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Interactive Comment

Interactive comment on "Environmental response of living benthic foraminifera in Kiel Fjord, SW Baltic Sea" *by* A. Nikulina et al.

A. Nikulina et al.

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Response to comments by Frans Jorissen

A.Nikulina, I. Polovodova and J. Schönfeld

We are grateful for the constructive comments, which helped us a lot to prepare a revision of our manuscript. As requested by the reviewer, here we provide a critical assessment of the methods, followed both studies in 1960s and 2006. We agree that more references on the distribution of foraminifera in the Baltic, their response to environmental changes, as well as previous pollution surveys in the study area are needed. They were not included in the first version of the paper because of size limitations. Census data and plate as supplementary material will be included during the revision of the paper. Below, we answer the comments in order they appear in the review:

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1. "The title is incorrect". We share the view of the referee that the title needs to be emended and changed it to "Foraminiferal response to environmental changes in Kiel Fjord, SW Baltic Sea".

2. "The main message of this paper is that tremendous faunal changes have taken place in this area since 1965. I have the feeling that part of the differences may be due to different sampling and observational protocols." Here we present a detailed description of methods that were used in both studies: G.-F. Lutze took the surface sediment (0-1 cm) samples with a Van-Veen grab during the period from spring 1962 to autumn 1963. The sample analysis was started in autumn 1963. Unfortunately, it was impossible to reconstruct the exact season of sampling, because all protocols are not available anymore in the archives of the Institute of Geosciences (University of Kiel). Sample preparation included staining with Rose Bengal, washing through a sieve with 100-micrometer mesh size, decanting of the organic detritus, and drying at 80°C. For samples with a high sand content, the procedure involved also the flotation of the dried residue in tetrachlorhydrocarbon to "concentrate" the foraminifera. From the wording of Lutze (1965) it is unclear whether wet or dry picking was done. The author explained that he checked the residue too when only a few living specimens were found (Lutze, 1965: p.79).

3. "The authors say that the 1965 samples were re-inspected (on page 202), but don't tell what was the result of this re-examination" In order to constrain the differences between our methods and those of G.-F. Lutze (see above), we re-examined four samples from Lutze' collection where both, the residues and concentrates are still available. The re-examination was also done in order to distinguish between E. excavatum excavatum and E. excavatum clavatum subspecies, which were lumped together by Lutze G.-F. in these samples. We did the re-examination twice with a time distance of several months, and our census from the re-examination appeared to be largely different from the data published in 1965 (Fig.5ab). According to Lutze (1965), the dominant elements of the living foraminiferal fauna in 1962-1963 were E. excavatum subspecies

(Fig. 5b). E. incertum had higher abundances, whereas A. cassis and R. dentaliniformis were less abundant as compared to our census. Lutze did not report species the E. albiumbilicatum and E. gerthi, which we found in his samples, and there might be the possibility that he recognized the respective specimens of both species as variants of E. excavatum. Moreover, some re-inspected samples contained less than 20 living specimens, that, according to Van der Plas and Tobi (1965), infers an absolute counting error of more than 16%. Unfortunately, Lutze did not provide the information about the total number of specimens that he has counted in his paper and therefore we cannot compare our absolute counts with previously reported ones. Another important thing is that the residues of 3 from 4 Lutze samples contained a very few or no living specimens whereas the respective flotation concentrates were very rich. There was only one sample where we found more than 30 presumably living individuals in the residue. This "fauna" had the same species composition as their counterpart that in the concentrate. As such we have to appreciate that Lutze's faunal analyses of the concetrates was seemingly representative. Even if Lutze processed only concentrates but not the whole samples, his results on the population density would not differ by two orders of magnitude to the results we obtained in our 2006 survey. Concerning the differences in size fractions, it was shown that there were no smaller living specimens than 80 micrometer observed in the western Baltic Sea (Schönfeld & Numberger, 2007a: p.85). Therefore it is unlikely that Lutze G.-F. missed or washed away a significant proportion of the fauna. The question about the sampling period in 1960s remains unclear. However, Lutze's sampling campaign started in spring 1962 and continued until the sample analysis was initiated in autumn 1963. Regarding the difference in sample numbering (342 vs. 239), it well might be that sampling in the 1960s also comprised several seasons per year, as we did in the current study. Thus we finally consider that differences in methods of sampling and sample analysis in this study comparing to the 1960s appear to be of minor importance, and they do not bias the final results significantly.

4. "Introduction: The authors mention several earlier studies in the same area. They

should give a short description of the main results of these studies." The previous studies in the Baltic Sea only gave a very short description of foraminiferal distribution, though they were started in XIX century. Ecological observations on foraminifera in the Kiel Bight were initiated by Rumbler (1935), who used rather descriptive than quantitative methods of investigation. In the following, Rottgardt (1952) distinguished three different foraminiferal assemblages in the Baltic Sea that were distributed according to the salinity pattern: marine, brackish-marine (fjords and shallow areas of the Kiel Bight), and brackish faunas. A detailed taxonomical and ecological overview on benthic foraminifera in the Baltic Sea was provided by Lutze (1965), who found out that rather the substrate than temperature and salinity were the main ecological factors controlling the foraminiferal distribution in this area. Vise versa, Wefer (1976) observed that the abundances of foraminifera in sediments off Bokniseck (open Kiel Bight) are regulated by substrate features, hydrodynamics and oxygen content of the bottom waters. Foraminiferal food preferences in the open Kiel Bight were described by Schönfeld and Numberger (2007a), who reported two reproduction events of Elphidium excavatum clavatum following the spring bloom and suggested the "bloom-feeding" strategy for this species.

5. "The authors mention a (very limited) number of papers on the foraminiferal response to environmental parameters and contamination. They say that "no clear relationships were recognized in heavily polluted environments". This is a personal point of view of the authors. I think that many scientist will not agree! The authors have to increase significantly the number of references of studies dealing with pollution, and give a serious summary of the main conclusions of these papers!" In our first version of the manuscript, we kept the summary on foraminiferal response to pollution very brief, and thereby we possibly lost the message. Under "no clear relationships" we meant that under different settings and conditions, foraminifera may respond differently and could show both, an increase and decrease of population density. This in particular holds true for high organic matter and nutrient content (see below). We extended this paragraph and added more references: A number of studies have addressed the foraminiferal

reactions to environmental parameters as salinity, temperature, oxygen, food availability, pH, (e.g. Bradshaw, 1957, 1961; Boltovskoy et al., 1991; Moodley and Hess, 1992; Alve and Murray 1999; Stouff et al., 1999ab; Gustafsson and Nordberg 2001; Le Cadre and Debenay, 2003), contamination by trace metals (Ellison et al., 1986; Sharifi et al., 1991, Alve, 1991, Alve and Olsgardt, 1999; Yanko et al., 1998; Debenay et al., 2001) and sewage effluents (e.g. Watkins, 1961; Schafer, 1973; Tomas et al., 2000). A decrease of population density, reproduction capability, enhanced mortality of some foraminiferal species, and increasing frequency of test abnormalities were observed under the high trace metal or organic matter levels (Schafer, 1973, Samir & El Din, 2001; Bergin et al., 2006; Burone et al., 2006; Ernst et al., 2006; Di Leonardo et al., 2007). On the other hand, it was shown that population density of foraminifera may increase in the vicinity of sewage outfalls (Watkins, 1961; and Tomas et al., 2000). Some foraminiferal species were mentioned as able to tolerate high levels of organic matter. For instance, the bloom of Ammonia beccarii was suggested by Tomas et al. (2000) as a result of an increased sewage inputs to the Long Island Sound (USA) over the last 35 years. At the same time, Schafer (1973) observed the dominance of Elphidium incertum in vicinity of sewage outfalls, whereas he suggested Ammotium cassis to be a pollution-sensitive species. Culture experiments revealed that A. beccarii produces abnormal chambers at 10-20 microgramm/l of copper in seawater (Sharifi et al., 1991; Le Cadre & Debenay, 2006) and die in concentrations range of 200 - 400 microgramm/l (Le Cadre & Debenay, 2006). Therefore, foraminifera appear to be a rather sensitive tool for the monitoring of pollution, though should be used with caution, because their distribution is determined by numerous environmental variables (Alve and Olsgardt, Stouff et al., 1999ab; 1999; Le Cadre & Debenay, 2006).

6. "On page 195, many studies about previous pollution surveys are mentioned. The authors should add a summary of the principal results of these summaries!" Here we give the extended paragraph about the previous pollution surveys: Measurements of metal concentrations in sediments of Kiel Bight have been made at a few stations in the frame of environmental monitoring in the Baltic Sea by the Institute for Marine Research

Warnemünde IOW (e. g. Nausch et al., 2003, Pohl et al., 2005). The data indicate that the concentrations of metals in Kiel Bight do not show significant temporal trend for 1998-2004 with respect to the high inter annual variability. Kiel Fjord is considered by LANU (The Regional Environmental Protection Agency of the Bundesland Schleswig-Holstein) as one of the most important local hot spots of cadmium, lead, copper, and zinc contamination in the coastal waters of Schleswig-Holstein. In the year 2000 for instance, the concentrations of Cu, Zn and Pb in sediment fraction $<$20 micrometer were 82, 300 and 130 mg/kg in the inner fjord correspondingly (Haarich et al. 2003), whereas in outer fjord Cu content was 30, Zn - 210, and Pb - 60 mg/kg (LANU archive, Ostseemonitoring Programme). No clear temporal trend in the metals concentrations could be seen from 1995 to 2004 in sediments of Kiel Fjord. Extremely high concentrations of Sn in form of organic compounds of 407-2556 microgramm TBT-Sn/kg were found by LANU everywhere in the fjord and supposed to cause the growth and reproduction anomalies of periwinkle (LANU, 2001). Besides, high concentration of metals Cu and Zn were found in fish (Senosack, 1995) and mussels (ter Jung, 1992) in the inner Kiel Fjord, however the organisms in the outer fjord showed the lowest metals content for Schleswig-Holstein coast. Kiel fjord has been affected by eutrophication for a long time (Gerlach et al., 1984) induced by a high load of nutrient and organic carbon from city and surrounding area until construction of sewage pipe out of fjord in 1930s (Kallmeyer, 1997). Than nutrients concentrations and primary production had clear horizontal gradient with increase to the inner fjord (Schiewer and Gocke, 1995). The treatment plant built in 1972 reduced significantly the input of nitrogen and phosphorus (Rheinheimer, 1998), but the proportion of oxygen in deep water showed improvement only in 1990s (Gerlach, 1996). Nevertheless oxygen deficiency in the fjord is reported regularly in late summer due to nutrient input as well as specific weather conditions led to water stratification (Gerlach, 1990). In 1993-1998 content of oxygen in bottom water in summer was about 1.1 mg O2/l in deep areas of outer Kiel fjord and 0.2 mg O2/l in 2002 (Haarich et al. 2003), whereas 4 mg O2/l were measured in the inner fjord (LANU 2003).

7. "The faunal reference list should give at least one good recent reference (containing a good picture!) for every taxon!" We provide an updated and extended faunal reference list, and we considered in particular references with appropriate SEM pictures. The exception is with Elphidium gerthi, because we did not find another taxonomic paper despite Lutze's manuscript considering this species in detail.

8. "As I already told the first author previously, I would be very surprised to find Ammonia beccarii, a fully marine species in the Adriatic Sea (its type area), in this brackish water environments. The taxon which is meant here may be the ornamented form previously described as Ammonia batavus, or the completely unornamented A tepida/parkinsoniana group. It is essential that the authors describe this dominant faunal element somewhat better. They should especially describe its intraspecific variability Some SEM pictures would be very useful!!" We compared our individuals of Ammonia beccarii with A. tepida described by Jorissen (1988) and found that they are different. The population of A. beccarii found in this study showed the high intraspecific variability (pl. 1, fig. 1-7). Some of our specimens (pl. 1, fig.4, 6) are morphologically similar to A. beccarii illustrated in Frenzel et al. (2005). Our specimens are poorly ornamented and they are missing the distinct interlocular spaces on the spiral side with deeply engraved sutures as reported by Debenay et al. (1998, p. 238, pl. 1, fig. 2-3). With reference to recent genetic studies, some of our specimens (pl. 1, fig.1-2, 5, 7) resemble the molecular types T1 and T2 described by Hayward et al. (2004, p. 256, pl. III-IV). However, types T1 and T2 originally come from the Playa Bailen (Cuba) and Venice (Italy). The only similar specimens from the German Wadden Sea that were closely related in terms of their geographic distance and ecological conditions were illustrated by Holzmann (2000, p. 33, pl. 2, fig. 8ab) and identified as molecular type T6. These specimens had, however more lobate tests than those observed in our study. Furthermore, it is difficult to consider the whole morphological variability of a population from two figured specimens only which were selected subjectively. Concerning the assumption that our specimens are simply a less ornamented variant of A. batavus, it was suggested that latter is a synonym of A. beccarii due to the existence of tran-

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sitional stages and the genetic similarity (Holzmann, 2000). At the moment, we are waiting for the results of DNA sequencing of the living Ammonia specimens from Kiel Fjord. Before we know the results of DNA analysis, we decided to preliminarily keep the traditional denomination A. beccarii in this paper.

9. "P198L24: seasonal increase in march à I don't see it in fig. 2! I see very comparable values everywhere on the 2 maps!" The maps of Corg distribution through the year show the distribution of parameters on a seasonal scale, and they were not intended to display monthly variations. In the text, we discuss the changes of Corg content one sampling month by another and therefore they cannot be clearly seen in maps. On the March-May maps, the area of distribution of sediments with organic carbon $>$6% is larger than in winter months and the maximum values are higher, close to 7%. Even though the mean values of Corg change through the year not significantly, but yet we observed in March and May the highest Corg values and the lowest C/N ratios. The C/N distribution maps are now incorporated in Fig. 2.

10. "P 199 discusses C/N ratios, but the results are not presented! The authors should add C/N ratios to their figure 2." The C/N distribution maps are now incorporated in fig. 2.

11. "P 198 L21: The reviewer noted that it is more appropriate to use the coefficient of determination r2 for describing the correlation than the correlation coefficient r." We consider that the correlation coefficient r provides additional information in particular whether the correlation is positive or negative. However, both coefficients don't describe the statistical significance of correlation. Nevertheless all correlations between metals content and Corg and sand content are significant according to the Student t-test.

12. "P201 L21: increased Sn concentrations: are you sure the same methods have been used??" The comparisons of metal content in sediments are always a challenge because of different methods, purposes and preferences of authors. In case of the tin

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contents of 2-2.5 mg/kg as reported by Cato and Kjellin (2005) for the open Baltic Sea, the same procedure of total digestion of bulk sediment was used. Concentration of tin in sediment fraction $<$ 2000 micrometer obtained by LANU (LANU Ostseemonitoring Programme) in 2004 for Kiel Fjord was 23-24 mg/kg whereas in other fjords and bays of Kiel Bight it varied from 4 to 17 mg/kg. We consider these values comparable to our data as we used for geochemical analysis the bulk sample excluding the fraction larger than 2000 mm.

13. "P202 L9: A. beccarii and E. excavatum excavatum presumably substitute each other in Kiel Fjord. You have to explain exactly what you mean by this, and what are your arguments for this statement!" The stations with predominance of A. beccarii generally have a lower abundance of E. excavatum excavatum and vice versa. We do not recognize any physical, biological or chemical parameter that would explain this spatial change in dominance. But we cannot entirely rule out, that these species occupy different ecological niches. As such, we only can presume a substitution.

14. "P203 L4: a ration A/E-index: the authors should cite Sen Gupta, who was the first to use this index." Ammonia/ Elphidium index was calculated in order to reveal the stress response capability of the benthic foraminiferal fauna. This ration of the tolerant species A. beccarii vs. the specialized E. excavatum was firstly described by Sen Gupta et al. (1996) as a proxy of hypoxia.

15. "P204 L1: 29-fold increase. However, on p. 202 the authors say that density was about 100 times higher à correct!!" "29-fold" increase of population density was calculated from the minimum values, whereas the maximum range was estimated in 100-fold. According to recalculated data we used further the mean value of population density increase of 67-fold (from 5 to 445 times at stations) (Fig.5d).

16. All linguistic and logical comments were taken into account, and corrections have been made.

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