THE IMPACT OF OIL POLLUTION ON INTERTIDAL MEIOFAUNA. FIELD STUDIES AFTER THE LA CORUNA-SPILL, MAY 1976

by

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Résumé

L'effet de la contamination par le pétrole sur la méiofaune intercotidale a été étudié immédiatement après la marée noire provoquée par le naufrage du pétrolier géant « Urquiola », puis l'année suivante.

La zone examinée le long de la côte septentrionale de l'Espagne s'est étendue des endroits les plus pollués jusqu'aux plages apparemment indemnes. L'impact sur la méiofaune est en relation avec l'exposition des stations de prélèvement par rapport au centre de la marée noire. Les divers groupes taxonomiques ont été différemment affectés ; beaucoup de Nématodes et d'Annélides ont relativement bien résisté alors que les Harpacticoïdes et les Turbellariés étaient plus sensibles.

En l'espace d'un an, la méiofaune s'est considérablement reconstituée, tant dans sa diversité que dans son abondance pourtant sérieusement affectées par la marée noire. Les raisons de cette réapparition relativement rapide et les différentes réactions de la faune interstitielle à la contamination par le pétrole sont discutées en relation avec les propriétés régionales spécifiques de l'habitat.

Introduction

Almost nothing is known about the reaction of intertidal meiobenthos to oil contamination despite the extreme exposure of littoral sediments to oil slicks stranding on the shore and pressed into the sediment by waves and tides. A superficial description of an oil disaster in a mangrove area was given by Rützler and Sterrer (1970). A closer examination of the meiofauna in an oil-polluted beach was conducted by Wormald (1976), but the accident in question was caused by heavy fuel and not by crude oil. Similarly, the report of Sanders et al. (1972) on the West Falmouth spill which peripherically dealt with some temporary meiofauna, referred to No. 2 fuel oil. Hence, our investigations in June 1976 and 1977 on beaches in northern Spain seem to represent the first occasion that intertidal meiofauna has been studied after a large spill of crude oil. This situation justifies a detailed discussion of the specific conditions and reactions of the meiobenthos after oil contamination.

Investigation area, material and methods

On May 12, 1976, the Spanish super-tanker "Monte Urquiola" grounded with 107,000 to of "Arabian Light" oil and 3,000 to of "Bunker C" fuel oil only a few miles from the city of La Coruña (northern Spain) causing

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CAHIERS DE BIOLOGIE MARINE
Tome XX - 1979 - pp. 231-251

a huge oil spill (Gundlach, et al., 1977; Gundlach and Hayes, 1977; Rodriguez, 1976). It is estimated that, despite a large fire after the subsequent explosion of the tanker, about 30,000 to of oil drifted ashore contaminating the coast of the "Rias Altas" with their rocky and sandy shores and covering an overall area of about 350km between the towns Malpica and Cedeira (Fig. 1).

Six weeks after the spill, the meiofauna of the polluted area was studied at certain selected stations. Due to shortage of time, sampling had to be restricted to some few quantitative horizontal and vertical profiles which could only yield relatively rough information about the noxious effects of oil on various meiofauna groups, about the interdependence between sediment structure and exposure of interstitial fauna to oil and, finally, about the regeneration of meiobenthic life.

Because of the low number of stations and profiles which could be sampled, the values obtained might not be statistically representative for a given beach as a whole. However, the figures presented here are selected from other parallel counts and samples from adjacent sites on the basis of reasonable accordance in order to provide reliable conclusions. An additional difficulty was the complete lack of previous information about the meiofauna of the area before the spill. For this reason, samples were taken from the uncontaminated beach at Corme (Fig. 1) which thus served as "reference station" which other stations in the polluted area could be compared with. Specificity of the detrimental impact between and within taxonomical groups is studied in a more detailed faunai analysis.

As a background to the meiobenthic studies, the oil residues were tentatively examined for their chemical structure and degree of decomposition by infrared spectrograms and gas-chromatograms and some representative examples are submitted here.

The sand samples were taken with a perspex corer of 5cm width from beaches differing in sediment structure and exposure. In the center of oil pollution, the two Mera beaches represent semi-exposed sites with medium to coarse sand and good oxygen supply throughout the sediment column. The sampling stations in Sta. Cruz and El Ferrol are sand flats with a rich content of organic matter in the fine sand. The zone of moderate contamination is represented by the station "Playa Baranan", an exposed, steep, broad beach with medium to coarse, well oxidized sand. Corme, the "reference" station beyond the zone of visual oil pollution, is a beach of intermediate character: semi-exposed medium sand, but still oxygen-supplied down to the ground water layer (GWL).

Sorting and counting of the meiofauna was done after fixation of the samples in buffered formaline, staining in Rose Bengal and elutriation. Some unpreserved parallel samples were taken for tentative examination of the "soft meiofauna" (ciliates, turbellarians). The subsamples for oil analysis were deep-frozen and later kept freeze-dried until further treatment.

RESULTS

1. Evidence of the oil polluted area

Six weeks after the spill, the beaches of Mera and Sta. Cruz, spaced around the Ria de La Coruña (Fig. 1), were found completely covered by stranded oil (about 3cm thick), and in sheltered coves slicks were up to 20cm thick. Underneath the slightly hardened tar surface, the oil was still rather liquid filling the air on the beaches with its typical smell. Some attempts were made by the authorities to remove the oil mechanically, but the shores were not cleaned up

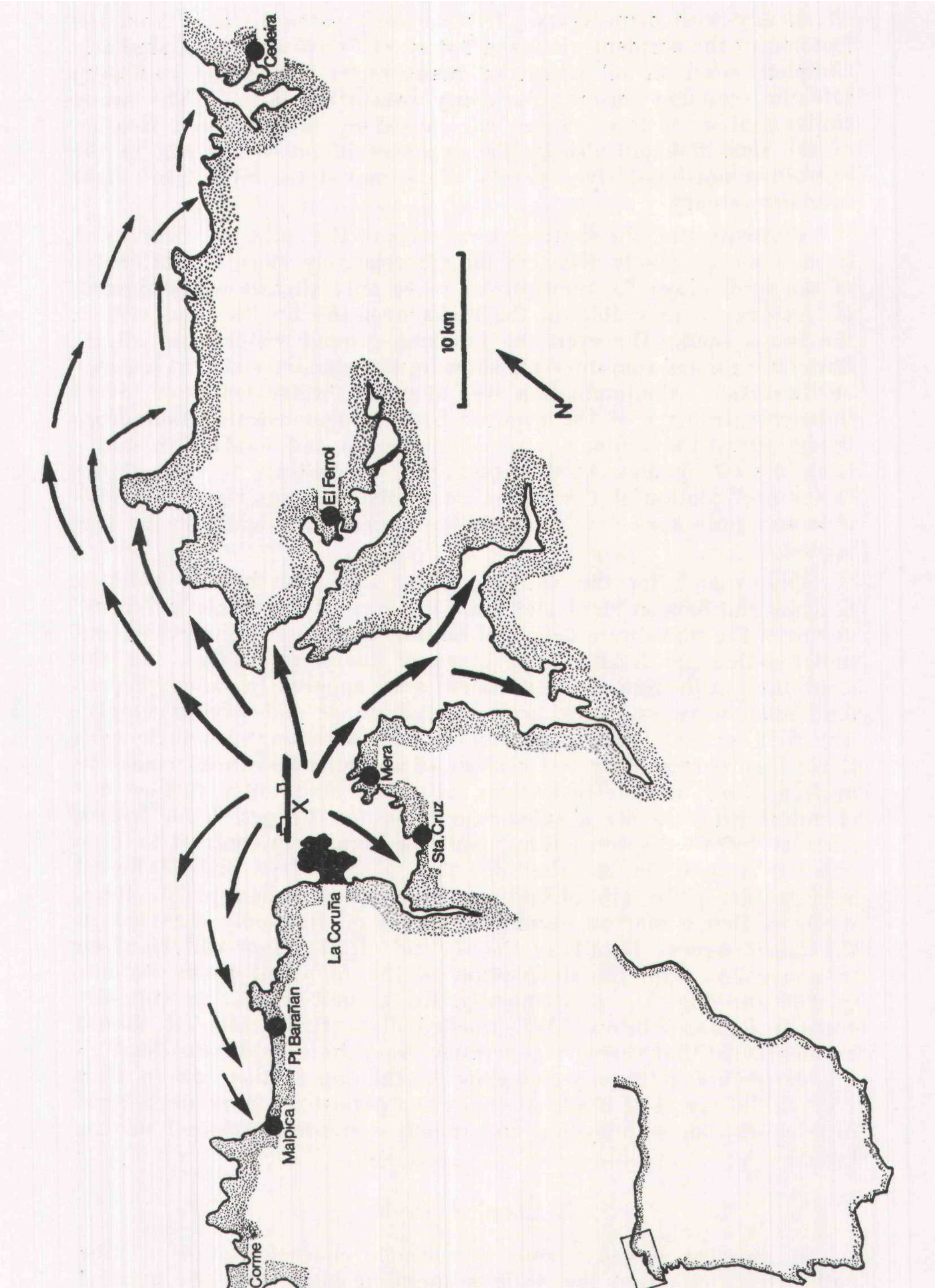


FIG. 1
Investigateci area (arrows indicate direction of drifting oil).

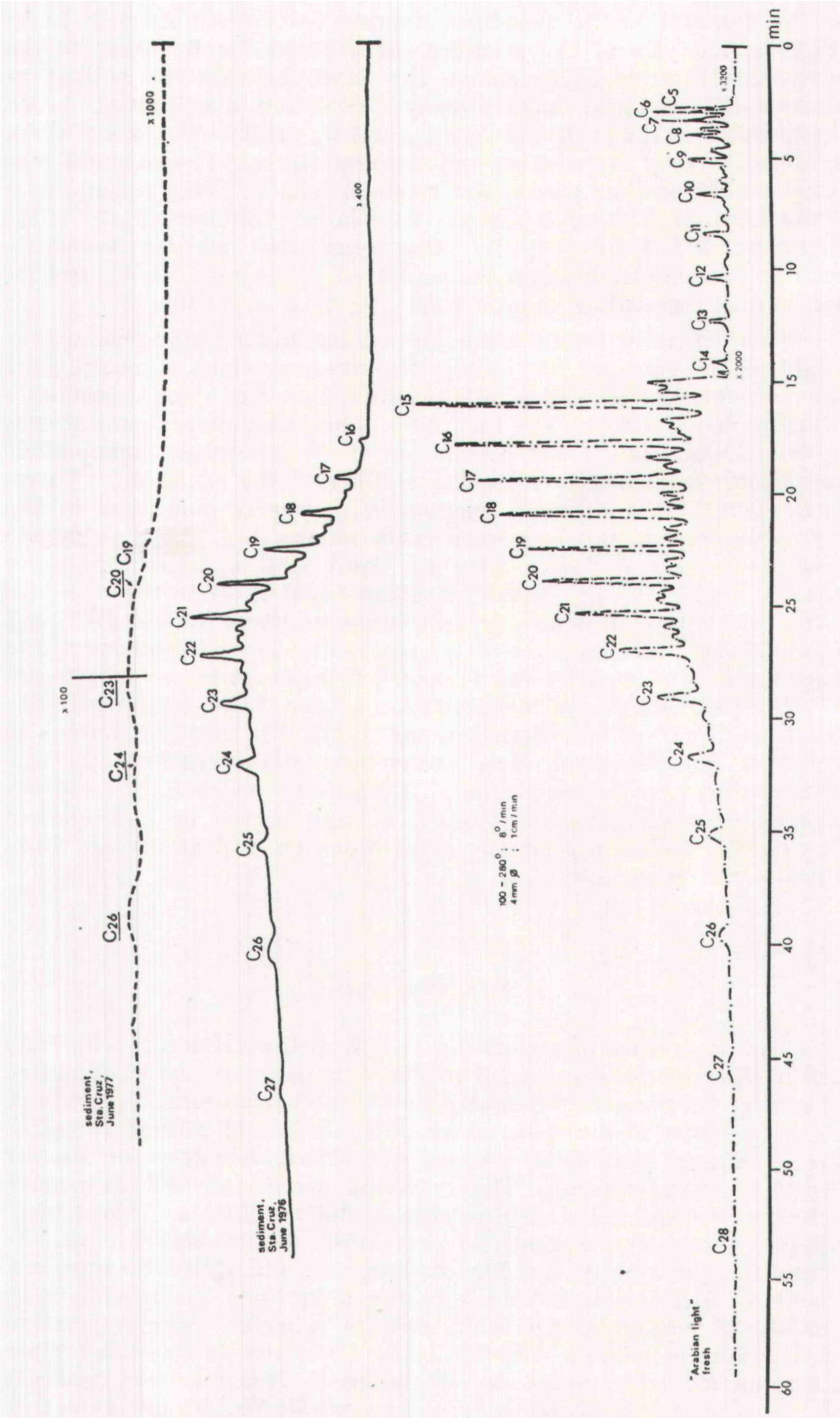
chemically with dispersants. Despite the greater distance from the location of the accident, the sand flat at El Ferrol showed a similarly complete cover of oil which in many cases had penetrated deep into the sediment forming dark oily subsurface layers. The heavy contamination of this station was caused by the sheltered location of the sand flat and also by the exposure of the whole Ria to the prevailing northeasterly currents which moved the oil patches right into the estuary.

Consequently, the southwestern parts of the coast were exempted from a more serious disaster: though relatively close to the centre of the spill, Playa Barañan proved to be only slightly contaminated, oil residues were visible on the rocks near the hw-line, but not on the beach sand. However, the brackish ground water from all Pl. Barañan-samples contained oil showing the characteristic iridescence on its surface. Contamination even at ground water depths of 140cm (intensive drainage of the exposed beach!) demonstrated that deep-living interstitial animais were also affected and could not escape from the oil by downward migrations. In contrast to this, at the "reference" station of Corme, no oil whatsoever was visually detectable and only very low concentrations were chemically to be discerned.

One year after the spill, in June 1977, the heavily polluted beaches and flats at Mera and Sta. Cruz seemed superficially "clean" and even the rocks were devoid of oil (however, in rocky crevices and underneath algal holdfasts, residues of tar were visible). In the sand, the purification of the sediment was, apparently, largely dependent upon wave exposure, grain size, drainage and oxygen supply: The well exposed beaches at Mera and Pl. Barañan, with their relatively high permeability and absence of any oligoxic zones, seemed to be free of oil; neither iridescence on the ground water surface nor chemical evidence for a substantial pollution by petroleum hydrocarbons (infra-red spectrograms) could be found. In contrast to these exposed stations, in the sheltered flats of Sta. Cruz and El Ferrol regeneration of the habitat had not proceeded quite as rapidly. Here, it seems that a marked decomposition of oil had only occurred in the upper layers. Details of the vertical stratification will be given in connection with the description of the fauna at these stations (p. 236 and Fig. 5). Consequently, the ground water was still oily and the sediment below GWL smelled distinctly of oil. (It should be mentioned that visible regeneration from the oil spill was least in the deep mud at the narrow ends in the inner Rias, where after 1 year solid layers of black oil slicks had persisted almost unchanged in thickness and composition underneath a mm-thin oxidized surface layer.)

2. Chemical results

It emerges already from this rough characterization of the pollution situation at the various sampling sites, that the gradual decomposition of Arabian Light oil by weathering can be followed and illustrated best in inhomogeneous, fairly sheltered sand flats (Figs. 2 and 3).



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Gas-chromatograms from fresh oil and selected sediment samples.

In contrast to the gas-chromatogram from fresh Arabian Light (Fig. 2), analysis of the stranded oil exposed for 6 weeks to the environment (June 1976) shows the short-chained, low boiling n-alkanes below C_{16} to have already completely disappeared. Also the decrease of the peaks between C_{16} and C_{24} exhibits the loss of these hydrocarbons by evaporation and decomposition. The isoparaffines (smaller intermediate peaks) are retained longer (peaks remain relatively high) indicating a slower degradation (Blumer et al., 1973; Hellmann and Müller, 1975). One year later, alkanes below C_{19} seem to be completely degraded and even peaks between C_{19} and C_{26} are hardly discernible despite high graphical expansion.

This generally found rapid loss of the lower boiling paraffines might be of considerable biological relevance since it could shift the composition of crude oil towards the more toxic aromates (Blumer et al., 1973). On the other hand, oxidative chemical and microbial degradation and dissolution of all unsaturated compounds commences immediately after the spilling of the crude oil. Therefore, aging of the original compounds is clearly monitored in the corresponding infrared spectrograms of the Sta. Scuz sediments (Fig. 3) already 6 weeks after the spill (first oxidative steps are already visible in the "Fresh" Arabian Light) : While there is still a high portion of aromates present (wave numbers around 1600 and 710—820cm^{1}), the increase in typical "aging groups" (carbonyl and ester bands between 1710 and 1780cm^{1}, C-O-groups between 1000 and 1200cm^{-1}; Hellmann and Müller, 1975; Kägler, 1969) is considerable. After one year of weathering (June 1977), the relative content of aromates has decreased, their peaks now being exceeded by those of the typical "oxidation bands". Altogether, the chemical analyses of the surface sediments indicate a high degree of hydrocarbon degradation within a relatively short time, as evident already from visual scrutiny (p. 239).

3. Meiofauna results

The occurrence of meiofauna groups at the various beaches and investigation periods, compiled in Fig. 4, is based on the examination of surface subsamples (0-5cm depth=100ccm) from mid-tide stations. Near the center of the spill, where thick sludges of oil had stranded, the meiofauna was totally wiped out (Mera, harbour) or heavily depleted (Mera, village). The surviving meiofauna was dominated here by few species of schizorhynchs and otoplanids (Turbellaria), whereas nematodes, usually representing the viable rest of the interstitial community, had like the harpacticoids, almost disappeared. The few oligochaetes belonged to the ubiquitous genus *Marionina* (mainly *M. subterranea,* few *M. preclitellochaeta).* The impression of a richer meiofauna community at Sta. Cruz is deceptive since the relatively large nematode population in fact consisted basically of two species only *(Trissonchulus benepapulosas; Microlaimus* sp.), and beside these apparently very resistant forms, only few harpacticoids were present *(Pseudosarsameira exilis* mainly). Thus, the

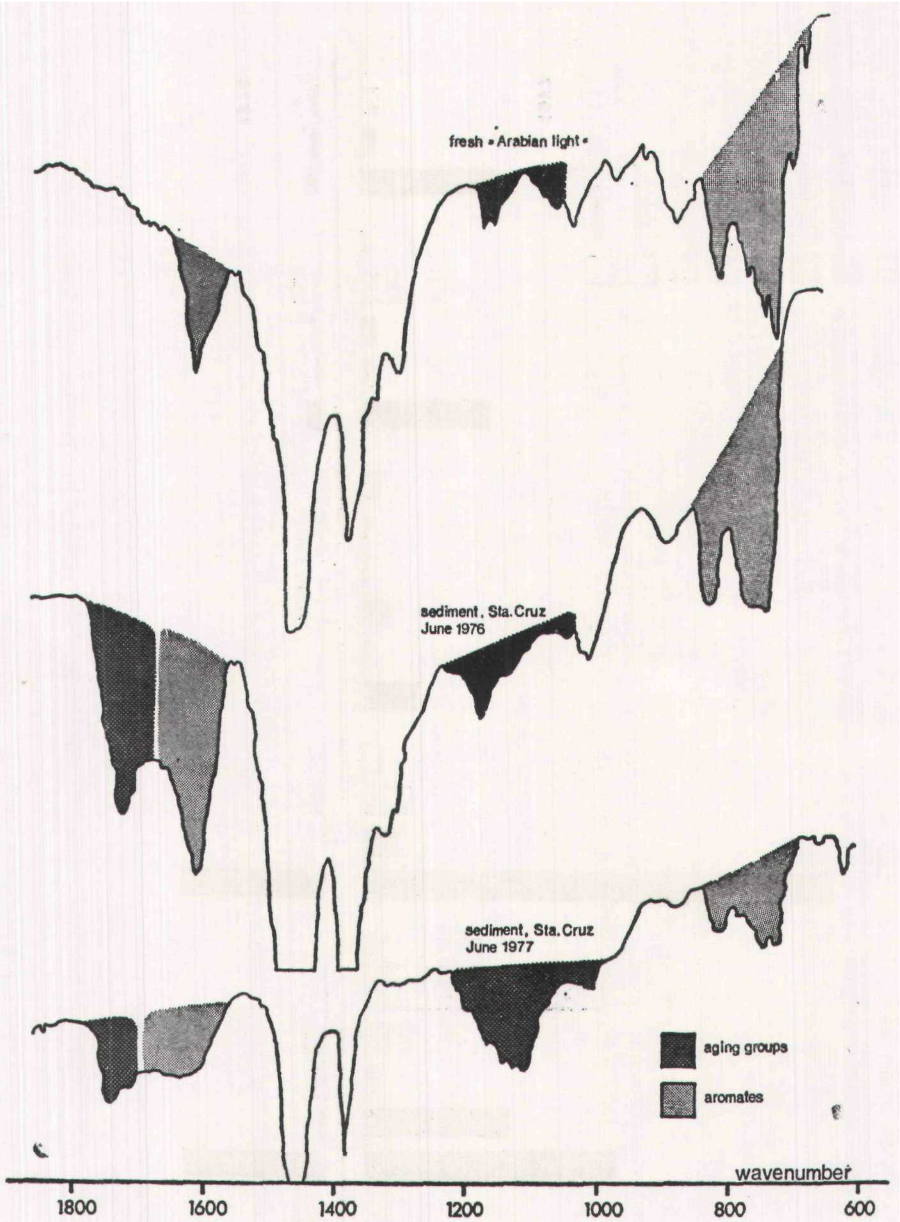

FIG. 3
Infra-red spectrograms from fresh oil and selected sediment samples.

relatively high abundance of total meiofauna at Sta. Cruz in 1976 did not indicate any less harmful impact of the oil than in Mera, village. The low diversity at Sta. Cruz demonstrated a similarly intensive meiofaunal stress situation.

Corresponding to the main direction of floating oil, and confirming the visual deterioration of sediment conditions described above, the 1976-samples from the flat at El Ferrol displayed a similarly

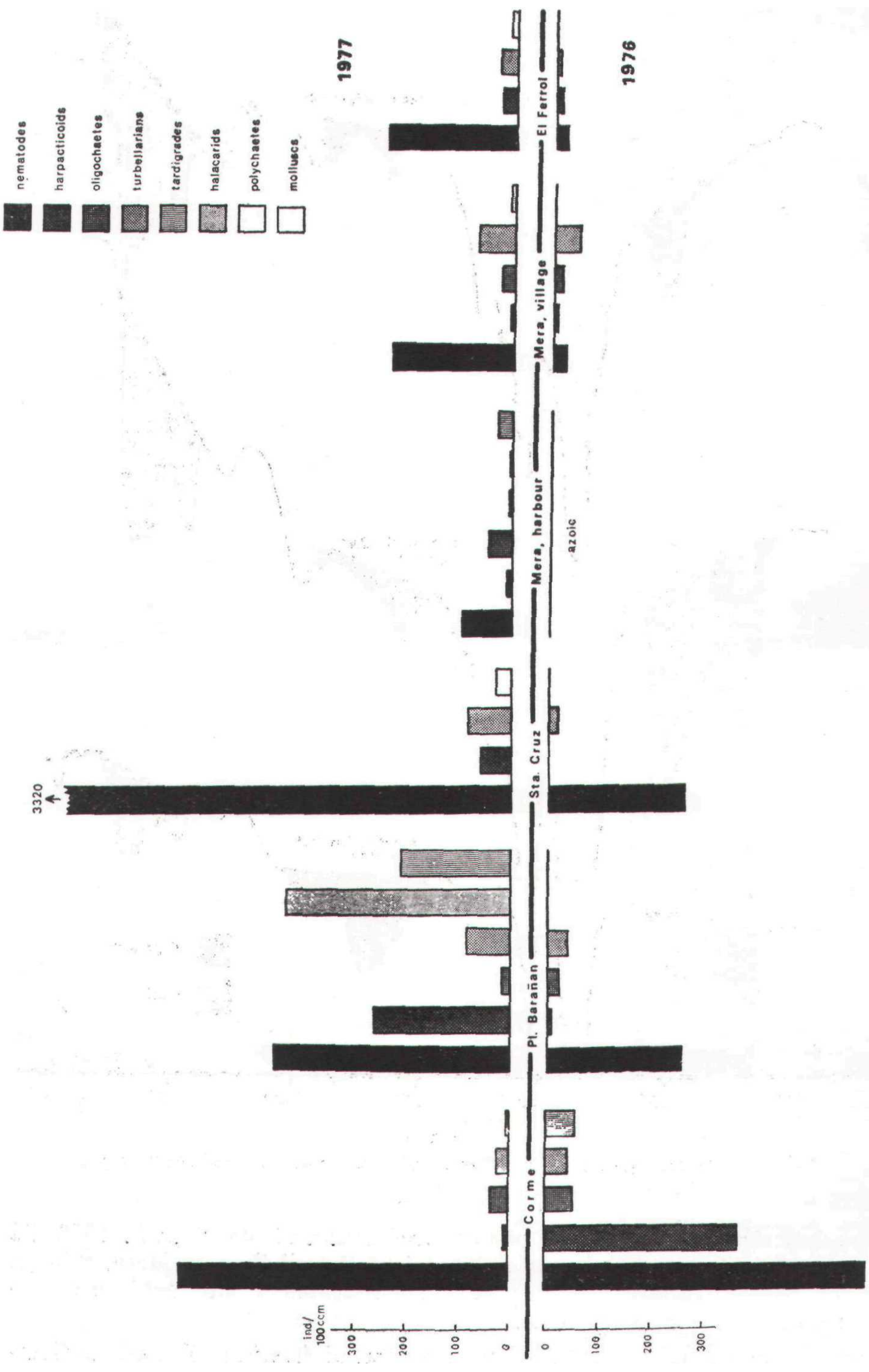

FIG. 4
Meiofauna populations in **1976 and** 1977.

massive obliteration of the meiofauna leaving only few nematodes (mainly *Bathylaimus),* harpacticoids (mainly *Asellopsis intermedia)* and turbellarians (un-identified). Even in areas with moderate oil contamination, the meiofauna seems to be markedly reduced, the samples from Pl. Barañan containing almost exclusively the nematode species *Enoplolaimus litoralis* beside a few species of oligochaetes (mainly *Marionina achaeta),* harpacticoids *(Arenopontia* sp.) and turbellarians (mainly otoplanids). In contrast to the rather uniform and poor meiobenthos inhabiting the oil-contaminated areas, the "reference beach" of Corme was populated by a diverse and rich interstitial fauna. Here, the nematode and harpacticoid populations consisted of a variety of species. It is of interest to note the survival of some less dominant groups in the contaminated area: numerous mystacocarids, some hoplonemerteans, few halacarids (Pl. Barañan), and one species of tardigrades (Mera, Pl. Barañan).

In June 1977, one year after the spill, the meiofauna communities in the polluted area differed substantially from the impoverished populations shortly after the accident: their abundance and diversity had increased indicating a considerable fauna regeneration. Even in the area formerly totally devoid of interstitial fauna (Mera, harbour), a diverse meiofauna had been established (including polychaetes, halacarids, tardigrades), although, here recovery had started slowly and abundance was still low. The striking aggregation of nematodes in the Sta. Cruz-sample was restricted to the upper cm-layer and probably an accidental phenomenon since it was caused mainly by one species, *Chromadora nudicapitata,* a form normally known from the phytal.

At Pl. Barañan, a major increase in population density was also found in acarids *(Actacarus becescui;* small Trombidiformes) and tardigrades (200 specimens of *Batillipes pennaki* per 100cm!).

In contrast to the change in meiofauna abundance and diversity at all stations in the area of pollution, at the unpolluted "reference station" Corme the 1977-meiofauna community had remained stable in diversity and, except for harpacticoids, also in abundance. (Since, here, counts from slightly deeper horizons resulted in a markedly higher harpacticoid number, their depression in the upper layers seems to be an irregular inhomogeneity probably not relatable to oil pollution.)

The occurrence of interstitial ciliates, though only evaluated qualitatively, followed the general trend in 1976: the "reference" and the slightly contaminated beaches in the west contained the richest and most diverse protozoans; the samples from the center of the spill were devoid of ciliates and the easternmost station at El Ferrol harboured only a few specimens just at the surface. Again, by 1977, even the heaviest polluted stations have been repopulated by some ciliates (Oxytrichidae, Euplotidae).

Recolonization and amendment of the heavily impoverished habitants within one year can also be demonstrated by comparing the physiography and meiofauna of vertical sediment cores from corresponding samples in 1976 and 1977 (sand flat in Sta. Cruz, mid-tide;

Fig. 5). In 1976, the fine sediment at the surface was covered by a 2cm thick layer of oily sand inhibiting any percolation of free water. Already at the very surface, the redoxpotential had dropped below zero and probably, as a result of the oxygen requiring decomposition of hydrocarbons, it remained negative throughout the whole sediment column investigated.

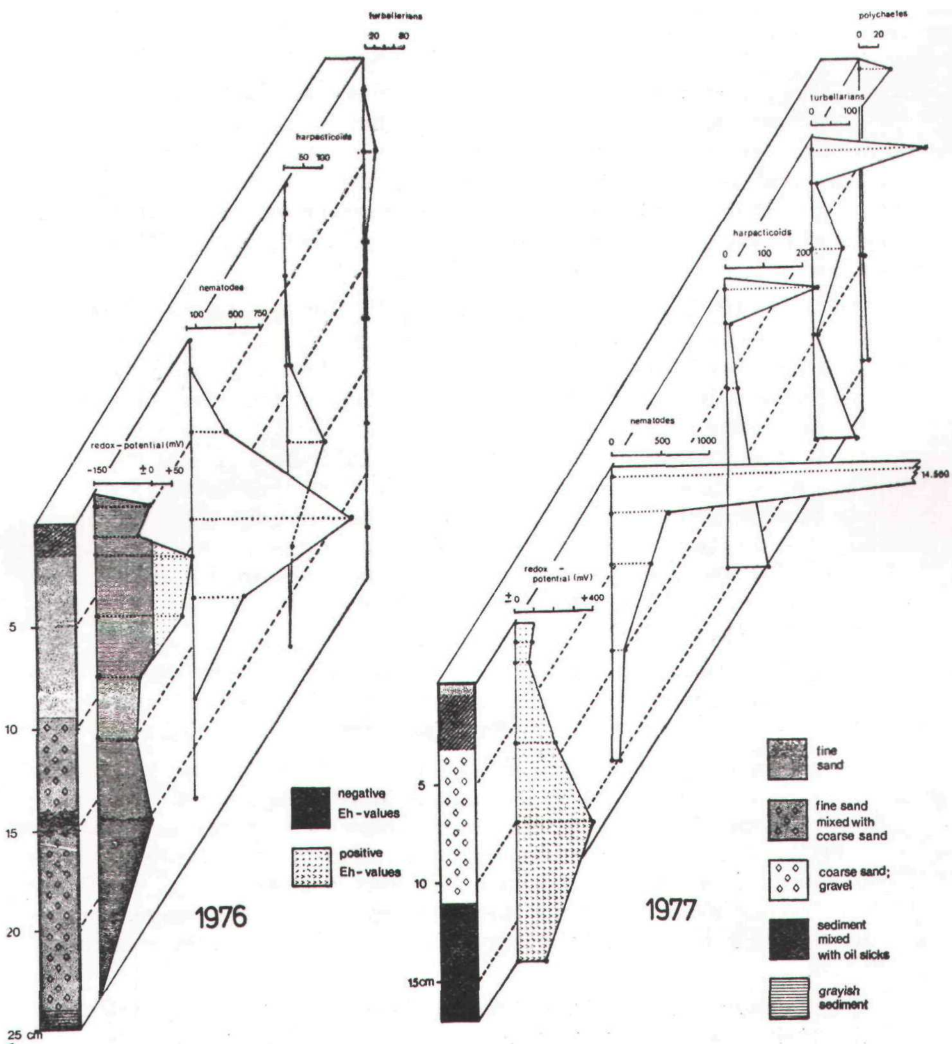

FIG. 5
Sediment properties and meiofauna distribution in vertical cores from Sta. Cruz in 1976 and 1977.

Only between 3 and 7cm depth, a rest of oligoxic sediment was maintained and, correspondingly, it was this layer that was preferably inhabited by some meiofauna (nematodes and harpacticoids). It is quite possible that the second horizon of oily sediment at about a 14cm depth lead to deterioration of life conditions of these populations, since they decreased steeply approaching that depth.

In 1977, the same place was characterized by a "clean", bright and fully oxidized surface. However, underneath this thin surface of (resuspended?) fine sand, tar particles were found mixed with the sediment. Apparently, the decomposition of this oily horizon had lead to the unusual depression in the redoxpotential curve within this layer. But Eh-values, in this case, never sank below zero, indicating an already advanced degradation of the oil, and, further down they increased again to highly positive recordings throughout the rest of the column.

The vertical distribution of the meiofauna in 1977 corresponded to the more "normal" sediment situation: rich aggregations of various different animal groups in the surface layers typical for sheltered sand flats. Apart from the distributional pattern, again, the increase in faunai diversity and abundance at Sta. Cruz (Fig. 4) indicates the habitat recovery (presence of harpacticoids, polychaetes, oligochaetes, bivalve larvae!).

The following list of identified meiofauna is based on some selected surface samples (if not stated otherwise) and qualitatively identified mostly to the generic level only. Moreover, in many cases, fixed, contracted or juvenile animais made any detailed identification impossible. Though originally assigned in this ecological study for the estimation of the fauna composition only, it was felt that the resulting information might nonetheless improve our scanty knowledge of the meiofauna of the Spanish coasts.

Tab. 1 : List of identified meiofauna

CILIATES

CORME, 1976: *Aspidisca* sp., *Euplotes* sp., *Chlamydodon triqnetrus, Loxophyllum* sp., Oxytrichidae (all forms typical for fairly exposed beaches).

PL. BARANAN, 1976 (0-5cm) : *Loxophyllum* sp., *Uronychia transfuga,* Trachelocercidae, Oxytrichidae (15-20cm): *Remanella* sp., *Coleps* sp., *Loxophyllum* sp., *Uronychia transfuga, Euplotes* sp., Trachelocercidae.
1977 (O-5cm) : *Loxophyllum* sp., *Coleps* sp.

MEHA, HARBOUR, 1977: *Euplotes* sp., Oxytrichidae.

MERA, VILLAGE, 1977: *Pleuzonema* sp.

EL FERROL, 1977: *Euplotes* sp., Trachelocercidae, several unidentified hypotrichous spp.

TURBELLARIANS

CORME, 1976: *Antromacrostomum armatum* (numerous), *Actinoposthia biaculeata,* Otoplaninae (abundant), Schizorhynchidae (numerous).
1977: Otoplaninae spp., *Antromacrostomum armatum.*

PL. BARANAN, 1976 (0-5cm) : *Pseudaphanostoma psammophilum* (numerous). Otoplaninae sp. (abundant), Acoela, unidentified, few).
(15-20cm) : *Anthroposthia unipara, Simplicomorpha gigantorhabditis* (common), Otoplaninae sp. (numerous), Kalyptorhynchidae, unident. (common).
1977 (0-5cm) : Otoplaninae (numerous), Typhloplanoida, Kalyptorhynchidae, Macrostomida, Coelogynoporoidae, Dalyellioidea.

STA. CRUZ, 1976: Acoela, Otoplaninae.

MERA, HARBOUR, 1977: Coelogynoporidae sp.

MERA, VILLAGE, 1976: Schizorhynchidae sp. (numerous), Otoplaninae sp. (numerous).
1977: Otoplaninae.

GASTROTRICHS

PL. BARANAN, 1977: *Turbanella ? cornuta.*

NEMERTEANS

PL. BARANAN, 1976: Hoplonemertini.

NEMATODES

CORME, 1976: *Enoplolaimus litoralis* (numerous), *Bathylaimus* sp., Chromadoridae, unident.
1977: *Trissonchulus benepapillosus* (numerous), *Latronema* sp. (numerous), *Axonolaimus* sp. (numerous), *Enoplolaimus litoralis, Bathylaimus* sp., *Nygmatonchus* sp., *Oncholaimellus* sp., *Rhabditis* sp. Chromadoridae sp.

PL. BARANAN, 1976: *Enoplolaimus litoralis* (abundant), *Axonolaimus* sp. (few).
1977: *Enoplolaimus litoralis* (numerous), *Axonolaimus* sp. (few), *Trissonchulus benepapillosus* (few).

STA. CRUZ, 1960 (0-7,5cm): *Trissonchulus benepapillosus* (numerous), *Microlaimus* sp. (numerous), *Paralinhomoeus* sp., *Tripyloides* sp., *Mesacanthoides* sp., *Leptolaimus* sp., *Spirinia* sp.
1977 (0-1cm): *Chromadora nudicapitata* (abundant), Chromadoridae sp., *Theristus setosus, Theristus* sp., *Oncholaimus* sp., *Cyatholaimus* sp., *Paracyatholaimus* sp., *Spirinia* sp.
(1-3,5cm): *Chromadora nudicapitata* (numerous), *Theristus* sp. (numerous), *Cyatholaimus* sp., *Sabatiera* sp., *Odontophora* sp., Linhomoeidae.
(3,5-7cm): *Chromadora nudicapitata* (few), *Theristus* sp., *Leptolaimus* sp., *Ascolaimus* sp., *Terfusia* sp.

MERA, VILLAGE, 1976 (0-5cm) : *Leptolaimus* sp., *Bathylaimus* sp., *Ascolaimus* sp., *Enoplolaimus* sp., Enoplidae.
(20-25cm): *Latronema* sp., *Trissonchulus benepapillosus, Enoplolaimus* sp. (common), *Enoploides* sp., *Ascolaimus* sp., *Bathylaimus* sp., *Leptolaimus* sp.

EL FERROL, 1976 (5-10cm): *Bathylaimus* sp., *Oncholaimus* sp., *Theristus* sp.

EL FERROL, 1977 (0-5cm) : Axonolaimus sp., *Tripyloides* sp., *Bathylaimus* sp. (all numerous), *Ascolaimus* sp., *Oncholaimus* spp., *Theristus setosus, Theristus* sp., Chromadoridae sp., *Enoplus* sp., *Enoplolaimus* sp., *Enoploides* sp., *Chromadorita* aff. *tentabunda, Paracanthonchus* aff. caecus, *Cyatholaimus* sp.
(5-10cm): *Monoposthia mirabilis* (numerous), *Dagda* sp. (common), *Paralinhomoeus* sp. (common), *Microlaimus* sp., *Ascolaimus* sp., *Trefusia* sp., *Leptolaimus* sp.

HARPACTICOIDS

CORME, 1976: *Paraleptastacus* sp. (dominant), *Halectinosoma* sp., *Stenocaris* sp.

PL. BARANAN, 1976 (5-10cm) : *Arenopontia* sp., *Protoleptastacus phyllosetosus.*
(75-80cm): *Leptomesochra* sp. (numerous), Cyclopidae, unident. (numerous), *Cylindropsyllus* sp., *Protoleptastacus* sp., *Paramesochra* sp. 1977 (5-10cm): *Arenopontia* sp. (abundant).

STA. CRUZ, 1976: *Pseudosarsameira exilis* (numerous), *Typhlamphiascus confusus, Leptastacus* sp. 1977: *Pseudosarsameira exilis* (abundant), *Leptastacus* sp., *Schizopera* sp.

OSTRACODS

CORME, 1976: *Paradoxostoma* sp. (usually living among algae!).

PL. BARANAN, 1976: *Cobanocythere* sp.

MERA, VILLAGE, 1976: *Polycope* (*?schüttei*).

MYSTACOCARIDS

PL. BARANAN, 1976, 1977: *Derocheilocaris* sp.

ACARIDS

PL. BARANAN, 1976: Actacarus *pygmaeus, Actacarus bacescui,* Gamasidae.
1977: *Actacarus bacescui,* Trombidiformes (terrestrial, numerous).

MERA, VILLAGE, 1976: *Halacarellus procerus.*
1977: *Halacarellus procerus,* Gamasides (terrestrial).

POLYCHAETES

PL. BARANAN, 1976: *Hesionides arenaria* (numerous), *Polygordius* sp.
STA. CRUZ, 1977: iuv. Capitellidae.
MERA, VILLAGE, 1977: iuv. Spionidae.
EL. FERROL, 1976: *Exodone naidina.*

OLIGOCHAETES

CORME, 1976: *Marionina subterranea, M. preclitellochaeta, M. achaeta, M.* sp., *Phallodrilus monospermathecus.*
PL. BARANAN, 1976: *Marionina achaeta, M.* sp.
STA. CRUZ, 1977: *Marionina subterranea, Phallodrilus monospermathecus,* **Tubi**ficidae, unident.
MERA, HARBOUB, 1977 (0-5cm) : *Marionina subterranea, Lumbricillus* sp., *Enchytraeus* sp., *Phallodrilus monospermathecus.*
(95cm) : *Enchgtraeus* sp., *Phallodrilus* sp.
MERA, VILLAGE, **1976** : *Marionina subterranea* (numerous), *M. southerni, M. preclitellochaeta, M.* sp.
1977: *Marionina subterranea, M. achaeta, Phallodrilus* sp.
EL FERROL, 1976: *Marionina subterranea* (numerous), *M.* sp., *Phallodrilus* sp.
1977: *Marionina subterranea.*

TARDIGRADES

CORME, 1976, 1977 ; **PL.** BARANAN, 1977; STA. CRUZ, 1976; MERA, HARBOUR, 1977; MERA, VILLAGE, 1976, 1977: *Batillipes pennaki.*

BIVALVE LARVAE **:** unident

MERA, HARBOUR, **1977;** **EL FERROL, 1976,** 1977.

DISCUSSION AND CONCLUSIONS

1. Effects of oil pollution on the interstitial habitat

The relevance of habitat conditions for the deleterious impact of oil pollution has never been examined for intertidal meiobenthos specifically. Regarding the properties of the interstitial biotope, its fauna seems to be especially threatened by oil pollution: beaches act as huge filter systems (Riedl et al., 1972) straining both oil particles and dispersants from the percolating water (Rützler and Sterrer, 1970) and, in this way, accumulating them by absorption on the grain surfaces or by capillary forces in the narrow crevices between them. The film of microorganisms covering the grains will enhance the absorptive forces and readily bind the oil droplets, thus storing large amounts of oil in the interstitial system. The coarser the sand, the greater the depth and the speed with which the "water pump" will press the oil into the sediment, thus removing it from the beach surface where it could quickly decompose by evaporation, light and oxidation, and, moreover, be most effectively cleaned up. Thus, in the high-energy beach of Pl. Barañan, oil had contaminated depths of more than 140cm and considerable depths of oil penetration have also been reported from other beaches (Wormald, 1976; Blumer et al., 1973). As a result, the system of strong ground water currents will also transport the oily water to other areas and layers, often not originally affected by oil from the surface (Rützler and Sterrer, 1970).

In fine sandy or muddy sediments of sheltered flats, oil slicks will, due to reduced permeability, be deposited at first as surface covers. However, the oil will gradually seep down into ground water layers (e.g. Sta. Cruz and El Ferrol) (Blumer et al., 1970b), often supported by bore-holes of clams and worms. Moreover, by slow diffusion of toxic substances into the sediment (Blumer et al., 1970a) and by oxygen deprivation, a superficial slick cover would cause similarly deleterious effects on the meiofauna as oily water does when soaked through beach sand. This impairment of oxygen conditions was visible in the vertical series at Sta. Cruz (Fig. 5) where after the spill almost complete anoxia was recorded in a sediment which normally is sufficiently oxidized (see the situation in 1977). Wormald (1976) and Johnston (1970) reported a corresponding lack of oxygen subsequent to oil pollution as a resuit of oxygen requiring degradative processes (Blumer et al., 1973; Hellmann and Müller, 1975; Zobell, 1969). Consequently, the anoxic deeper layers of sheltered shores represent perfect "traps" for the penetrated oil which will keep its original and highly toxic composition for a long period of time since in this oxygen-free environment chemical and microbial degradation is slowed down considerably (Blumer, 1971; Blumer et al., 1970a; Cox, Anderson and Parker, 1975; Johnston, 1970; Meyers, 1976; Shaw et **al., 1977).**

Another, rarely considered effect of oil contaminating the interstitial habitat is the physical stabilization of the sediment by increased coherence of particles through the oil film leading to reduction of permeability, nutrient flow and bioturbation which additionally aggravates the breakdown of hydrocarbon (Lee, 1976; Prouse and Gordon, 1976; Vandermeulen and Gordon, 1976).

Apart from these physical and chemical reasons for the serious threat an oil spill means to the intertidal soft-bottom biota, the strong thigmotaxis which meiofauna organisms generally have as an adaptive characteristic, specifically enhances the toxic effect of oil pollution on mesopsammic life: in the narrow interstitial system, the animais will inevitably get smeared by tiny oil droplets and, thus, will become increasingly mechanically inactivated (Cox et al., 1975) and gradually exterminated. Moreover, there is evidence from experiments (Giere, in press) and field studies (Branch, 1973; Brown et al., 1974) that animais, even if highly resistant to toxic water-soluble fractions of hydrocarbons, will be killed quickly by direct contact with oil. Thus, in the case of an oil spill, the intertidal meiofauna is in a principally different situation than planktonic, hard bottom or subtidal benthic communities. This point has to be considered in discussing the meiofauna data after the Spanish oil disaster.

2. Aspects of meiofauna extermination and regeneration after oil spills

Compiling the results from June 1976, shortly after the accident, extermination of meiofauna by and large followed the spatial stress gradiant caused by the concentration of stranded oil, i.e. reflected horizontally the polluting current system (Fig. 4) and vertically the rate of oil degradation (Sta. Cruz, Fig. 5). Sanders et al. (1972) found a similar pattern of deterioration in benthic macrofauna after the West Falmouth oil spill its impact on species diversity and density paralleling the gradients of oil contamination. The 1977-samples showed that even in areas of formerly only moderate contamination (Pl. Barañan), relatively few species essentially contributed to the increasing population density, but they were encountered throughout the whole sediment column down to a depth of lm. This complete vertical recolonization was possible through the effective breakdown of hydrocarbons also at greater depths. However, at the heavily contaminated sand flat of El Ferrol, the meiofauna was concentrated in the surface layers and abundance decreased rapidly below 10cm depth. Again, this corresponds to the physiographical conditions, which in the deeper layers caused only a slow degradation of hydrocarbons in combination with low oxygen content. A similar gradual recolonization starting from the surface horizons is reported by Blumer et al. (1970a) and Wormald (1976).

Conclusions about the sensitivity of whole meiofauna groups for hydrocarbons and about the pattern of recolonization have to be tentative due to the almost complete lack of knowledge. Moreover, initial experiments with meiofauna (Giere, in press) and evidence from macrofauna studies (Day et al., 1971) indicate a greatly varying resistance to oil beetween different taxonomical and trophic groups, even within the same genus. This renders any generalization problematical. However, it can be concluded with some certainty that new life conditions after increasing decomposition of the oil are first utilized by nematodes. They belong to the most oil-resistant meiobenthic groups, since their number was in most instances highest in the contaminated Spanish sites, and they reappeared first in the Hong Kong beach studied by Wormald (1976). Similar observations were made by Smith (1968) after the "Torry Canyon" spill, by Sanders et al. (1972) studying the West Falmouth disaster and by Giere (in press) in experiments.

It is interesting to note that many of the *Enoplolaimus litoralis*-specimens, densely aggregated in Pl. Barañan in 1976, had ingested oil droplets which were covered by bacteria. This species, so far, is known as a typical predator. Furthermore, in the intestine of *Bathylaimus* and *Tripyloides* oil particles were found surrounded by clouds of bacteria (pers. communication Dr. F. Riemann; aspects of oil ingestion by meiofauna will be discussed in a separate paper).

Whereas nematodes have been known to be relatively resistant to many pollutants (Gray and Ventilla, 1971), it is surprising that, at least in the more lotic beaches, some turbellarians (Otoplaninae and Schizorhynchidae) and annelids (juvenile capitellids and spionids, oligochaetes like *Marionina subterranea)* also survived heavy oil contamination. For oligochaetes, a considerable resistance to oil, though of differing inter-specific degree, is reported also from fresh water species (McCauley, 1966), and confirmed by further experiments (Giere, in press). The ability of some polychaetes, especially of *Capitella* and some nereids, to withstand hydrocarbon contamination has been repeatedly reported (George, 1970; Kasymov and Aliev, 1971; Rossi et al., 1976; Sanders et al., 1972; Wharfe, 1975). Few papers, however, have dealt with truly meiobenthic forms: in experiments by Carr and Reish (1977), *Ctenodrilus* and *Ophryotrocha* sp. were even able to reproduce in about 10ppm Louisiana Crude oil (see also Åkesson, 1975).

Little is known about the resistance of harpacticoids, the other large group in the samples from Spain. They were rarely found in the zone of heavy oil pollution, although *Pseudosarsameira exilis, Leptastacus* sp. and *Orthopsyllus* sp. seem to be fairly hardy forms. (The large populations of *Asellopsis intermedia* at El Ferrol was little exposed to the oily sediment since this epibenthic form lived on the surface of the sand). Experiments with *Tigriopus californicus* indicated a rather high sensitivity for hydrocarbons (Barnett and Kontogiannis, 1975) which is in contrast to the minimal sensitivity of *Tisbe bulbisetosa* (Dalla Venezia and Fossato, 1977). In the field, Rützler and Sterrer (1970) and Wormald (1976) found harpacticoids to disappear after an oil spill and to reappear relatively late.

The grossly varying resistance of meiofauna groups to oil pollution, observed both after the "Urquiola" spill and in other reports, indicates that it is not simply the structure of the body surface which determines the animal's survival. Whereas nematodes and some tardigrades with their solid cuticle survive quite well, the chitinous body of many harpacticoids does not prevent them from being rather sensitive to oil. On the other hand, halacarids like *Halacarus procerus* with chitinous integument, survive high hydrocarbon concentrations. "Soft meiofauna" like many annelids, turbellarians and ciliates with their "open" body surface has not been wiped out immediately by solved hydrocarbons, as was assumed. Their ability to excrete lots of mucous might explain their fairly high resistance (Bleakley and Boaden, 1974). Moreover, in polychaetes and probably in other worms too, the existence of hydrocarbon metabolizing enzyme systems (MFO's) certainly enhances their tolerance of high oil input (Lee, 1977; Payne, 1977). Also in macrofauna, body protection (tubes, shells) does not necessarily constitute resistance to oil (Day et al., 1971). It is suggested that interstitial animals with protruding body appendages and external respiratory devices like complicated legs and gill systems are especially threatened by oil pollution both through mechanical inactivation (Percy and Mullin, 1977) and physiological disfunction.

3. Factors influencing reappearance of meiofauna

The restricted vagility and dispersal capacity usually assumed for permanent meiofauna poses the question along which lines might the relatively rapid reappearance of meiofauna in the polluted area have proceeded. It is assumed, in the light of observations on the occurrence of stranded oil slicks, that the rugged character of the coast line leads to formation of unpolluted "refuge islets" protected from the patches of incoming oil, which thus could have served as centers of regeneration. The two stations from Mera might be taken as examples for the resulting inhomogeneous depletion: although just one mile apart, they exhibited considerable differences in meiofauna survival. Consequently, an oil disaster near the smooth coasts of sand flats and wadden areas lacking any protecting niches, would spill the sediment rather uniformly and impair life conditions homogeneously and for a long period of time.

On the other hand, occurrence of early benthic stages from bivalves and polychaetes in the sediment already 6 weeks after the spill in zones of heavy pollution (e.g. El Ferrol) indicates that regeneration via plankton might be an additional source of meiofaunal recovery. Planktonic animals, due to their dispersed occurrence and high vagility were found in field studies to be often less affected by oil than benthos (Straughan, 1971; Nelson-Smith, 1972). Thus, planktonic larvae of benthic forms, temporarily belonging to the meiofauna community and originating from distant unpolluted areas, could contribute to the recovery of meiofauna in contaminated sites. This stresses the importance of the strong sea currents existing along the northern Spanish coast for recolonization of the polluted shores. It is generally assumed that larval stages are more sensitive to hydrocarbons than adults (Carlberg, 1973; Hyland and Schneider, 1976; Kühnholt, 1977), but in the Spanish samples, the numerous juvenile polychaetes and the high number of young and fully mature oligochaetes found only 6 weeks after the spill, indicate no serious interference of reproduction and maturation by high oil concentrations in the field. Also George (1970, 1971) and Dalla Venezia and Fossato (1977) observed polychaetes and harpacticoids to spawn without incident shortly after an oil spill.

Concerning permanent meiofauna like the oligochaetes, there is good evidence (Giere, in press) that brood protecting egg capsules and cocoons (common in many interstitial groups) give additional protection against the toxic impact of oil. This might account for the rich number of some turbellarians and oligochaetes right after the spill.

When assessing the meiofaunal impact of the "Urquiola"-spill, the most striking features are the quick restoration of the habitats and of the interstitial fauna after intensive oil degradation. However, the marked numerical differences, typical for re-establishing fauna communities after stress situations, indicate a still badly balanced population growth. Species like the nematode *Enoplolaimus* *litoralis* could produce extremely rich populations in the regenerating habitats probably because of minimal competition and predation. Similar "explosive" developments of some few species after an oil spill, caused by increased growth, reproduction and survival, have been observed by Wormald (1976) and, in macrofauna animals, by Branch (1973). Hence, it needs both assessment of faunal abundance and diversity in combination with chemical investigations to aptly characterize the biological recovery of oil-contaminated areas.

Although correspondingly short time spans have, in other areas, been found to be sufficient for resettlement of meiofauna (Wormald, 1976) and macrofauna (Stander, 1968; Straughan, 1971; Stirling, 1977) after oil spills, the consequences of the spill on Spanish beaches have been influenced by specific favourable circumstances: biological and chemical decomposition of hydrocarbons was accelerated by relatively high temperatures, intensive UV-radiation, exposure of beaches to waves and tides, strong currents and negligible application of dispersants (Blumer et al., 1973; Stirling, 1977; Zobell, 1969).

Finally, it should be pointed out that the results obtained from the "Urquiola"-spill refer mainly to the effect of acute primary toxicity. The possible long-term stress induced by oil, and known from macrofauna studies (reduction of metabolism, feeding rates, growth and reproduction; Blumer et al., 1970a; Dow, 1975; Gillfillan, 1972; Hargrave and Newcombe, 1973; Prouse and Gordon, 1976) could not be analysed here, though these effects are especially threatening in the sheltered areas of the inner Rias and flats where repeated contamination by re-turbation of oily deposits from deeper horizons is probable (Blumer, 1971; Thomas, 1977) and could have long-lasting noxious effects on the meiofauna. Hence, clean beaches and their repopulation by some meiofauna groups one year after an oil spill are relatively rough estimates, and do not allow any definite or generally optimistic conclusion regarding the fate of meiofauna after an oil accident, since they represent only a first phase in the process of environmental recovery. Just as the intertidal biota is characterized by a constantly fluctuating factor system, the combination of normal ecological oscillations with sublethal pollutional stressors may gradually lead to substantial interference with the highly dynamic system of faunal interactions. The re-establishment of a well balanced and diversified meiofauna community will take much more time than the high population densities, locally monitored, might suggest. In this respect, the La Coruña-area will certainly need further time to overcome the effects of the "Urquiola" grounding of May 1976.

Acknowledgements

This investigation was supported by the « Forschungsbereich Umweltforschung und Umweltgestaltung der Universität Hamburg ». My thanks go to Mrs. L. Seitz-Hildebrand and Mr. H. Jelinek for their technical assistance. I am also grateful to the Applikationslabor der Philips GmbH, Kassel (Dr. Heisz) and Beiersdorf AG, Hamburg (Dr. Klein) who generously helped me in chemical analyses and interpretations. For identification of meiofauna I am deeply indebted to the following specialists : Dr. I. Bartsch, Dr. A. Faubel, Dr. G. Hartmann-Schröder, Prof. Dr. G. Hartmann, Dr. E. Hartwig (all Hamburg), Dr. F. Riemann (Bremerhaven), and Dr. W. Scheibel (Kiel).

Summary

The effect of oil contamination through the spill from the super-tanker "Monte Urquiola" on the intertidal meiofauna was studied shortly after the accident and also one year later. The investigated sites along the northern Spanish coast covered an area from heavily polluted shores to beaches without visual oil contamination. The impact on the meiofauna could be related to the exposure of the sampling stations to the centre of the spill and affected the various taxonomical groups differently, many nematodes and annelids being relatively resistant, harpacticoids and turbellarians more sensitive. Within one year, the meiofauna had recovered considerably with regard to diversity and abundance both of which had been heavily suppressed shortly after the spill. The reasons for this relatively quick reappearance and the different reactions of interstitial fauna to oil contamination are discussed in relation to the specific habitat properties in the area.

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