MICROPALAENOTOLOGY NOTEBOOK

Opportunistic features of the foraminifer *Stainforthia fusiformis* (Williamson): evidence from Frierfjord, Norway

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Frierfjord is the innermost part of a fjord system which connects with the open sea via Grenlandsfjord. Sills between fjords restrict bottom water circulation and in Frierfjord (sill depth: 23 m, max. water depth: 100 m) efficient deep water renewals at depths greater than about 50 m occur once every one to three years (Rygg *et al.*, 1987). For several centuries waste products (primarily bark and wood fibres), initially from saw mills and later from pulp and paper industries, have been deposited in Frierfjord. Additionally, the fjord has received substantial amounts of organic material and nutrients from domestic sewage. In summary, this led to more or less permanent anoxic deep bottom water conditions. However, slight improvements have occurred over the last decade in response to reduced pollution input (Alve, in prep.). Investigations of short sediment cores (<50 cm) from the deeper areas of Frierfjord (>50 m) show that *Stainforthia fusiformis* exhibits typical opportunistic features. The oxygen concentration of the bottom water immediately above the sediment-water interface was >1 ml l^{-1} at all stations at the time of collection, but the surface sediments reflected recent anoxic conditions. This was especially evident at >70 m where the sediments had a soupy appearance and black colour, with brownish faecal pellets and sometimes light grey, fluffy sediment aggregates in the topmost veneer. The total organic carbon content of the surface sediments is typically between 4 and 6%.

DISCUSSION

The following features characterize *Stainforthia fusiformis* as an opportunistic *r*-strategist:

Distribution. *Stainforthia fusiformis* is a widespread, typical infaunal, shelf and slope species. It is common in shelf areas off NW Europe, along the Atlantic seaboard of North America and off NW Africa (summary in Murray, 1991). Additionally, it was abundant (as '*Bulimina*' *fusiformis*) in Gullmarfjord, SW Sweden, between 40 and 50 m water depth and 'extremely abundant on the Danish side of the Skagerrak' (Höglund, 1947). It dominated (as *Virgulina fusiformis*), together with *Bulimina marginata*, in the black, muddy sediments of the organically-polluted inner Oslo Fjord (Risdal, 1963), it strongly dominated the muddy sediments, close to the redox cline in Drammensfjord, southern Norway (Alve, 1990) and it dominated (as *Fursenkoina fusiformis*) the living assemblages off Humberside, SW North Sea (Murray, 1992). The maximum salinity and temperature ranges in the cited studies (including those in Murray, 1991) where *S. fusiformis* was found to be dominant were 33–35‰ and 5–26°C, except in Drammensfjord where the salinity range was 30.0–31.2‰ in the area of its maximum occurrence. Alve (1990) concluded that in temperate environments, *S. fusiformis* is able to benefit from excess organic matter in oxygen depleted (<2 ml l^{-1}), muddy sediments, as long as the bottom water salinity exceeds 30‰.

Recolonization properties. Detailed analysis of dead foraminifera in 7 sediment cores collected in 1991 from north to south between 50 and 93 m water depth in Frierfjord have shown that diverse *Cassidulina laevigata* assemblages dominated the deeper areas before the effects of organic load became too severe (Alve, in prep.). Development of nearly permanent, anoxic conditions wiped out the foraminiferal assemblages in the northern, deeper (>70 m) areas as early as one century ago and up to at least about 50 m water depth during the 1970s. Further south, anoxic conditions have also occurred frequently but the foraminifera have always recolonized the areas during periods of reoxygenation. For comparison, it can be mentioned that the faunal composition of the well oxygenated areas at 65 m water depth just outside the sill has been fairly constant and dominated by *Bulimina marginata*, over recent centuries. In contrast, the faunal composition of the recolonized areas in Frierfjord differs completely from the natural background assemblages: today, almost monospecific *Stainforthia fusiformis* assemblages strongly dominate both the living (stained) and dead foraminiferal assemblages at >50 m water depth in Frierfjord except in the deeper, northern parts which still have not been recolonized. *S. fusiformis* also strongly dominates the assemblages closest to the redox cline in Drammensfjord, where anoxic conditions had predominated only a few years earlier (Alve, 1990, 1991). This shows that *S. fusiformis* responds quickly to improved oxygen conditions and that it is the most successful recolonizer of formerly anoxic environments in these areas.

Population size. The abundance of empty tests of *S. fusiformis* per gram dry sediment in a core from 90 m water depth was consistently around 7 in the background assemblages (>18 cm core depth; abundance of all species was around 30). At shallower core depths drastic population fluctuations of *S. fusiformis* (e.g. 50 to 10 to 210 to 4 to 125 per gram dry sediment up core) reflected alternating oxic/anoxic bottom water conditions with blooms of *S. fusiformis* during oxic periods. Similar patterns were seen in other cores. In the cited core, H_2S was recorded below the upper 0.5–1.0 cm of the sediments, yet, stained specimens of *S. fusiformis* were present down to a depth of 5 cm in these unbioturbated, anoxic sediments. The number of stained specimens per 10 cm^3 of wet sediment in each 1 cm interval from 0 to 5 cm was 53, 11, 12, 4, and 2 respectively, indicating that this species is able to withstand anoxic conditions at least for a short time period. The absolute abundances with depth must be considered as minimum values as only the coarse fraction >125 μm was analysed because of logistical problems with large amounts of wood fibres. Despite this, the main trends are clear. Overall, these findings show that *S. fusiformis* is able to utilize a transient habitat: a characteristic feature of opportunists (Grassle & Grassle, 1974).

Implications of test characteristics. *Stainforthia fusiformis* has a small (generally <0.3 mm), elongate, tapering, fusiform, finely perforate and slightly compressed test with a smooth surface. It is rounded in section and has a thin, radial, hyaline test wall. Features such as small size and smooth, thin test walls suggest that a minimum of energy is needed to build the shells and, consequently, it is not unrealistic that *S. fusiformis* grows and reproduces quickly; has rapid turnover rate. Light, delicate juveniles may easily be transported (for instance after resuspension of surface sediments by bottom currents) to build up pioneer populations in recently reoxygenated areas. The elongate, smooth, fusiform test with a terminal aperture (at least in the adult stage, Höglund, 1947) may enhance its possibilities to quickly work its way along environmental gradients towards more beneficial microhabitats. Little is known about its feeding strategy but its ability to flourish in a wide variety of environments (this study and Murray, 1991) suggests that it is able to benefit from various kinds of organic material. Both in Frierfjord and in Drammensfjord many specimens of *S. fusiformis* were more or less completely covered by a thin, whitish or sometimes yellowish agglutinating veneer of mud sized particles. This might act as a protecting layer, for instance against chemical compounds which form in the microenvironment in connection with the degradation of organic material around the redox boundary in the sediments.

CONCLUSIONS

S. fusiformis is a small, thin-shelled, primarily infaunal, opportunistic r-strategist which can withstand short periods of anoxic conditions (facultative anaerobic species) and is able to rapidly recolonize formerly anoxic, organic-rich sediments. It is widespread and flourishes in temperate, shelf and marginal marine environments independently of whether the sediments primarily consist of mud or fine sand but it seems to require salinities >30‰.

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REFERENCES

Alve, E. 1990. Variations in estuarine foraminiferal biofacies with diminishing oxygen conditions in Drammensfjord, SE Norway. *In* Hemleben, C., Kaminski, M.A., Kuhnt, W. & Scott, D.B. (Eds), *Paleoecology, Biostratigraphy and Taxonomy of Agglutinated Foraminifera*, 661-694, Kluwer, Dordrecht.

Alve, E. 1991. Foraminifera, climatic change and pollution: A study of Late Holocene sediments in Drammensfjord, SE Norway. *The Holocene*, **1**(3): 243-261.

Alve, E. (in prep.). Foraminiferal evidence of temporal changing oxygen concentrations in the organically polluted Frierfjord.

Grassle, J.F. & Grassle, J.P. 1974. Opportunistic life histories and genetic systems in marine benthic polychaetes. *Journal of Marine Research*, **32**: 253–284.

Höglund, H. 1947. Foraminifera in the Gullmarfjord and the Skagerrak. *Zoologiska Bidrag Från Uppsala*, **26**.

Murray, J.W. 1991. *Ecology and palaeoecology of benthic foraminifera*, Longman.

Murray, J.W. 1992. Distribution and population dynamics of benthic foraminifera from the southern North Sea. *Journal of Foraminiferal Research*, **22**: 114–128.

Risdal, D. 1963. Foraminiferfaunaen i en del sedimentkjerner fra indre Oslofjord. *Norges Geologiske Undersøkelse*, **224**: 5–90.

Rygg, B., Green, N., Molvær, J. & Næs, K. 1987. Grenlandsfjordene og Skienselva 1986. *NIVA overvåkningsrapport nr.* 287/87.