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A Possible New Meiofaunal Tool for Rapid Assessment of the Environmental Impact of Marine Oil Pollution

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Abstract: Five months after the oil spillage from the *Braer* tanker a limited survey of the meiofaunal copepod assemblage was carried out to the west of the south Shetland peninsula, where sediment oil content ranged from 19 to 8816 ppm. There was no evidence for any impact of oil on species diversity. Copepod abundance and species composition did show correlations with oil content but this was explicable in terms of the influence of sediment type, which was also related to oil content in the area. A strong correlation between the relative abundance of ectinosomatid copepods and oil content appeared unlikely to be due to the influence of natural factors. It is suggested that ectinosomatids may be highly sensisitive to oiled sediments. Further evidence for enhanced susceptibility to oil was manifest in the finding of ectinosomatids coated in oil droplets, suggesting the possession of a lipophilic cuticle. It is proposed that under certain conditions the relative abundance of ectinosomatids may provide a rapid tool for monitoring the impact of oil on benthic communities, if this putative sensitivity is confirmed by further studies.

Résumé : *Une utilisation possible de la méiofaune pour une évaluation rapide de l'impact de la pollution marine par les hydrocarbures sur l'environnement.*
Une étude portant sur l'ensemble des copépodes de la méiofaune a été réalisée à l'ouest de la partie méridionale de la péninsule Shetland, 5 mois après le déversement d'hydrocarbures par le pétrolier *Braer*. Dans cette région, des concentrations d'hydrocarbures variant de 19 à 8 816 ppm dans les sédiments ont été relevées. Aucune incidence de l'impact des hydrocarbures sur la diversité des espèces de copépodes n'a pu être mise en évidence. L'abondance des copépodes et la composition spécifique montrent des corrélations avec la concentration en hydrocarbures, mais ces relations s'expliquent par l'influence du type de sédiment lui-même, dont dépend en partie la concentration en hydrocarbures dans le site étudié. La forte corrélation observée entre l'abondance relative de copépodes ectinosomatidés et la concentration en hydrocarbures n'est probablement pas due à l'influence de facteurs naturels mais il semble que les ectinosomatidés soient très sensibles à la contamination des sédiments. De plus, l'examen de spécimens englués dans des gouttelettes d'hydrocarbures, suggère qu'ils possèdent une cuticule lipophile. Si cette sensibilité présumée est confirmée par des études ultérieures, l'abondance relative des ectinosomatidés pourrait servir, sous certaines conditions, d'outils de mesure rapide pour évaluer l'impact des hydrocarbures sur les communautés benthiques.

Keywords : Harpacticoida, Copepoda, meiobenthos, oil, pollution, *Braer*.

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Introduction

The grounding of the tanker, *Braer*, at Garths Ness, Shetland Islands on 5th January 1993 was followed by the release of 85000 t of light crude oil and 500 t of heavy fuel oil over the following 2 weeks (ESGOSS, 1994). It is estimated that about 14% of the cargo became incorporated in seabed sediments to the west of the south Shetland peninsula. The highest concentrations (>4000 ppm hydrocarbons) were found in a discrete area about 10 km west of Burra Isle, where fine sediments occur. To assess the impact on the benthos, a detailed macrobenthic survey of the area was carried out by the Scottish Office Agriculture, Environment and Fisheries Department (SOAEFD) in April and May 1993; the results have been reported by Kingston *et al.* (1995). Unfortunately the opportunity was not taken to perform a similar detailed survey of the meiobenthos. However, a limited amount of meiobenthic sampling was carried out to the west of the Shetlands by SOAEFD and the samples conveyed to the authors for analysis. While the survey was not sufficiently extensive to incorporate adequate uncontaminated reference areas, it is believed that the findings are of sufficient interest to warrant their dissemination. In particular we report on a novel impact of oil on the meiobenthos and examine possible implications of these findings for oil pollution impact assessment.

Methods

Sediment samples for meiobenthic analysis were taken by Craib corer (core area 25 cm^2) during cruises in May and June 1993 (i.e. 4-5 months after the spillage) by SOAEFD off the west coast of the south Shetland peninsula at depths of 74-126 m. Samples were taken at nine stations, with triplicate cores at six stations and single cores at the other stations. The stations were a subset of those sampled for macrobenthos by Kingston *et al.* (1995, Fig. 2).

Meiobenthic copepods were extracted from the sediment by a process of decantation and density separation. The core sample was first suspended in 1 litre of tapwater in a stoppered measuring cylinder. After allowing 30 s for settlement, the supernatant was decanted off. This decantation stage was performed a total of 6 times, after which the combined supernatants were sieved through meshes of 500 µm and 45 µm. The 45 µm screenings were transferred to a 2 litres conical flask, which was then filled with colloidal silica (Ludox TM, Du Pont Chemicals) at a specific gravity of 1.15. The meiofauna was allowed to separate out from the residue overnight, after which the upper layer of Ludox, containing the meiobenthos, was decanted through a 45 µm screen. This density separation stage was performed a total of 4 times. By checking of the residues it was found that this extraction method had an efficiency of >93%.

Total copepod abundance was determined in each core sample and copepods enumerated at the species level by identifying all individuals in a subsample of c. 120 individuals.

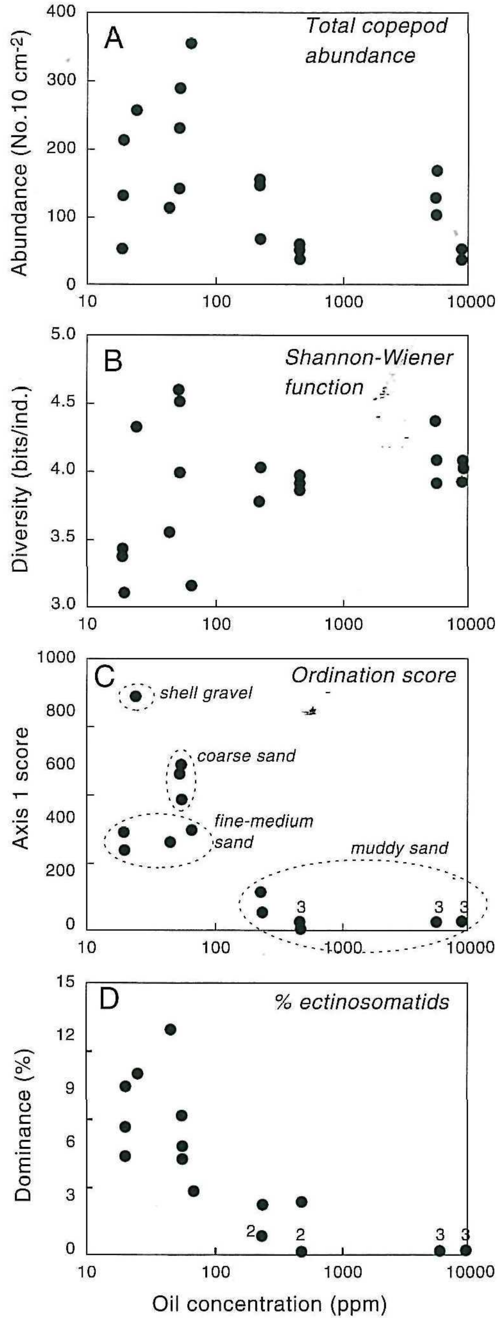

Figure 1. Relationship between total sediment hydrocarbon content (determined by ultraviolet fluorescence spectrophotometry, UVF) and four parameters of the benthic copepod assemblage determined from 21 Craib core samples taken off the west coast of the south Shetland peninsula 4-5 months after the *Braer* oil spill. A, total abundance of copepods; B, Shannon-Wiener species diversity; C, score on the first axis of ordination, with the sediment type also shown; D, ectinosomatids as a percentage of total copepods. Numbers indicate the number of coincident points.

Figure 1. Relation entre la concentration totale en hydrocarbures des sédiments (déterminé par spectrotométrie par fluorescence dans l'ultraviolet, UVF) et quatre paramètres de l'assemblage des copépodes benthiques déterminés à partir de 21 échantillons de carottes Craib, prélevés à l'ouest de la partie méridionale de la péninsule Shetland, 4-5 mois après le déversement d'hydrocarbures par le *Braer*. A, abondance totale des copépodes; B, diversité spécifique Shannon-Wiener; C, pointage de l'Axe 1 de l'ordination avec la nature du sédiment également indiquée ; D, nombre d'ectinosomatidés exprimé en pourcentage du nombre total de copépodes. Les chiffres indiquent le nombre de points qui coïncident.

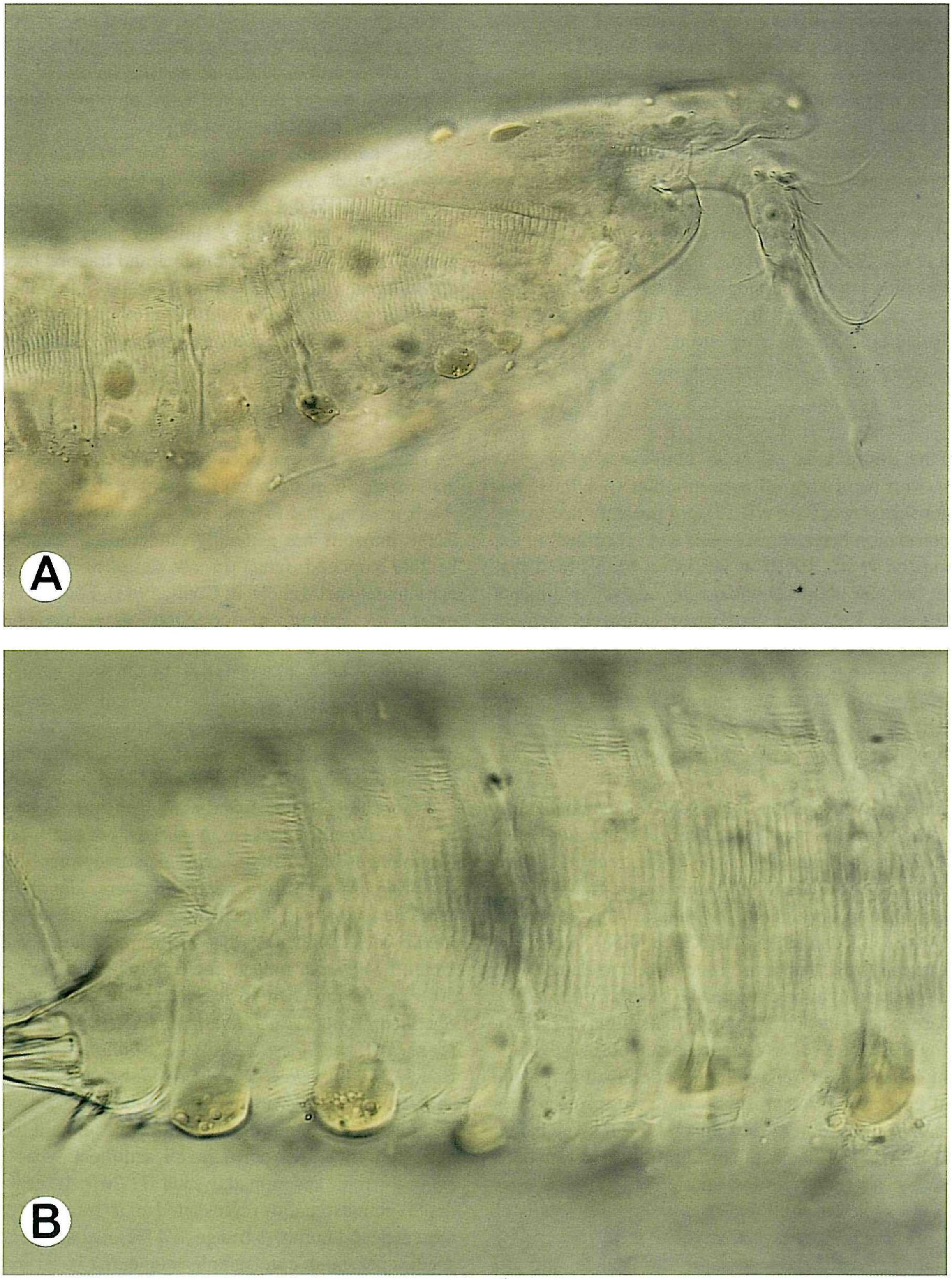

Figure 2. The anterior (A) and posterior (B) regions of an ectinosomatid copepod, *Halectinosoma* sp., showing yellow oil droplets adhering to the cuticle. The specimen originated from medium sand with an oil content of 44 ppm, 33 km from the *Braer* wreck at a depth of 88 m.

Figure 2. Partie antérieure (A) et postérieure (B) d'un ectinosomatidé, *Halectinosoma* sp., montrant des goutelettes jaunâtres d'hydrocarbures adhérant à la cuticle. Le spécimen provient d'un sable moyen, avec une concentration en hydrocarbures de 44 ppm, situé à une distance de 33 km de l'épave du *Braer* et à 88 m de profondeur.

Copepod species diversity was calculated using the Shannon-Wiener function, employing $\log_2$. Spatial trends in species composition of the copepod assemblage were identified by detrended correspondence analysis, based on log-transformed copepod abundance data.

Detailed particle size analysis data was made available for six of the study sites by Environment and Resource Technology Ltd., Edinburgh and total sediment hydrocarbon concentration at all sites by SOAEFD (see Kingston *et al.*, 1995 for details).

Relationships between biological and physicochemical variables were investigated by linear regression analysis, following suitable linearizing transformations of the variables.

Results

Over the study area copepod abundance (Fig. 1A) decreases with increasing oil concentration ($p = 0.01$) but the relationship is weak ($r^2 = 0.29$) and possibly due to the inverse correlation between grain size and oil content in the area (Kingston *et al.*, 1995). It has often been found that copepods become more abundant in coarser sediments (Hicks & Coull, 1983) and the coarser sediments sampled off Shetland exhibited lower oil contents.

There is no correlation between species diversity and oil content (Fig. 1B). The most strongly polluted sediments (5481-8816 ppm oil) exhibit similar diversities to those found in similar muddy sand sediments elsewhere (Moore, 1979).

The first axis of ordination of the species abundance data exhibits an eigenvalue over twice that of subsequent axes and provides a good summary of the major trend in species composition. Fig. 1C shows that the major trend in the faunal composition throughout the sample sites correlates strongly with oil content ($p<0.01$, $r^2 = 0.56$). However, Fig. 1C also shows that axis 1 is also correlated with sediment type, as might be expected (Hicks & Coull, 1983), and so there is no evidence, from this, that oil plays a role in influencing the nature of the copepod assemblage.

Although the overall trend in faunal composition may be explained in terms of faunal responses to natural factors, a pattern in one component of the copepod assemblage is less easily explained. The harpacticoid family Ectinosomatidae was virtually absent from the more heavily-oiled sites (muddy sand sediment with 6-13% silt/clay and depths of 104-126 m). Fig. 1D shows that there is a very strong relationship between ectinosomatid dominance and oil content ($p<0.01$, $r^2 = 0.81$).

Some evidence that oil may have caused this reduction in ectinosomatids off the Shetlands was revealed when ectinosomatids from several stations were found to be coated in yellow oil droplets (Fig. 2). The cuticle is evidently lipophilic. Several specimens of interstitial species were found to exhibit a fine spray of oil droplets on the body somites, while some specimens of the larger burrowing species displayed large droplets over the body surface or amongst the appendages.

Oil contamination was not restricted to the ectinosomatids. A few burrowing representatives of other families were found to exhibit oil droplets at some of the more heavily-oiled sites. However these droplets were almost exclusively few in number and trapped between the appendages, rather than broadly clinging to the smooth cuticular surface of the body somites as they were in the ectinosomatids. Yellow oil droplets were also found in the guts of a few non-ectinosomatid specimens.

Discussion

There is no evidence from the literature that the ectinosomatid distribution pattern off Shetland is likely to result from natural factors, such as granulometry or depth. Ectinosomatids are generally common constituents of the benthic copepod fauna in all sediment types over the continental shelf (Hicks & Coull, 1983). For example, in an extensive survey of copepod assemblages in the Mediterranean, Soyer (1970) found ectinosomatids to be common in all sediment types. In offshore muddy sand at depths of 85-150 m, which represent the habitat most similar to that of the more heavily-oiled sediments off Shetland, Soyer (1970) found ectinosomatids to be the dominant family, representing 21% of the copepod fauna.

Moore (1979) also found ectinosomatids to be common in all sediment types in a survey of benthic copepod assemblages of the Irish Sea. This survey involved similar sampling methods, the copepods were identified by the same personnel and it included a region with a very similar muddy sand deposit to that of the most heavily impacted area off Shetland. Indeed, the following five taxa represent 50% of the fauna in Irish Sea muddy sand and 40% off Shetland: *Amphiascus tenuiremis* (Brady & Robertson), *Mesochra pygmaea* (Claus), *Laophonte longicaudata* Boeck, *Normanella* spp. and *Cletodes tenuipes* Scott. Fig. 3 shows that there is no relationship between ectinosomatid dominance and depth or between ectinosomatid dominance and grain size. All cores in all sediment types included ectinosomatids and in muddy sand (11-26% silt/clay, 33-72 m depth) ectinosomatids represented an average of 12% of the total copepod numbers (range, 6-17%) and an average of 10 species per Craib core sample (range, 6-17). At the deepest stations examined (>100 m) ectinosomatids represented 20% of the copepod fauna (range, 13-28%).

Ectinosomatids have not hitherto been considered as a pollution-sensitive taxon. The affinity of the ectinosomatid cuticle for oil, previously unknown, appears to explain their

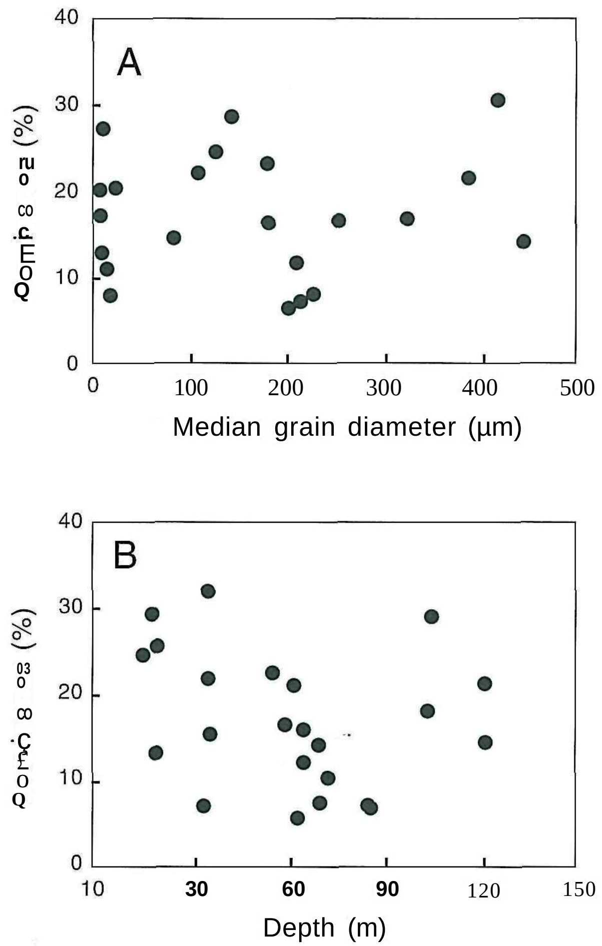

Figure **3.** The relationship between ectinosomatid dominance (percentage of total copepods) in **23** sediment samples from depths greater than 10 **m** in the Irish Sea and two ecological factors: A, median grain diameter of the sediment; B, depth below chart datum.

Figure **3.** Relation entre la dominance des ectinosomatidés exprimée en pourcentage du nombre total de copépodes dans **23** échantillons de sédiments prélevés **à** des profondeurs supérieures **à** 10 m dans **la** mer d'Irlande et deux facteurs écologiques **:** A, diamètre médian des grains du sédiment **;** B, profondeur.

absence from off Shetland, although it is unclear whether an accumulation of oil over the body surface, and perhaps limbs, eventually incapacitates them or whether they become too buoyant to sustain their benthic habit. It is also possible that the oil has exerted a toxic impact as Gyllenberg (1986) found concentrations of crude oil in seawater as low as 25 ppb to cause 50% mortality in 12 days for the ectinosomatid, *Halectinosoma curticorne* (Boeck). The work of Feder et *al.* (1990) may suggest that some ectinosomatids are highly tolerant to oiled sediments, these workers recording a rise in the abundance of *Halectinosoma gothiceps* (Giesbrecht) following the experimental oiling of a mudflat. However, the extent to which these copepods came into contact with the oil is unknown and may have been minimal as Feder et *al.* (1990) concluded that the sediment had a low permeability to the oil and the sediment particles a low affinity for hydrocarbons.

It is impossible to assess the ecological significance of the paucity of ectinosomatids in this area as there is, unfortunately, little quantitative information on the importance of ectinosomatids in benthic food chains. It is known, however, that benthic copepods form the predominant prey items in the guts of juvenile fish of many species (Coull, 1990; Gee, 1989) and that ectinosomatids are components of the diet of juvenile flatfish, gobies and whiting (Coull et *al.*, 1995; Gee, 1987). Thus it is possible that the oiling of ectinosomatids could lead to a reduction in food for higher trophic levels, or the predators may merely turn to other forms of prey. Predation on oiled copepods will be a mechanism for the passage of *Braer* oil up the food chain.

Kingston et *al.* (1995) found little evidence for impact of the *Braer* oil spill on the macrobenthos in the same area. The major factors determining -the distribution of the macrobenthos appeared to be related to the nature of the sediments and not the degree of oil contamination. Species diversity was also found to be unaffected by the oil spill. Although there was some evidence for slight changes in a small number of polychaete species (such as *Capitella* spp. and *Chaetozone setosa* Malmgren), the clearest effect of the oil was in the elimination of amphipods at the more heavily-oiled stations. Thus the short-term impact on the macrobenthos appears to be at a similar level to that on the meiobenthos, with amphipods and ectinosomatids showing similar responses.

Montagna & Harper (1996) also found harpacticoid and amphipod abundance to show similar responses to pollution from gas platforms in the Gulf of Mexico. However, in contrast to the *Braer* study, the family Ectinosomatidae dominated the harpacticoid fauna around the platforms. This difference is explicable in terms of the disparity in sedimentary hydrocarbon levels, which were very low in the Gulf of Mexico as a result of the use of water-based drilling muds.

The apparent sensitivity of ectinosomatids to sedimentary oil contamination requires conclusive proof and work is now underway in the authors' laboratory to ascertain the universality of the ectinosomatid response to oil and to investigate the mechanisms of any impact. Although ectinosomatids are extremely difficult to identify at the species level, identification to family is simple; all non-interstitial species have characteristic fusiform body shapes which permit their recognition under a stereo microscope. This offers the prospect of the development of a rapid but sensitive monitoring tool for assessment of the presence of disturbance of the benthos by oil spills. The development of such a methodology, possibly based on the percentage dominance of ectinosomatids, may offer valuable confirmatory evidence of pollution impact when the macrofaunal evidence is weak or could possibly replace conventional macrofaunal monitoring where only small sediment samples can be taken, such as by R.O.V or diver.

Although the advantages of incorporating meiofauna into environmental monitoring programmes have been repeatedly recognized (e.g. Coull & Chandler, 1992; Heip, 1980; Moore & Bett, 1989; Warwick, 1988), perceived taxonomic difficulties are probably largely responsible for the slow adoption of such methods. The *Braer* study contributes to an increasing body of evidence that indicates the potential for univariate and multivariate meiofaunal monitoring methods based on relatively rapid, supra-specific identification of faunal samples (e.g. Heip et *al.* 1988; Moore & Bett, 1989; Moore & Somerfield, 1997; Raffaelli, 1987).

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