased organic carbon, the index was calculated for and tested on separate, independent data sets from the same geographic region. To avoid circular arguments, the test data sets had not been used in the species assignments. The data sets were chosen so that they covered the widest possible range in TOC and represented both live (stained) and fossil (sub-recent) assemblages. The Foram-AMBI was calculated for the test data sets and correlated against 1) the pressure parameter used for assigning the species; i.e., the TOC of the test data sets, and 2) a biotic index which measures species diversity rather than sensitivity. For the latter, Shannon's H′log$_2$ (Shannon and Weaver, 1963) was chosen because it is one of the best metrics to detect clear gradients of degradation in macroinvertebrates (Borja et al., 2011) as well as in benthic foraminifera (Bouchet et al., 2012). H′log$_2$ was calculated using PRIMER version 6.1.6 (Clarke and Gorley, 2006). Data on living (stained) assemblages included samples from the continental shelf in the northern Gulf of Cadiz (Mendes et al., 2012; surface 0–1 cm sediment, >63 μm), the Frisian Front, southern North Sea (de Nooijer et al., 2008; 0–1 cm, >63 μm, 2 pooled replicates), and the Norwegian Skagerrak coast (Bouchet et al., 2012; 0–1 cm, >63 μm, 3 pooled replicates) (Table 1). Test data on fossil assemblages included samples from the Oslofjord, Norway (Dolven et al., 2013; >63 μm).

3. Results and discussion

3.1. Species assignments

Of the 419 species recorded in our NE Atlantic and Arctic data sets, 31% (128 species) were assigned to one of the ecological groups defined above. The fact that about two thirds of the species could not be assigned is probably both due to the rarity of many species and to the narrow TOC range in most data sets (Table 1). As the majority of the unassigned taxa were rare, they would not seriously affect the Foram-AMBI values. We did not introduce any cut-off values for accessory species because in the future, as more data become available, many of these species will probably be assigned. The effect of narrow TOC ranges is discussed in Section 3.2.
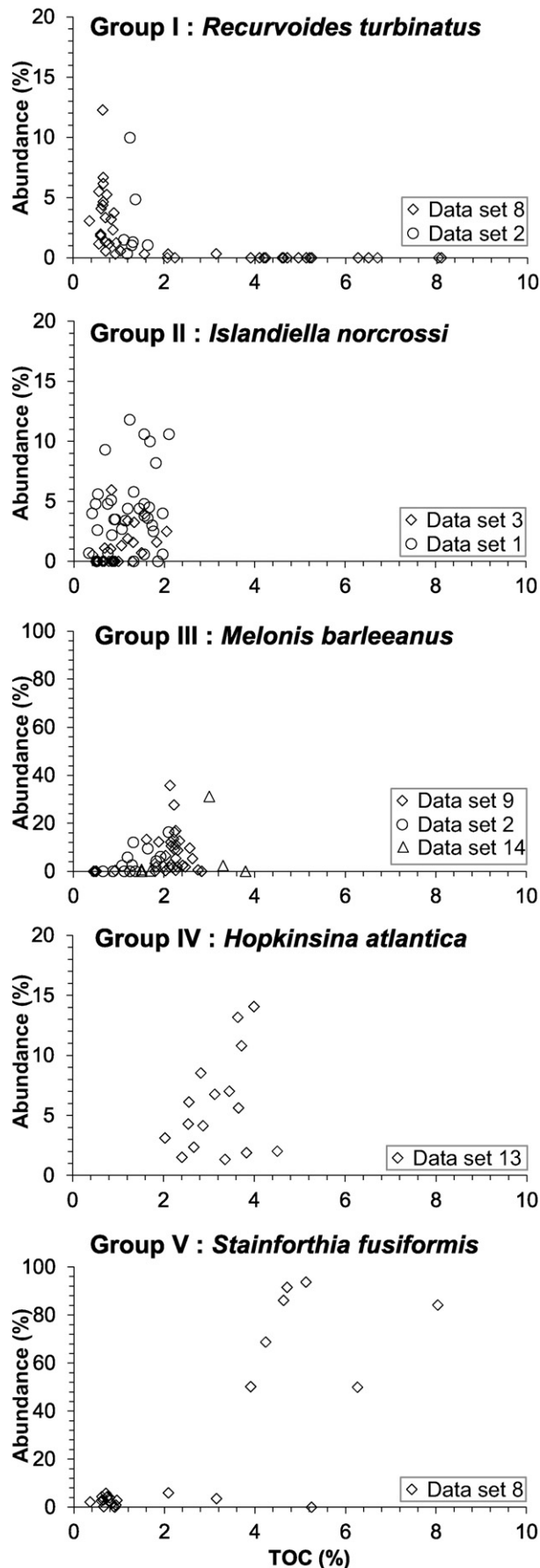
Examples of distribution patterns for species with characteristic patterns within the different groups are shown in Fig. 3. The majority of species were assigned to Groups I (65 species), II (33 species), and III (27 species). Groups IV and V only had 1 and 2 species, respectively (Table 2, Fig. 4, Web Appendix Table 1).

Epifaunal species like *Textularia bocki* and attached forms like *Cibicides* spp. or *Rosalina* spp. were mostly assigned to Group I. Their abundance was not directly linked to sedimentary TOC, but rather reflected the impact of bottom-near currents (Lutze and Thiel, 1989; Linke and Lutze, 1993). Passive suspension feeders, such as *Marsipella cylindrica*, *Rhabdammina abyssorum* and *Saccorhiza ramosa* showed Groups I and II patterns. Their abundance was related to near-bottom or intermediate nepheloid layers, regardless of whether the suspended organic particles were deposited where the species dwelled, or moved along the slope by contour currents (Altenbach et al., 1988; Schönfeld, 1997, 2002).

Slope and shelf species previously reported as indicators of high organic matter fluxes (Caralp, 1989; Altenbach et al., 1999) showed multiple patterns. For instance, *Uvigerina mediterranea* generally showed a Group I pattern whereas *Uvigerina peregrina* was assigned to Group III at the Portuguese margin where it showed a regional abundance maximum in C$_{org}$-rich surface sediments on the lower continental slope off Cape Sines (Schönfeld, 1997; Schönfeld and Altenbach, 2005). The same applies to *Nonionella iridea* which not only responds opportunistically to phytodetritus (e.g., Mackensen et al., 1990; Gooday and Hughes, 2002; Duchemin et al., 2005) but also shows maximum abundance where no fresh organic detritus recently was deposited. The latter strongly indicates that *N. iridea* also may feed on degrading organic matter and associated microbes (Duffield et al., 2015). *Melonis barleeanus* was mainly assigned to Group III, once to Group II or III, and often with a conditional assignment. This may reflect the motile behaviour of the infaunal *Melonis barleeanus*, which ascends to the sediment surface during times of seasonally restricted availability of fresh organic matter (Linke and Lutze, 1993; Schönfeld, 2001) or follows the bacterial flora of the migrating nitrate-reduction zone (Fontanier et al., 2002).

Hopkinsina atlantica displayed a Group IV pattern. This species has been considered opportunistic (Diz and Frances, 2008), preferring sandy muds and muddy sands at inner shelf settings (Moodley, 1990; Schönfeld et al., 2013), and showing abundance maxima under river discharge-induced high productivity (Mendes et al., 2012).

Stainforthia fusiformis and *Quinqueloculina stalkeri* were the only species assigned to Group V. *Stainforthia fusiformis* is an opportunistic species that commonly occurs in intertidal to outer shelf environments of northwestern Europe (Alve, 2003; Murray, 2006). It is related to organic-rich muds and blooms in oxygen-deficient, stressed environments (Alve, 1994; Alve and Murray, 1997). *Quinqueloculina stalkeri* has been reported in high numbers from some glaciated fjord heads (<50 m) affected by turbid meltwater (Korsun and Hald, 1998, 2000; Guilbault et al., 2003).

Fig. 3. Examples of distribution patterns for species with characteristic patterns within the five ecological groups. For data set numbers; see Fig. 1 and Table 1. Note different scales on y-axes.

3.2. Regional differences

The data sets can be divided into two groups, a northern and a southern, by a latitudinal line through the southern North Sea at approximately 55°N. For most data sets of the northern group, >45% of the species were among the assigned ones (Fig. 5). On the other hand, among the southern data sets, all but one had <45% assigned species. Hence, fewer assignments were possible at lower latitudes, south of the southern North Sea. Along the same lines, the southern data sets seemed to have a higher gamma diversity (Shannon's H'$_{log2}$ calculated from pooled samples for each data set). These differences may partly reflect that several of the southern data sets had narrow TOC ranges and low values (Fig. 5). A narrow TOC range in a data set strongly hampers the possibility to decide which abundance pattern a species follows along the organic carbon axis (Fig. 2). This further hampers the possibility to assign species only occurring in the south to specific ecological groups. The southward increase in gamma diversity may reflect a general north–south increase in species richness (e.g., Saidova, 2008; Dorst and Schönfeld, 2013). The maximum values in this index may also be linked to the consistently low sediment TOC values in the same samples. Irrespectively, the lower percent of assigned species in the south compared to the north makes Foram-AMBI more useful in northern waters at the moment. New data along broad TOC ranges are needed to improve the usefulness of Foram-AMBI from the southern North Sea to the western Iberian Margin.

3.3. Validation of Foram-AMBI

On average, unassigned species made up 8% (maximum 22%) of the living assemblages from the Norwegian Skagerrak coast (Bouchet et al., 2012, VDS 1) (Table 3). This is well within the limit of 20% unassigned species above which the AMBI-values should be evaluated with care (Borja and Muxika, 2005). Therefore, Foram-AMBI was considered to be applicable for this data set. The index ranged from 1.8 to 5.9 indicating a good to moderate, and for less than half the samples, a poor to bad ecological quality status (EcoQS) (Borja et al., 2003, Table 1). A positive correlation between the Foram-AMBI and the associated sedimentary TOC ($r^2 = 0.42$, n = 27) (Fig. 6) indicates that this sensitivity index reflects the change in ecological status along a gradient of increase in organic load in the Skagerrak data set (VDS 1). The correlation with Shannon's diversity H' was even better (r = 0.90) indicating that the Foram-AMBI reflects EcoQS as well as H'.

The fossil assemblages from the Oslofjord (Dolven et al., 2013, VDS 2) consisted of a similarly low abundance (10% on average) of unassigned species as the living assemblages from the adjacent Skagerrak (Table 3). In VDS 2 the Foram-AMBI ranged from 1.5 to 5.4 indicating good to poor EcoQS (Borja et al., 2003). The index showed a high positive correlation with sedimentary organic carbon of samples from the same strata ($r^2 = 0.52$, n = 59). The correlation with H' was about the same ($r^2 = 0.87$) as in the Skagerrak. Deciding whether or not a particular ecological quality status is a result of natural or human induced processes is important for decision makers but a challenge for traditional environmental monitoring strategies. As pointed out by Dolven et al. (2013), even oxygen depletion may represent the reference conditions. So far, measures have not been taken by governmental bodies to follow up the consequences of this perspective so the same reference conditions are used for all water types (e.g., Veileder, 2013).

In the two more southern validation data sets, unassigned species made up substantially higher proportions of the assemblages (Table 3). In samples from sandy bottoms of the southern North Sea (de Nooijer et al., 2008, VDS 3), unassigned species made up on average 28% of the living assemblages, with 7 of 11 samples exceeding 20%.

Table 2
All assigned species in alphabetical order and their final assignment (fa) to the respective ecological groups, Groups I to V. Group numbers I–V are given in Arabic numerals.

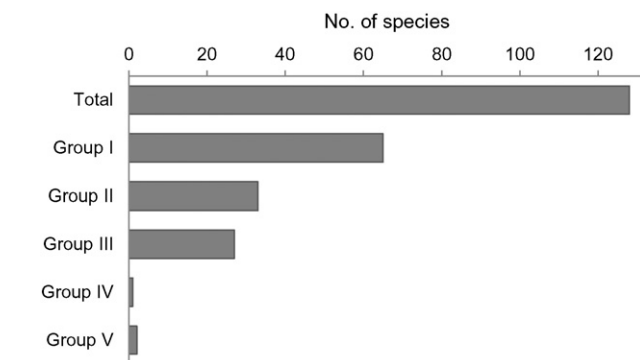| Species	fa	Species	fa	Species	fa
Adercotryma glomerata	1	*Deuterammina* cf. *rotaliformis*	1	*Pullenia bulloides*	3
Adercotryma wrighti	1	*Deuterammina rotaliformis*	1	*Pullenia osloensis*	3
Ammodiscus catinus	1	*Discanomalina semipunctata*	1	*Quinqueloculina seminula*	2
Ammoglobigerina globigeriniformis	1	*Discorbinella bertheloti*	1	*Quinqueloculina stalkeri*	5
Ammolagena clavata	1	*Eggerelloides medius*	3	*Rectuvigerina bononiensis*	2
Ammoscalaria tenuissima	1	*Eggerelloides scaber*	3	*Rectuvigerina phlegeri*	2
Ammosphaeroidina sphaeroidiniformis	1	*Elphidium albiumbilicatum*	3	*Recurvoides trochamminiforme*	3
Amphicoryna scalaris	2	*Elphidium bartletti*	3	*Recurvoides turbinatus*	1
Astrononion gallowayi	2	*Elphidium excavatum clavatum*	1	*Reophax bilocularis*	1
Baggina bradyi	3	*Elphidium magellanicum*	3	*Reophax micaceus*	1
Bigenerina cylindrica	2	*Epistominella exigua*	1	*Reophax scorpiurus*	3
Bigenerina nodosaria	1	*Epistominella vitrea*	2	*Reophax subfusiformis*	2
Bolivina pseudoplicata	2	*Fursenkoina bradyi*	3	*Rhabdammina abyssorum*	1
Bolivinellina pseudopunctata	2	*Gavelinopsis praegeri*	1	*Robertina arctica*	3
Bolivinellina translucens	2	*Globobulimina auriculata*	3	*Saccammina sphaerica*	2
Brizalina dilatata	2	*Globobulimina turgida*	3	*Saccorhiza ramosa*	2
Brizalina skagerrakensis	3	*Globotrochamminopsis pygmaeus*	2	*Silicosigmoilina groenlandica*	2
Brizalina spathulata	3	*Haplophragmoides bradyi*	2	*Siphogenerina columellaris*	1
Brizalina striatula	2	*Haplophragmoides fragile*	1	*Siphonina bradyana*	1
Buccella frigida	3	*Hoeglundina elegans*	1	*Spirillina vivipara*	1
Bulimina elongata	2	*Hopkinsina atlantica*	4	*Spiroplectammina biformis*	3
Bulimina gibba	2	*Hormosinella guttifera*	1	*Stainforthia complanata*	2
Bulimina marginata	3	*Hyalinea balthica*	1	*Stainforthia fusiformis*	5
Bulimina striata mexicana	2	*Ioanella tumidula*	1	*Stainforthia loeblichi*	1
Buliminella elegantissima	3	*Islandiella norcrossi*	2	*Textularia agglutinans*	2
Cancris auriculus	1	*Jaculella obtusa*	1	*Textularia bocki*	1
Cassidulina carinata	1	*Lagenammina* aff. *difflugiformis*	2	*Textularia earlandi*	3
Cassidulina laevigata	1	*Lagenammina atlantica*	2	*Textularia kattegatensis*	2
Cassidulina neoteretis	1	*Lagenammina difflugiformis*	1	*Textularia pseudogramen*	1
Cassidulina reniforme	1	*Lepidodeuterammina ochracea*	1	*Tolypammina vagans*	1
Cassidulina teretis	1	*Leptohalysis scottii*	3	*Trifarina angulosa*	1
Chilostomella oolina	3	*Liebusella goesi*	2	*Trifarina bradyi*	1
Cibicides lobatulus	1	*Marsipella elongata*	1	*Trifarina fluens*	1
Cibicides refulgens	1	*Melonis barleeanus*	3	*Triloculina frigida*	1
Cibicides wuellerstorfi	1	*Melonis zaandami*	1	*Tritaxis conica*	1
Cornuloculina balkwilli	1	*Neoconorbina williamsoni*	1	*Tritaxis fusca*	1
Cribrostomoides crassimargo	2	*Nonion commune*	2	*Trochammina squamata*	1
Cribrostomoides kosterensis	1	*Nonion labradoricum*	3	*Trochamminopsis quadriloba*	1
Cribrostomoides nitidum	1	*Nonionella iridea*	3	*Uvigerina celtica*	2
Cribrostomoides subglobosum	1	*Nonionella turgida*	2	*Uvigerina elongatastriata*	1
Crithionina mamilla	1	*Nonionella turgida digitata*	2	*Uvigerina mediterranea*	1
Cyclammina cancellata	1	*Oridorsalis tener*	1	*Uvigerina peregrina*	3
Dendrophrya arborescens	1	*Oridorsalis umbonatus*	1		

Consequently, Foram-AMBI values from this data set should be evaluated with care. The Foram-AMBI values ranged from 1.1 to 3.4 indicating high to moderate EcoQS. However, no correlation was recognised between Foram-AMBI and TOC or H′. It has to be noted that TOC values were generally lower than 1%, and the sand content was high (85–92%). Physical disturbances of the sea bed by wave action and frequent re-suspension of fine-grained material as well as a highly seasonal and spatially confined flux of particulate organic matter to the sea-floor

Fig. 4. Histogram showing the total number of assigned species and their distribution among the five ecological groups, Groups I to V. For further explanation, see the text.

from high primary production at the Frisian Front were considered as predominant environmental factors for benthic foraminifera in this area rather than eutrophication (de Nooijer et al., 2008 and references therein). Therefore the lack of correlation between the Foram-AMBI and TOC or H′ is probably due to a combination of high sand content in a hydrodynamically active environment and high relative abundance of unassigned species.
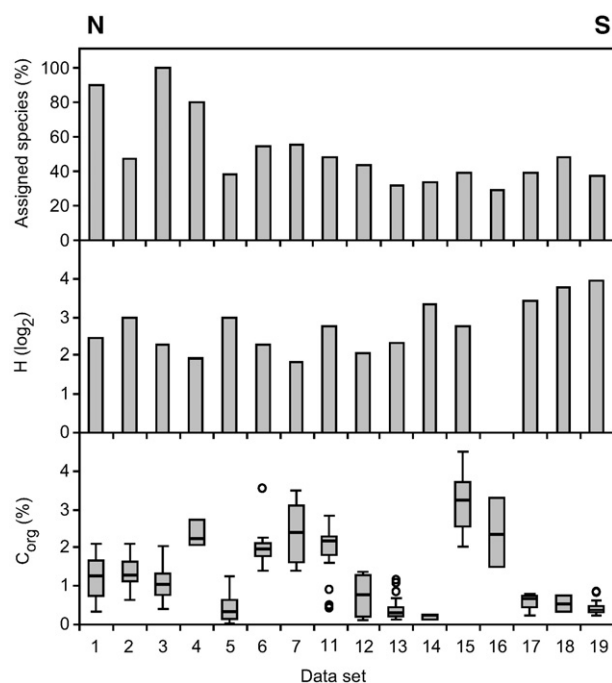
The Gulf of Cadiz data (Mendes et al., 2012; VDS 4) included a large number of unassigned species comprising 36 to 88%, on average 60% of the assemblages, which is far too high for reliable AMBI estimates (Borja and Muxika, 2005). Indeed, the Foram-AMBI values showed no correlation with Shannon's diversity H′ or with the organic carbon concentration as depicted by the interpolated suspension concentration at the sampling sites.

3.4. Limitations of the study

The literature data sets were obtained using a variety of different methods. This applied in particular to sampling gear used, sediment depth sampled, and size fraction analysed (Table 1). Since opportunistic species commonly are small in size, opportunistic responses in some species could not be recorded in studies focusing on larger size fractions. In studies based on the >63 μm-fraction, changing abundance patterns in larger species may not have been detectable due to high abundance of smaller species. The data sets also documented large differences in

Fig. 5. Proportion of assigned species (top), gamma-diversity expressed as Shannon's diversity H′ (middle), and sedimentary organic carbon (bottom) in the study areas from north to south. The box plot displays ±25% of the Corg data around the median value. Circles = outliers off the range of 75% of the values around the median. Data set numbers and source references are given in Fig. 1.
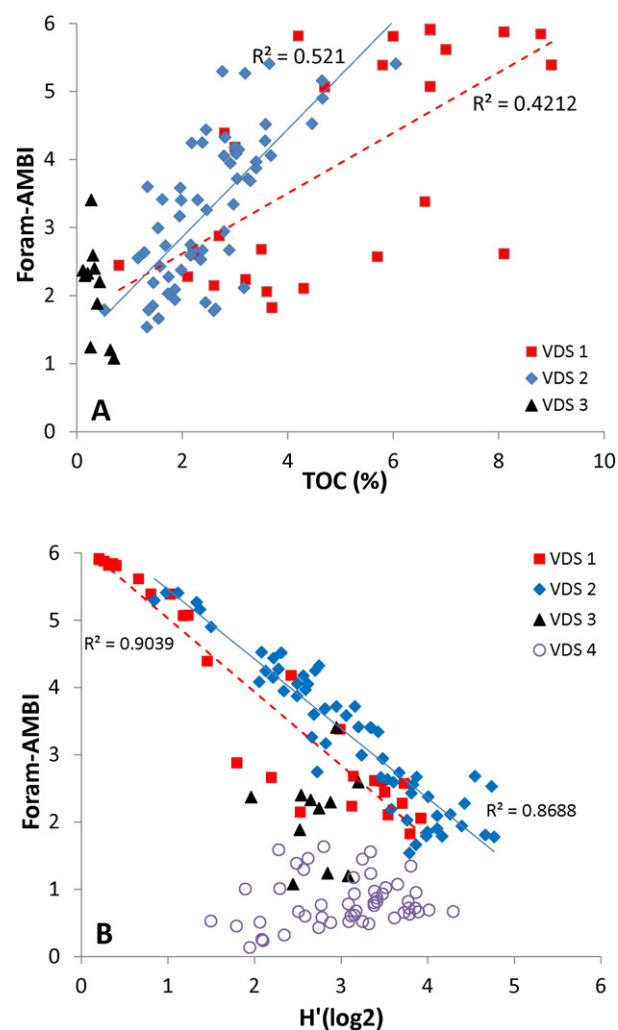
sand content (Table 1). Sandy sediments generally have lower TOC contents than muddy ones (e.g., Rytter et al., 2002), because the organic carbon particles commonly occur in the fine fraction. Hence, the availability of food to the foraminifera is not necessarily correctly expressed in the TOC-values of the bulk samples due to dilution by larger detrital grains (Alve and Murray, 1997). Ideally, organic carbon analyses should be performed on the finer (<63 μm) size fraction. Furthermore, organic carbon data from the literature rarely differentiate between labile compounds and refractory organic matter, the latter being of low nutritional value for benthic foraminifera (e.g., Jorissen et al., 1998; Fontanier et al., 2008). Supplementary information on C/N ratios, pigment or protein concentrations, which would allow to better constrain the availability of fresh food (e.g., Koho et al., 2008; Nardelli et al., 2010; Hess et al., 2014), were not available in most cases. Even if proxy data depicting the availability of food for foraminifera were provided (e.g., Scott et al., 2003), the data reflect the actual situation during sampling (e.g., Billett et al., 1983), and do not necessarily mirror the weeks or months when the actual living assemblage has grown (Alve and Murray, 1997).

Another limitation is the identification of stained specimens as living at the time of sampling, picking, and species determination by many different authors. Different species concepts may induce a bias to the census data (Schönfeld et al., 2013). A taxonomic inter-calibration of benthic foraminifera in the North Atlantic realm is still pending (Dorst and Schönfeld, 2013; see also Pawlowski and Holzmann, 2014).

Fig. 6. A. Relationship between Foram-AMBI and TOC (%) for three validation data sets (VDS). B. Relationship between Foram-AMBI and H′ for four validation data sets. Linear regression lines shown for VDS 1 (dashed line) and VDS 2 (solid line). For VDS numbers and associated references, see Table 1.

Finally, the fact that only three species were assigned to the two groups comprising the most organic-enrichment tolerant taxa, reflects that most data sets documenting both foraminifera and wide ranges and high values in TOC originated from the Skagerrak area. Of the >1500 assemblages on living (stained) benthic foraminifera available from the NE Atlantic region (Murray, 2015) only a minority report associated sediment TOC data.

4. Summary and concluding remarks

This study aimed to test if AMBI, a benthic macroinvertebrate-based biotic sensitivity index commonly used in marine environmental monitoring, may be applied to benthic foraminifera. Data sets from published NE Atlantic and Arctic fjord, continental shelf, and slope areas

Table 3

Relative abundance of unassigned species and ranges in biotic indices for the validation data set (VDS) assemblages.

Validation data sets	Reference	Abundance of not assigned species (%)			Biotic index (range)	
		Min	Max	Average	Foram-AMBI	H′(log2)
Norwegian Skagerrak coast (VDS 1)	Bouchet et al. (2012)	0	22	8	1.8–5.9	0.2–3.9
Oslofjord, Norway (VDS 2)	Dolven et al. (2013)	0	31	10	1.5–5.4	0.8–4.8
Souther North Sea (VDS 3)	de Nooijer et al. (2008)	11	55	28	1.1–3.4	2.0–3.2
Gulf of Cadiz, Spain (VDS 4)	Mendes et al. (2012)	36	88	60	0.1–1.6	1.5–4.3

were used. The choice of data sets was dictated by criteria defined so that the properties of the data should be as comparable as possible. For example, all samples should be from marine habitats below the halocline, and include data on organic carbon concentration as well as on benthic foraminifera. The relative abundance of each species along an environmental pressure gradient, here organic carbon, in 19 data sets was used to assign the species to five ecological groups according to the AMBI scheme. Based on the assignments, the AMBI formula was tested by calculating what we term the Foram-AMBI for four independent foraminiferal data sets. To avoid circular arguments, these validation data sets had not been used in the species assignments.

Two validation data sets from the Norwegian Skagerrak coast, which showed a wide range in the Foram-AMBI values, correlated well both with the associated sediment organic carbon values and with Shannon's diversity (H′). These correlations indicate that the Foram-AMBI reflects the change in ecological status along the dominating environmental pressure gradients in these two areas. On average, unassigned species account for 8 and 10% of the assemblages in these two data sets.

The other two validation data sets, one from the southern North Sea and one from the Gulf of Cadiz, Spain, had low and low to moderate organic carbon values, respectively. Despite the low TOC in the southern North Sea samples, the Foram-AMBI ranged between low and moderate values. This discrepancy may partly be explained by the fact that on average 28% of the assemblages did not belong to assigned species and partly by the sand-dominated sediments which negatively impact the reliability of TOC-values. The consistently low Foram-AMBI values in the Gulf of Cadiz samples were probably due to the fact that on average, unassigned species made up 60% of the assemblages.

The present study is a first attempt to investigate if one of the most commonly used biotic indices in environmental monitoring, AMBI, may apply when based on benthic foraminifera. Given the wide latitudinal and environmental span represented by the NE Atlantic and Arctic fjord, continental shelf and slope data sets used here, a total number of 128 assigned species is rather low. Of these, only three belong to groups characterising the most and second most impacted conditions. Relatively speaking, there are fewer assigned species in the southern compared to the northern investigated data sets. The present study illustrates that although analyses of more than 1500 living (stained) benthic foraminiferal assemblages have been undertaken within the NE Atlantic region (Murray, 2015) only a minority report faunal patterns along documented environmental gradients relevant to environmental monitoring. Our preliminary results point in a positive direction, but in order to properly test the Foram-AMBI, more studies along wide organic carbon gradients are needed. There is a particular need for such data sets from the southern North Sea and southwards.

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.marmicro.2015.11.001.

Acknowledgements

Appendix A. Taxonomical reference list

Foraminiferal species assigned to ecological groups in this study are listed alphabetically by genus names. Original descriptions and taxonomic references were given by Ellis and Messina (1940–2005) (www.micropress.org) and Loeblich and Tappan (1987). They are not included in the reference list.

Adercotryma glomerata (Brady) = *Lituola glomerata* Brady 1878.

Adercotryma wrighti Brönnimann and Whittaker 1987.

Ammodiscus catinus Höglund 1947.

Ammoglobigerina globigeriniformis (Parker and Jones) = *Lituola nautiloides* var. *globigeriniformis* Parker and Jones 1865. Note: *Trochammina globigeriniformis* of authors.

Ammolagena clavata (Jones and Parker) = *Trochammina irregularis* var. *clavata* Jones and Parker 1860.

Ammoscalaria tenuissima Zheng and Fu 2001.

Ammosphaeroidina sphaeroidiniformis (Brady) = *Haplophragmium sphaeroidiniforme* Brady 1884.

Amphicoryna scalaris (Batsch) = *Nautilus scalaris* Batsch 1791.

Astrononion gallowayi Loeblich and Tappan 1953.

Baggina bradyi (Brotzen) = *Valvulineria bradyi* Brotzen 1936.

Bigenerina cylindrica Cushman 1922.

Bigenerina nodosaria d'Orbigny 1826.

Bolivina dilatata Reuss 1850.

Bolivina pseudoplicata Heron-Allen and Earland 1930.

Bolivina skagerrakensis Qvale and Nigam, 1985.

Bolivina spathulata (Williamson) = *Textularia variabilis* Williamson var. *spathulata* Williamson 1858.

Bolivina striatula Cushman 1922.

Bolivinellina pseudopunctata (Höglund) = *Bolivina pseudopunctata* Höglund 1947.

Bolivinellina translucens (Phleger and Parker) = *Bolivina translucens* Phleger and Parker 1951.

Buccella frigida (Cushman) = *Pulvinulina frigida* Cushman 1921.

Bulimina elongata d'Orbigny 1826.

Bulimina gibba Fornasi 1902.

Bulimina marginata d'Orbibny 1826.

Bulimina striata mexicana Cushman 1922.

Buliminella elegantissima (d'Orbigny) = *Bulimina elegantissima* d'Orbigny 1839.

Cancris auriculus (Fichtel and Moll) = *Nautilus auricula* Fichtel and Moll 1798.

Cassidulina carinata Silvestri 1896.

Cassidulina laevigata d'Orbigny 1826.

Cassidulina neoteretis Seidenkrantz 1995.

Cassidulina reniforme Nørvang 1945.

Cassidulina teretis Tappan 1951.

Chilostomella ovoidea Reuss 1850.

Cibicides lobatulus (Walker and Jacob) = *Echinus lobatulus* Walker and Jacob 1798. Note: *Lobatula lobatula* of authors.

Cibicides refulgens de Montfort 1808.

Cibicides wuellerstorfi (Schwager) = *Anomalina wuellerstorfi* Schwager 1866. Note: *Cibicidoides wuellerstorfi* or *Fontbotia wuellerstorfi* of authors.

Cornuloculina balkwilli (MacFayden) = *Ophthalmidium balkwilli* MacFadyen 1939.

Cribrostomoides crassimargo (Norman) = *Haplophragmium crassimargo* Norman 1892. Note: *Labrospira crassimargo* of authors.

Cribrostomoides kosterensis (Höglund) = *Labrospira kosterensis* Höglund 1947.

Cribrostomoides nitidum (Goës) = *Haplophragmium nitidum* Goës 1896.

Cribrostomoides subglobosus (Sars) = *Lituola subglobosa* Sars 1868.

Crithionina mamilla Goës 1894.

Cyclammina cancellata Brady 1879.

Dendrophrya arborescens (Heron-Allen and Earland) = *Dendronina arborescens* Heron-Allen and Earland 1922.

Deuterammina rotaliformis (Heron-Allen and Earland) = *Trochammina rotaliformis* Heron-Allen and Earland 1911.

Discanomalina semipunctata (Bailey) = *Rotalina semipunctata* Bailey 1851.

Discorbinella bertheloti (d'Orbigny) = *Rosalina bertheloti* d'Orbigny 1839. Note: *Hanzawaia rhodiensis* (Terquem 1878) of authors is considered as junior synonym.

Eggerelloides medius (Höglund) = *Verneuilina media* Höglund 1947.

Eggerelloides scaber (Williamson) = *Bulimina scabra* Williamson 1858.

Elphidium albiumbilicatum (Weiss) = *Nonion pauciloculum* (Cushman) subsp. *albiumbilicatum* Weiss 1954.

Elphidium bartletti Cushman 1933.

Elphidium excavatum clavatum Cushman 1930.

Elphidium magellanicum Heron-Allen and Earland 1932.

Epistominella exigua (Brady) = *Pulvinulina exigua* Brady 1884.

Epistominella vitrea Parker 1953.

Fursenkoina bradyi (Cushman) = *Virgulina bradyi* Cushman 1922.

Gavelinopsis praegeri (Heron-Allen and Earland) = *Discorbina praegeri* Heron-Allen and Earland 1913.

Globobulimina auriculata (Bailey) = *Bulimina auriculata* Bailey 1851.

Globobulimina turgida (Bailey) = *Bulimina turgida* Bailey 1851.

Globotrochamminopsis pygmaeus (Höglund) = *Trochammina globigeriniformis* var. *pygmaea* Höglund 1947.

Haplophragmoides bradyi (Robertson) = *Trochammina bradyi* Robertson 1891.

Haplophragmoides fragile Höglund 1947.

Hoeglundina elegans (d'Orbigny) = *Rotalia elegans* d'Orbigny 1826.

Hopkinsina atlantica Cushman 1944.

Hormosinella guttifera (Brady) = *Reophax guttifera* Brady 1881.

Hyalinea balthica (Schröter) = *Nautilus balthicus* Schröter 1783.

Ioanella tumidula (Brady) = *Truncatulina tumidula* Brady 1884. Note: *Eponides tumidulus* of authors.

Islandiella norcrossi (Cushman) = *Cassidulina norcrossi* Cushman 1933.

Jaculella obtusa Brady 1882.

Lagenammina atlantica (Cushman) = *Proteonina atlantica* Cushman 1944.

Lagenammina difflugiformis (Brady) = *Reophax difflugiformis* Brady 1879.

Lepidodeuterammina ochracea (Williamson) = *Rotalina ochracea* Williamson 1858.

Leptohalysis scottii (Chaster) = *Reophax scottii* Chaster 1892.

Liebusella goesi Höglund 1947.

Marsipella elongata Norman 1878.

Melonis barleeanus (Williamson) = *Nonionina barleeana* Williamson 1858.

Melonis zaandamae (Van Voorthuysen) = *Nonion zaandami* Van Voorthuysen 1952.

Neoconorbina williamsoni (Chapman and Parr) = *Discorbis williamsoni* Chapman and Parr 1932.

Nonion commune (d'Orbigny) = *Nonionina communis* d'Orbigny 1846.

Nonionella digitata Nørvang 1945.

Nonionella iridea Heron-Allen and Earland 1932.

Nonionella labradorica (Dawson) = *Nonionina scapha* var. *labradorica* Dawson 1860. Note: *Nonionellina labradorica* of authors.

Nonionoides turgida (Williamson) = *Rotalina turgida* Williamson 1858.

Oridorsalis tenerus (Brady) = *Truncatulina tenera* Brady 1884.

Oridorsalis umbonatus (Reuss) = *Rotalia umbonatus* Reuss 1851.

Pullenia bulloides (d'Orbigny) = *Nonionina bulloides* d'Orbigny 1846.

Pullenia osloensis Feyling-Hanssen 1954.

Quinqueloculina seminula (Linné) = *Serpula seminulum* Linnaeus 1758.

Quinqueloculina stalkeri Loeblich and Tappan 1953.

Rectuvigerina bononiensis (Fornasini) = *Uvigerina bononiensis* Fornasini 1888.

Rectuvigerina phlegeri Le Calvez 1959.

Recurvoides trochamminiforme Höglund 1947.

Recurvoides turbinatus (Brady) = *Lituola turbinatum* Brady 1881.

Reophax bilocularis Flint 1899.

Reophax micaceus Earland 1934.

Reophax scorpiurus de Montfort 1808.

Reophax subfusiformis Earland 1933.

Rhabdammina abyssorum Sars 1869.

Robertina arctica d'Orbigny 1846.

Saccammina sphaerica Brady 1871. Note: *Astrammina sphaerica* of authors.

Saccorhiza ramosa (Brady) = *Hyperammina ramosa* Brady 1879.

Silicosigmoilina groenlandica (Cushman) emend Loeblich and Tappan 1953. Note: *Quinqueloculina groenlandica* Cushman 1933 of authors.

Siphogenerina columellaris (Brady) = *Uvigerina columellaris* Brady 1881.

Siphonina bradyana Cushman 1927.

Spirillina vivipara Ehrenberg 1843.

Spiroplectammina biformis (Parker and Jones) = *Textularia agglutinans* d'Orbigny var. *biformis* Parker and Jones 1865.

Stainforthia complanata (Egger) = *Virgulina schreibersiana* var. *complanata* Egger 1893. Note: *Fursenkoina complanata* of authors.

Stainforthia fusiformis (Williamson) = *Bulimina pupoides* d'Orbigny var. *fusiformis* Williamson 1858.

Stainforthia loeblichi (Feyling-Hanssen) = *Virgulina loeblichi* Feyling-Hanssen 1954.

Textularia agglutinans d'Orbigny 1839.

Textularia bocki Höglund 1947.

Textularia earlandi Parker 1952 = new name for *Textularia tenuissima* Earland 1933. Note: *Spiroplectammina earlandi* of authors.

Textularia kattegatensis (Höglund) = *Textularia gracillima* Höglund 1947.

Textularia pseudogramen Chapman and Parr 1937.

Tolypammina vagans (Brady) = *Hyperammina vagans* Brady 1879.

Trifarina angulosa (Williamson) = *Uvigerina angulosa* Williamson 1858.

Trifarina bradyi Cushman 1923.

Trifarina fluens (Todd) = *Angulogerina fluens* Todd 1948.

Triloculina frigida Lagoe 1977.

Tritaxis conica (Parker and Jones) = *Valvulina triangularis* var. *conica* Parker and Jones 1865.

Tritaxis fusca (Williamson) = *Rotalina fusca* Williamson 1858.

Tritaxis squamata (Jones and Parker) = *Trochammina squammata* Jones and Parker 1860.

Trochamminopsis quadriloba (Höglund) = *Trochammina quadriloba* Höglund 1948 = new name for *Trochammina pusilla* Höglund 1947.

Uvigerina celtica Schönfeld 2006.

Uvigerina elongatastriata (Colom) = *Angulogerina elongatastriata* Colom 1952.

Uvigerina mediterranea Hofker 1932.

Uvigerina peregrina Cushman 1923.

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