

regime (House of Lords, 1996) and a total ban on deep-water fisheries to the west of the British Isles to protect the remaining highly vulnerable species (Greenpeace, 1997). Merrett & Haedrich (1997) suggest that the only possible deep sea fisheries that might be viewed as continued and sustainable operations are those that operate on a small scale with searching done very locally and which take a very small volume of high-quality fish. They refer to the black scabbard fishery in Maderia as an example of such an operation.

It has been said that the success of any management scheme can only be measured after the passage of several fish generation times which could be at a minimum of 150-200 years for deep sea fish (Merrett & Haedrich, 1997). Clearly it is therefore essential that such fisheries should only proceed under very conservative regimes, if at all.

2.11 Xenophyophores

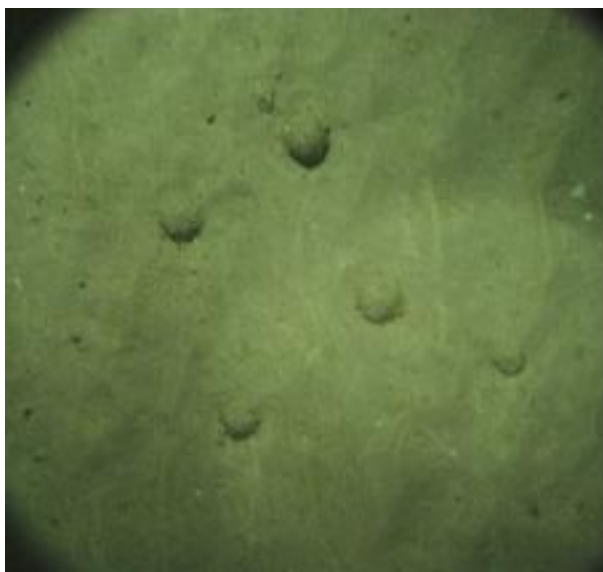
Deep sea samples often contain sediment balls, faecal pellets, and concretions of foraminiferan tests, spicule balls and organic detritus. Since the last century it has been known that some of these structures contain animals but it is only in recent years that they have been studied in any detail. One such group of animals is the xenophyophores. They were described in a monograph in the early 1970s (Tendal, 1972), and include species such as *Maudammina arenaria*, *Galatheimmina calcara*, *Psammmina globigerina*, *Reticulammina labyrinthica* and *Cerelasma massa*.

Xenophyophores are unusually large protozoans. Individuals can grow to more than 20cm in diameter and, although they are often fragile, their relatively large size has made them easier to study when compared to other protozoans found in the oceans. Their size also means that they can be categorised as part of the macrofauna of the deep sea. Most species have been observed on the surface of the sea-bed where they form part of the benthos but at least one species, *Occultammina profunda*, is known to consist of branching tubes buried 1-6cm deep in the sediment (Gage & Tyler, 1991).

A characteristic feature of xenophyophores is that they glue together sediment particles and other materials such as the tests for foraminiferans, to form a test which protrudes above the sea-bed. This contains the protoplasm but also extensive accumulations of faecal pellets known as stercomes. Particles are collected from the environment, accumulated in loose masses of 'ingested material', then gradually transferred into stercomes which are present as strings or masses (Tendal, 1979). These are deposited outside the plasma but within the test and are enclosed by membranes. It is this characteristic of agglutination of sediment particles to form large tests which has resulted in the name xenophyophore, derived from the Greek meaning "bearer of foreign bodies". They are thought to feed using pseudopodia, which collect food from the surface of the sediment or by trapping particles suspended in the water column.

The colour and shape of xenophyophore tests varies a great deal. Using photographs of specimens taken at depths of between 1,000-4,000m, Tendal & Gooday (1981) described a number of different growth forms. These could be categorised into branched, reticulate, platy, and various intermediate forms. Some of the differences were thought to be due to local conditions, which would determine the composition and grain size of the sediment particles used to form the test for example.

Plate 5: Xenophyophores on the Darwin Mounds tail.



Photograph courtesy of DEEPSEAS Group. © SOC.

Levin & Thomas (1988) have suggested that the shape of the test and its orientation varies to increase feeding efficiency and that some tests function as elaborate particle traps. They note that flattened fan-shaped xenophyophores often orientate parallel to flow when currents are uni or bidirectional, which would expose the maximum surface area to any food in the currents. Hemispherical, reticulate forms exhibit local variations in the size and shapes of the divisions which may enhance particle trapping under different flow conditions. For example the tendency of xenophyophores exhibiting this growth form to be concentrated near features such as basalt pillows which protrude from the sea floor may be because the currents generated around them provide better conditions for feeding. There is presumably some upper limit of suitability, however, as that they appear to be less abundant in areas where the water flow is strong enough to transport sediments and produce ripples on the sea-bed.

Little is known about the biology of xenophyophores, particularly how they feed or their mode and manner of growth. In the early 1990s, three specimens of *Reticulammina labyrinthica* in the abyssal north-east Atlantic were observed over an eight month period using time-lapse photography (Gooday *et al.*, 1993). Growth occurred episodically in several distinct phases, each lasting two or three days, separated by fairly regular periods of about two months with sediment collected and incorporated into the test throughout the two months between growth phase. These phases were when the organisms showed little obvious activity. It was not clear whether the periodicity and apparent synchronisation of these events in all three specimens was caused by some external environmental cue or if the growth was controlled internally and the synchronisation arose by chance.

Apart from feeding by collecting particles from the sea-bed and the water column, it has been proposed that the xenophyophores ferment micro-organisms on the masses of stercomata which they hold within their tests (Tendal, 1979). These provide the substrate for commensal

microflora which multiply to such an extent that the animal can re-digest the stercomata to take advantage of this food source. This process could be repeated several times and may be part of the strategy that allows them to gain enough food in a poor environment where there is considerable competition for food.

The large numbers of xenophyophores found in particular areas suggest that they may dominate and influence the ecology of certain deep sea benthic communities (Tendal & Gooday, 1981). This view is reinforced by studies that have found filter-feeding, deposit-feeding and carnivorous animals within their tests of xenophyophores and an increased abundance of some species in the sea-bed in the immediate vicinity. Godday (1984) reported sipunculans, polychaetes and nematodes within tests of xenophyophores and nematodes and harpacticoid copepods the dominant groups in larger eastern Pacific xenophyophores. He has suggested that they may be using the test as substrate, refuge, feeding site or breeding ground.

During investigations of deep seamount benthos in the Pacific, Levin *et al.*, (1987) reported that xenophyophores provided a habitat for 16 major metazoan taxa. This included also a family grouping of 10 isopods (*Hebefustis* sp.) within the largest test, suggesting that the tests may provide a semi-permanent residence for some species. Others, such as certain amphipods and polychaetes were highly mobile forms, so are unlikely to be resident.

The sediments immediately surrounding the animals also had higher faunal densities and species richness compared to sediment one meter from the tests (Levin *et al.*, 1987). Amphipods were exclusively associated with the tests or sediments beneath them while molluscs, and some crustaceans and echinoderms were three or four times more abundant under the xenophyophores than in control cores. Total faunal density and species richness were enhanced in the core with xenophyophores.

Interactions between xenophyophores and large epifauna have also been studied (Levin & Thomas, 1988). From short-term observations it appears that the most apparent interaction was the consistent presence of one or more large ophiuroids beneath most xenophyophore tests observed on seamounts in the Pacific (Levin & Thomas, 1988). On sandy sediments the arms typically protruded from beneath the tests and occasionally ophiuroids were on top of the tests. Photographs taken in quiet muddy settings showed urchin and scaphopod tracks that circled xenophyophore tests suggesting some form of attraction.

Another result of xenophyophore activity may be an increase in the particle flux of fine-grained material to the sea-bed and enhancement subsurface mixing. In this way they may be altering the hydrodynamic conditions. Radiochemical studies support the idea that xenophyophores are focii of sediment deposition. Particle selection for test construction and feeding may be an important source of the heterogeneity in texture and composition of seamount sediments.

2.11.1 Distribution in the OSPAR maritime area

Xenophyophores are confined to the deep sea but occur throughout the world's oceans. They were once thought to be rare as few specimens survived early sea-bed sampling techniques but they are now known to be widespread and especially abundant in regions of high surface productivity and on topographic features such as seamounts, ridges, canyons, troughs and continental slopes (Levin & Thomas, 1988). They are a common element of the epifauna at

depths greater than 500m in regions of the Atlantic, Indian and Pacific oceans and some species have widespread distributions that extend into the Arctic. Their physical dominance of the macrofaunal of deep sea sediments in the north-east and north-west Atlantic, as well as the eastern, central and south-west Pacific, is reflected in the fact that they have been reported in densities of hundreds per 100m² to more than 2,000 per 100m² (Tendal & Gooday, 1981).

2.11.2 Conservation issues

The widespread distribution of xenophyophores, their synecology, and the fact that they can occur in very high densities has led to the suggestion that they are an important source of sedimentary and faunal heterogeneity and as such may contribute to maintenance of benthic diversity in the deep sea.

2.11.3 Conservation actions

Xenophyophores occur throughout the OSPAR maritime area and consequently no sites are singled out here for particular attention. If areas are found to be of special importance for this species in the future, conservation efforts may need to be focused on such locations. The more likely scenario is for xenophyophores to be one element of the benthos to be safeguarded through general conservation measures applied to the deep sea.

2.12 DEEP SEA MUD

Contribution by Maria C. Baker and Brian J. Bett. DEEPSEAS Group, George Deacon Division, Southampton Oceanography Centre (2001).

This directory covers a number of interesting and exciting deep-water habitats, biological communities and species. By contrast deep sea mud may seem a little “dull”. Plain deep sea mud is nevertheless the dominant habitat in the OSPAR maritime area; indeed it is the dominant habitat on this planet. Despite its apparently featureless nature, recent research has shown that deep sea mud supports a previously unexpected wealth of biological diversity. It is quite possible that the majority of animal species on this planet live in deep sea mud. Of the tens of millions of animal species that probably live on Earth today, it is quite possible that over 75 per cent of them will be found on the deep sea floor – although to date we are only aware of a tiny fraction of this diversity.

Muds and other deep sea sediments

Marine sediments are classified on the basis of the most abundant particle type found in a particular deposit. The abundance of a particle type is dependent upon: (1) the rate of its supply to the sediment, (2) the degree to which it is preserved in the sediment, and (3) the rate of sedimentation of other particles (Libes. 1992). In the deep sea, exposed hard rock is rare, being found only on steep continental slopes, seamounts and along mid-ocean ridges (Gage and Tyler, 1991). The only other substantial sources of solid substrata are: a) the polymetallic nodules or crusts that may form in some regions (for example, around the Goban spur in the north-east Atlantic, Karpoff et al., 1985), and b) glacial erratics (iceberg dropstones) that, for example, provide a significant habitat on the upper slope of the UK continental margin (Bett, 2001).

Deep sea sediments are primarily composed of clays or biogenic oozes, depending upon the productivity of overlying waters. Abyssal clay covers most of the deep-ocean floor. It