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The Impact of Pollution on the Nematode and Harpacticoid Copepod Species Composition of an Estuarine Mudflat

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Key words: Nematodes, harpacticoid copepods, diversity, cluster analysis, ordination of stations.

ABSTRAK

Kajian ini telah dilakukan untuk melihat kesan daripada buangan industri ke atas spesies nematoda dan harpaktikoida pada dataran berlumpur di muara Sungai Forth (Scotland). Spesies nematoda dan harpaktikoid kopepoda di kawasan kajian menunjukkan tindak balas yang berbagai-bagai kepada pencemaran; bermula daripada spesies yang tiada langsung di kawasan buangan kepada spesies yang wujud pradominan di kawasan sedimen yang paling tercemar. Adalah difikirkan bahawa sekurang-kurangnya beberapa spesies yang terdapat berdekatan dengan saluran buangan berhubungan dengan lapisan tebal mikroalga yang terdapat di pinggir saluran buangan tersebut. Dua faktor yang nampaknya dominan bagi mengawal taburan spesies nematoda dan harpaktikoida kopepoda di kawasan kajian ialah ketinggian pantai dan pencemaran. Analisis kelompok data kelimpahan spesies dari stesen pensampelan jelas menunjukkan pengasingan stesen pada paras tikas air tinggi, tikas air pertengahan dan tikas air rendah. Ordinasi terhadap stesen juga menunjukkan ia dipengaruhi oleh ketinggian pantai dengan bantuan pencemaran.

ABSTRACT

A study was carried out in the Forth estuary (Scotland) to determine the impact of industrial effluents on the nematodes and harpacticoid copepods species of an estuarine mudflat. The nematodes and harpacticoid copepods species in the area ranging from the species which are absent from the vicinity of the effluents to the species which occure predominantly in the most highly polluted sediments display a spectrum of responses to the discharges. It is thought at least some of the species favouring the immmediate vicinity of the effluent channels would be associated with the dense microalgal mat that fringes the channels. Two factors seemed to be dominant in controlling the species distribution of nematodes and harpacticoid copepods in the area; interdal height and pollution. Cluster analysis of the species abundance data from the sampling stations clearly showed the separation of sites on the upper, middle and lower shore. The ordination of the stations was also strongly influenced by intertidal height superimposed by pollution.

INTRODUCTION

The study of the response of nematode communities to the presence of oil has been examined by a number of workers (Boucher 1980; 1985; Gourbault 1984; Fleeger & Chandler 1983; Alongi *et al.* 1983; Bonsdorff 1981; Fricke *et al.* 1981; Giere 1979; Wormald 1976). However, the results of these studies have been inconsistent.

The effect of oil on nematode and harpacticoid copepods species compositions has not received much attention. The studies on the impact of oil on nematode and harpacticoid species generally seem inconsistent. Several workers found that oil had an impact on the nematode species (Wormald 1976; Giere 1979; Boucher 1980; Decker & Fleeger 1984) whereas others did not (Fleeger & Chandler 1983; Fricke *et al.* 1981; Alongi *et al.* 1983). Similarly several workers found that oil had an effect on harpacticoid copepods species (Ustach 1979; Decker & Fleeger 1984) while others did not (Alongi *et al.* 1983; Dalla Venezia & Fossato 1977).

The objective of the present study was to examine the impact of chronic oil pollution on the species composition of the nematode and harpacticoid copepods of the mudflat in the Forth estuary, Scotland.

MATERIALS AND METHODS

The study area, station location and collection of core samples for physico-chemical and biological studies have been described by Mohd Long (1987). The Kinneil mudflat was chosen for the present study because mudflats usually support a large community of meiofauna, and site selection was based on the hypothesis that stations which are far from the sources of pollution suffer less impact on meiofauna communities and vise versa. Due to the abundance of nematodes, a subsample of about 200 individuals was taken randomly for identification. Nematodes and harpacticoid copepods were identified to the species level.

In order to see the effect of pollution on the meiofaunal species in Forth estuary, the Shannon-Wiener diversity index, Pielou evenness and species richness were calculated based on the computer programme written by Moore (1983). The dendrograms illustrating the similarity of the stations were drawn based on density (no. 10 cm $^{-2}$) of nematode and harpacticoid species. The computer programme used was CLUSTAN (Wishart, 1978). The ordination technique was used to separate the effects of pollution from the effects of other environmental factors. Therefore the sampling sites were ordinated based on log (x + 1) transformed densities (no. 10 cm $^{-2}$) of nematode and harpacticoid species at 28 stations by using the computer programme called DECORANA (Detrended Correspondence Analysis).

RESULTS

Nematodes Species Composition

A total of 49 species representing 36 genera were identified from 5228 nematodes examined. Thirty-three species were recorded on the upper shore, 28 on the middle shore and 38 on the lower shore transects. A total of 19 species were common to all three transects. A total of 7 - 9 species comprised more than 90% of the nematodes along each of the three transects.

Sabatieria pulchra was the dominant species on the lower shore (mean, 859 ind. 10 cm $^{-2}$), *Ptycholaimellus ponticus* on the middle shore (mean, 352 ind. 10 cm^{-2}) and *Metachromadora remanei* on the upper shore transect (mean, 569 ind. 10cm^{-1} *(Fig. 1)*. Four species were common on all three transects, viz. *Sabatieria pulchra, Ptycholaimellus ponticus, Atrochromadora microlaima* and *Daptonema setosum*. However, *Sabatieria pulchra* showed a drastic reduction in density from the lower to the upper shore transects. *Terschellingia longicaudata, Terschellingia communis* and *Desmolaimus zeelandicus* were virtually restricted to the lower shore, and *Tripyloides gracilis* to the middle and upper shore. *Innuoconema tentabundum, Neochromadora poecilosoma, Daptonema procerum* and *Ascolaimus elongatus* were virtually restricted to the lower shore, *Sphaerolaimus hirsutus* and *Theristus acer* to the middle shore and *Calyptronema maxweberi, Metachromadora remanei, Diplolaimella ocellata* and *Microlaimus globiceps* to the upper shore transect.

Three groups of species were observed on the upper shore transect *(Fig. 2)*. Species of the first groups were virtually restricted to the Skinflats, namely *Halalaimus aff. gracilis, Calyptronema maxweberi, Paracanthonchus heterodontus, Metachromadora remanei, Microlaimus globiceps, Ptycholaimellus ponticus* and *Axonolaimus typicus*. The second group contained species which were common towards the ends of the upper shore at Kinneil, viz. *Hypodontolaimus balticus* and *Triploides gracilis* whilst species of the third group were present in moderate numbers between the discharges, viz. *Sabatieria pulchra, Atrochromadora microlaima, Diplolaimella ocellata* and *Daptonema setosum*.

On the middle shore, only 11 species (39% were found at one or both ends of the transect, being unrecorded closer than 288 metres upstream of the oil and 900 metres downstream of the chemical channels *(Fig. 3)*. Most of these species were rare but common forms included *Terschellingia communis, Eleutherolaimus stenosoma, Sphaerolaimus gracilis* and *Daptonema tenuispiculum*.

Two species were generally very common but diminished near the effluent channels *(Fig. 3)*. *Ptycholaimellus ponticus* had a reduced density at sites 188 metres and 483 metres downstream of the oil channel and was unrecorded 190 metres downstream of the chemical channel. *Sabatieria pulchra* was not found 188 metres downstream of the oil channel. A third common species, *Desmolaimus zeelandicus*, attained its minimum density at the site just downstream of the oil channel, although the density of this species was somewhat erratic along the transect.

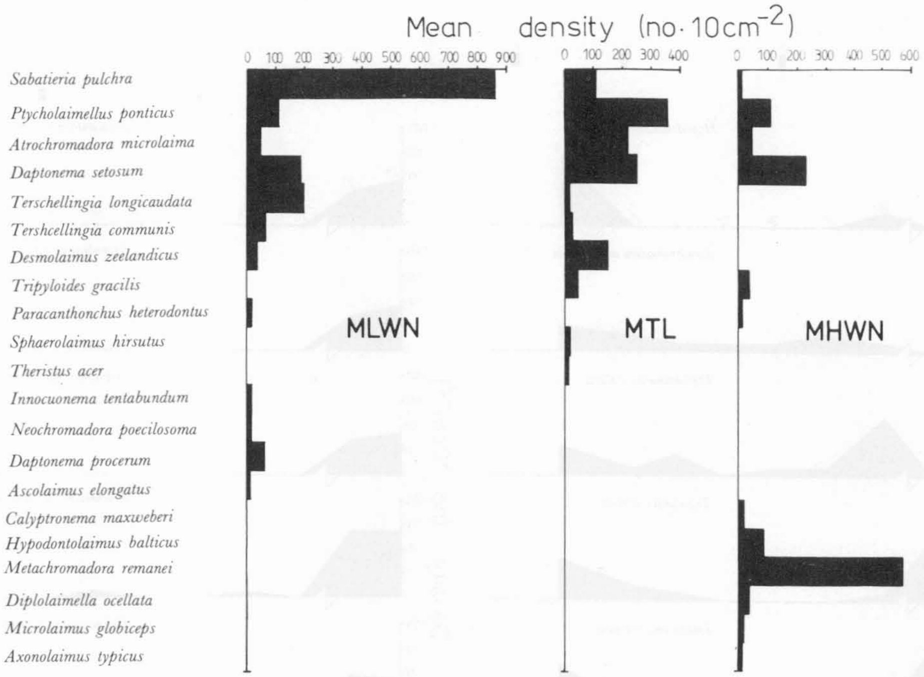

Fig. 1: Bar chart showing mean density (no. ind. 10 cm^{-2}) of nematode species along three transects at approximately Mean Low Water Neap (MLWN), Mid Tide Level (MTL) and Mean High Water Neap (MHWN) at Grangemouth mudflats. The species with a mean density lower than 10 ind. 10 cm^{-2} on all three transects were excluded.

Of the remaining common species *Atrochromadora microlaima* and *Tripyloides gracilis* seemed little or not effected by the effluents, whereas *Daptonema setosum* showed strong density peaks at the sites immediately downstream from both effluent channels.

Only a few species were recorded in the vicinity of the effluent channels, viz. *Adoncholaimus fuscus, Diplolaimella ocellata, Monhystera parva* and *Monhystera anophthalma*. Densities were, however, low.

On the lower shore, only 8 species (21%) were found at one or both ends of the transect, being unrecorded closer than 666 metres upstream of the oil and 600 metres downstream of the Avon channels (*Fig. 4*).

As on the middle shore, *Ptycholaimellus ponticus* showed a reduction in density in the area of Avon channel (7 ind. 10 cm^{-2}) and at the site immediately downstream of the oil channel (8 ind. 10 cm^{-2}) (*Fig. 4*). *Sabatieria pulchra* was lowest in density at the western end station but also showed a reduction in density at the 3 sites immediately downstream of the oil channel. A third common species, *Desmolaimus zeelandicus,* also decreased to minimum density at the station immediately downstream of the oil channel. Of the remaining common species, *Atrochromadora microlaima* seemed little affected by the effluent channels on the middle shore.

Five species (13%) were only recorded in the vicinity of the effluent channels, viz, *Hypodontolaimus balticus, Prochromadorella ditlevseni, Paracanthonchus caecus, Diplolaimella ocellata* and *Dorylaimidae* sp. However their densities were low. The other species were sporadically distributed along the transect.

Harpacticoid Copepods Species Composition

Seventeen species of harpacticoids were recorded but these were dominated by just 4 species constituting more than 90% of the copepod fauna on the lower and middle transects, viz. *Amphiascoides limicola, Stenhelia palustris, Platychelipus littoralis* and *Enyhdrosoma longifurcatum* (Table 1).

Stenhelia palustris, Amphiascoides limicola and *Enhydrosoma longifurcatum* were common along the lower transect with other species occurring only

Fig. 2 (cont.)

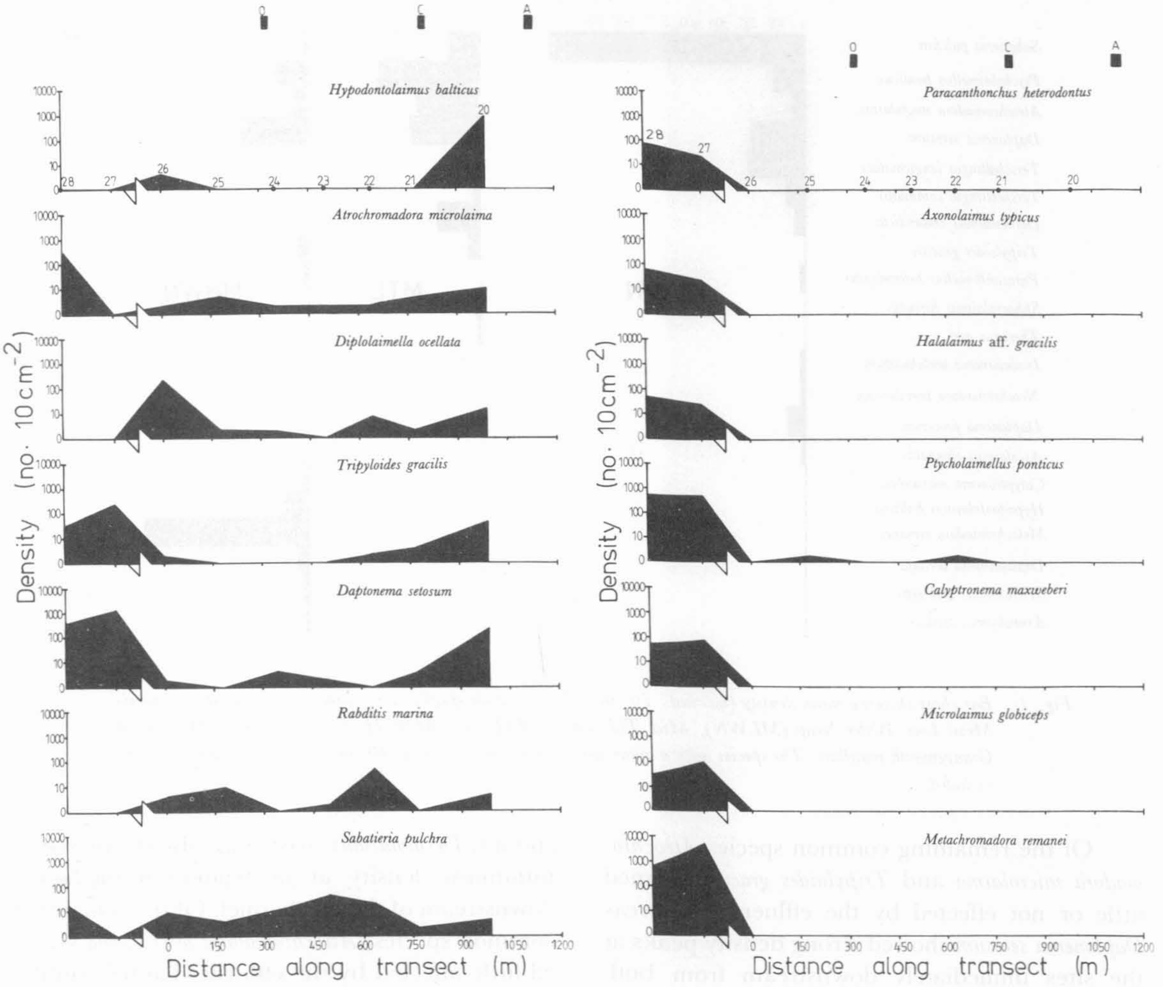

Fig. 2: Density (no. ind. 10 cm^{-2} of the common nematode species along a transect at approximately Mean High Water Neap (MHWN) at Grangemouth mudflats. A - River Avon, C - Chemical effluent channel and O - Oil refinery channel. Station numbers are given.

sporadically. The only clear pattern discernible along this transect is the virtual diappearance of all copepod species near the Avon channel *(Fig. 5).* An increase in the density of *Platychelipus littoralis* at the stations towards the western end of the transect may be associated with the somewhat higher interdal height of these stations (Stations 8 & 10).

Most species occurred sporadically along the middle transect, although *Stenhelia palustris, Amphiascoides limicola* and *Platychelipus littoralis* were abundant, reaching their highest densities here *(Fig. 5).* These three species, however, have different patterns of abundance along the transect. *Platychelipus littoralis* attained maximum density in the vicinity of the refinery channel. *Stenhelia palustris* also peaked in this area but unlike *Platychelipus littoralis,* declined to virtual extinction in the vicinity of the Avon channel. *Amphiascoides limicola* was the most abundant of the species over most of the transect but nearly disappeared, like *Stenhelia palustris,* near the Avon channel and showed a further depression in the vicinity of the refinery channel. Although most species were absent or showed severely depressed population densities at station 17 near the Avon, this area harboured a flourishing population of *Mesochra lilljeborgi.*

The harpacticoid fauna along the upper transect was somewhat different *(Fig. 5).* At

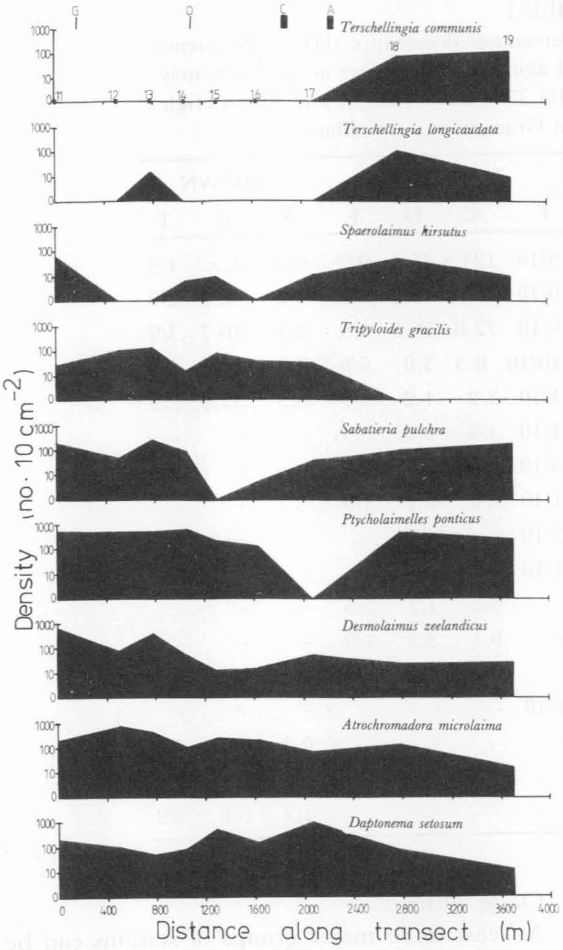

Fig. 3: Density (no. ind. 10 cm^{-2}) of the common nematode species along a transect at approximately Mid Tide Level (MTL) at Grangemouth mudflats. A - River Avon, G - Grangeburn O - Oil refinery channel, C - Chemical effluent channel. Station numbers are given.

Skinflats common species included *Microarthridion fallax, Stenhelia palustris, Metis ignea* and *Platychelipus littoralis.* However, at Kinneil, copepods particularly *Harpacticus gracilis* were found.

Nematodes Diversity

The number of species fluctuated between 12 and 22 with no obvious pattern on the lower shore transect *(Fig. 6).* The maximum number of species was recorded at the station immediately downstream of the refinery channel (217 metres). The number of species near the Avon channel was higher than those at three other sites. Diversity and evenness followed a similar pattern, peaking at three sites immediately downstream of the refinery channel. The mean diversity on the lower shore transect was 2.4 bits individual^{-1}.

On the middle shore transect, the number of species peaked at 17 - 18 species at the ends of the transect and fluctuated between 9 - 14 species over the rest with no obvious localized effect by the oil and Avon channels. Diversity and evenness followed a similar pattern showing clear depressions at site 17 in the vicinity of the Avon, due to strong dominance by *Daptonema setosum.* Mean diversity was 2.2 bits individual^{-1}, slightly lower than the lower shore transect.

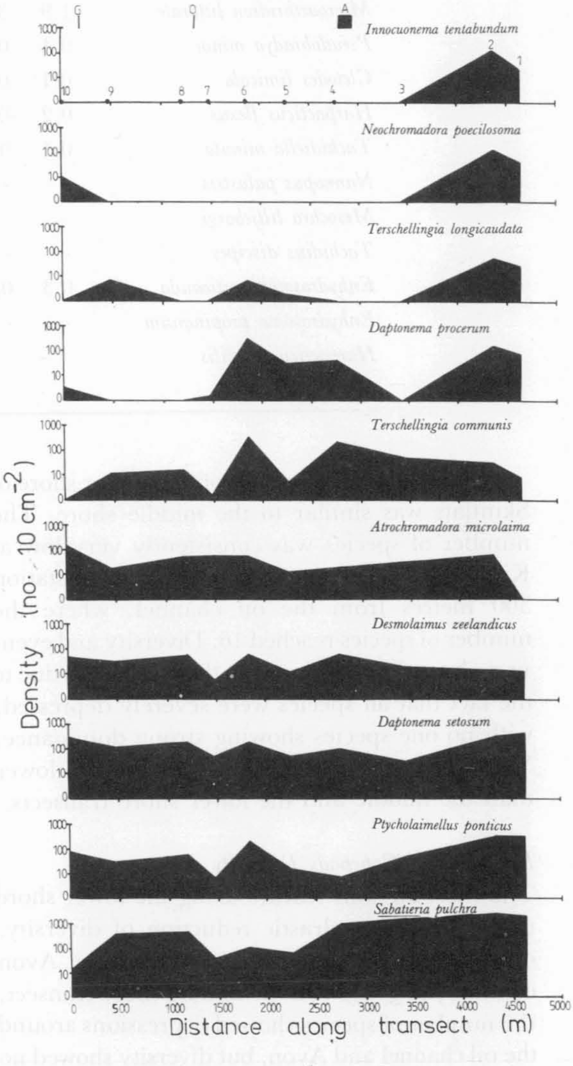

Fig. 4: Density (no. ind. 10 cm^{-2}) of common nematode species along a transect at approximately Mean Low Water Neap (MLWN) at Grangemouth mudflats. A - River Avon, G - Grangeburn and O - Oil refinery channel. Station numbers are given.

TABLE 1
The mean density (x)(no. 10 cm^{-2}), percentage dominance (D) and frequency occurrence (F) of harpacticoid copepod along three transects at approximately Mean Low Water Neap (MLWN), Mid Tide Level (MTL) and Mean High Water Neap (MHWN) at Grangemouth mudflats.

	MLWN			MTL			MHWN		
	$\overline{X}$	D	F	$\overline{X}$	D	F	$\overline{X}$	D	F
Amphiascoides limicola	18.9	37.3	9/10	124.3	45.4	9/9	0.3	1.5.	1/9
Stenhelia palustris	12.8	25.2	9/10	50.0	18.3	9/9	7.2	36.5	2/9
Platychelipus littoralis	3.7	7.3	6/10	72.8	26.6	9/9	2.1	10.7	3/9
Enhydrosoma longifurcatum	10.3	20.3	10/10	8.3	3.0	6/9	0.3	1.5	2/9
Microarthridion fallax	2.0	3.9	4/10	3.2	1.2	2/9	6.9	35.0	2/9
Microarthridion littorale	1.9	3.7	4/10	1.5	0.5	3/9	-	-	-
Pseudobradya minor	0.4	0.8	3/10	0.9	0.3	3/9	-	-	-
Cletodes limicola	0.1	0.2	1/10	0.2	0.1	1/9	-	-	-
Harpacticus flexus	0.2	0.4	2/10	-	-	-	-	-	-
Tachidiella minuta	0.1	0.2	1/10	-	-	-	-	-	-
Nannopus palustris	-	-	-	3.2	1.2	5.9	-	-	-
Mesochra lilljeborgi	-	-	-	9.1	3.3	1/9	-	-	-
Tachidius discipes	-	-	-	0.2	0.1	1/9	-	-	-
Enhydrosoma curticauda	0.3	0.6	1/10	-	-	-	-	-	-
Enhydrosoma propinquum	-	-	-	-	-	-	0.3	1.5	2/9
Harpacticus gracilis	-	-	-	-	-	-	1.3	6.6	4.9
Metis ignea	-	-	-	-	-	-	1.3	6.6	2/9

The number of species on the upper shore of Skinflats was similar to the middle shore. The number of species was consistently very low at Kinneil (6 - 8) except at the westernmost station 300 metres from the oil channel, where the number of species reached 16. Diversity and evenness showed peaks closest to the discharges due to the fact that all species were severely depressed, with no one species showing strong dominance. Mean diversity was 2.0 bits individual^{-1}, lower than the middle and the lower shore transects.

Harpacticoid Copepods Diversity

The most obvious feature along the lower shore transect was the drastic reduction of diversity, eveness and number of species near the Avon channel (*Fig. 7).* On the middle shore transect, the number of species showed depressions around the oil channel and Avon, but diversity showed no clear pattern with respect to the channels. The number of species on the upper shore at Skinflats was similar to the middle shore but was reduced to 0 - 2 at Kinneil.

Cluster Analysis

At least three major groups of stations can be detected from the dendrogram *(Fig. 8).* The first cluster includes stations close to the discharges at Kinneil on the upper shore transect (stations 25 to 21). The second cluster, which runs from stations 17 to 7, is dominated by stations on the middle shore transect, whilst the third cluster is dominated by stations from the lower shore. Three upper shore sites were isolated from these three major groups : station 20 at Kinneil, which was furthest from the refinery discharge, and stations 27 and 28 from Skinflats.

Ordination of Stations

The first ordination of all stations sampled was strongly dominated by the first axis which only served to separate stations 27 and 28 at Skinflats from the other stations at Kinneil. The eigen values indicate the relative importance of axes (axes 1 = 0.399, 2 = 0.147, 3 = 0.120 and 4 = 0.072). Therefore, in order to see the effect of pollution on the meiofauna at Kinneil mudflats in greater

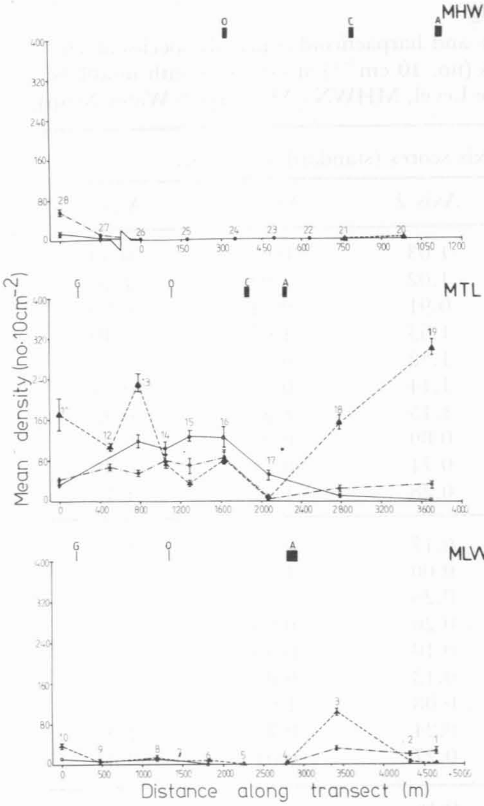

Fig. 5: The mean density (no. ind. 10 cm^{-2}) of the three dominant species of harpacticoid copepods along three transects at approximately Mean High Water Neap (MHWN), Mid Tide Level (MTL) and Mean Low Water Neap (MLWN) at Grangemouth mudflats. A - River Avon, C - Chemical effluent channel, G - Grangeburn and O - Oil refinery channel. ○—○ Platychelipus littoralis. ▲----▲ - Amphiascoides limicola, ●-●-● - Stenhelia palustris.

detail, the ordination of the stations was repeated after excluding stations 27 and 28 (Table 2). Only axes 1 and 2 could be interpreted and these are plotted in Fig. 9.

The ordination of the stations is strongly influenced by interdidal height superimposed by pollution effects. In order to facilitate description, the stations can be divided into groups. The upper shore stations fall into four groups: first, the stations which are very close to the discharges (stations 21 and 24), second, the stations slightly further from the discharge (stations 22, 23 and 25), the third and fourth are stations at both ends of the transect (stations 20 and 26). On the middle shore transect, the stations are divided into three groups. Station 17 just downstream of the chemical channel, is separated from those stations in the area of the refinery channel (stations 12, 13, 14, 15 and 16) and also from those stations far away from the discharge channels (stations 10,11,18 and 19). On the lower shore transect, the stations are divided into two groups. The stations near the Avon channel (station 4) and the oil channel (stations 7 and 8) are separated from the cleaner stations (stations 1,2,3,5,6 and 9).

DISCUSSION

There is clear chemical evidence of pollution in the sediments from the top to the bottom of the Kinneil mudflats. This is especially evident at the top of the shore where extremely high levels of hydrocarbons extend at least 173 metres upstream

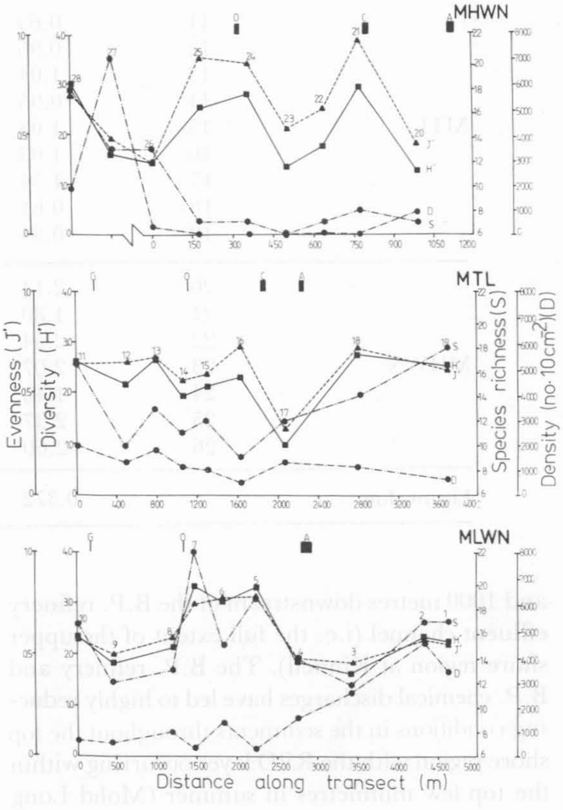

Fig. 6. Shannon-Wiener diversity (H')(bits individual^{-1}), Pielou eveness (J'), species richness (S) and density (D)(no. ind. 10 cm^{-2}) of nematodes along three transects at approximately Mean High Water Neap (MHWN), Mid Tide Level (MTL) and Mean Low Water Neap (MLWN) at Grangemouth mudflats. Station numbers are given. A - River Avon, C - Chemical effluent channel, G - Grangeburn and O Oil refinery channel ■——■ *- diversity,* ▲----▲ *- eveness,* ◆——◆ *- species richness* ●—·—● *- density.*

TABLE 2

Detrended correspondence analysis of nematodes and harpacticoid copepods species at 26 stations based on log (x + 1) transformed densities (no. 10 cm^{-2}) at Grangemouth mudflats (MLWN - Mean Low Water Neap, MTL - Mid Tide Level, MHWN - Mean High Water Neap).

			Axis scores (standard deviation)		
Transect	Station	Axis 1	Axis 2	Axix 3	Axis 4
MLWN	1	0.00	1.03	0.68	0.58
	2	0.28	1.02	1.05	1.18
	3	0.60	0.91	0.61	0.09
	4	0.66	1.63	1.05	0.40
	5	0.42	1.52	0.91	0.53
	6	0.50	1.14	0.57	0.79
	7	0.90	1.15	1.43	0.92
	8	0.92	0.89	0.91	0.93
	9	0.73	0.71	0.71	0.97
	10	0.52	0.28	1.57	1.42
MTL	11	0.63	0.17	0.95	1.11
	12	0.96	0.00	1.02	1.17
	13	1.04	0.25	0.83	1.07
	14	0.95	0.20	0.83	1.17
	15	1.03	0.10	0.99	1.07
	16	1.03	0.13	0.83	1.03
	17	1.54	0.08	1.06	0.69
	18	0.61	0.24	0.19	1.05
	19	0.34	0.27	0.01	0.84
MHWN	20	2.14	0.16	1.27	0.44
	21	1.80	1.07	0.82	0.42
	22	2.54	1.46	0.52	1.25
	23	2.07	1.49	0.17	0.87
	24	1.40	1.39	0.63	0.29
	25	2.37	1.59	0.00	1.73
	26	2.60	0.63	1.15	0.00
Eigenvalue		0.372	0.157	0.101	0.051

and 1000 metres downstream of the B.P. refinery effluent channel (i.e. the full extent of the upper shore region at Kinneil). The B.P. refinery and B.P. chemical discharges have led to highly reducing conditions in the sediments throughout the top shore region with the RPD layer occurring within the top few milimetres in summer (Mohd Long 1987).

The nematode species display a spectrum of responses to the discharges, ranging from species which are absent from the vicinity of the effluents to species which are present predominantly in the most highly polluted sediments. At least 20% of species were totally absent from the area affected by pollution. Species such as *Axonolaimus typicus, Daptonema normandicus, Aegialoalainus elegans, Innuoconema tantabundum, Neochromadora poecilosoma, Calyptronema maxweberi, Enoplus brevis, Oxytomina elongata, Spilophorella paradoxa* and *Paracyatholaimus proximus* perhaps cannot tolerate the presence of oil or chemical pollution, as they were only found far away form the sources of pollution (at Skinflats or at either one or both ends of the bottom and middle shore at Kinneil).

Among the common species at Kenneil, *Ptycholaimellus ponticus* appeared strongly effected by pollution; however, this species was not so restricted in distribution as the first group, being present in much of the area affected by pollution, although virtually disappearing in the reduced sediment areas at the bottom and at the top of the shore and becoming extinct just downstream of

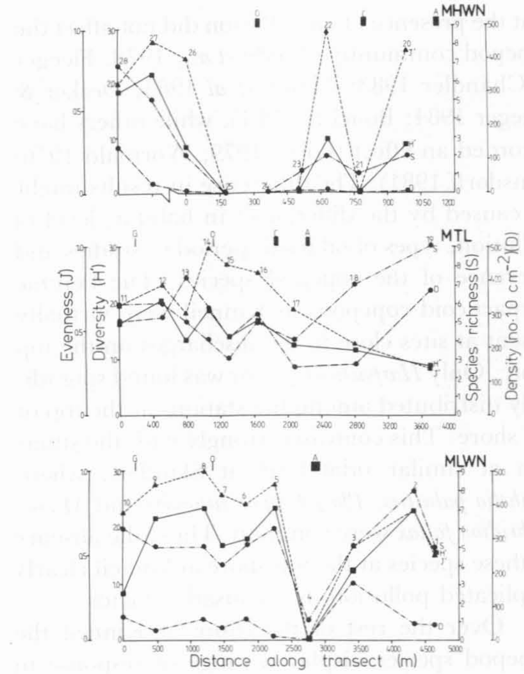

Fig. 7: *Shannon-Wiener diversity (H')(bits individual^{-1}), Pielou evenness (J'), species richness (S) and density (D)(no. ind. 10 cm^{-2}) of harpacticoid copepods along three transects at approximately Mean High Water Neap (MHWN), Mid Tide Level (MTL) and Mean Low Water Neap (MLWN) at Grangemouth mudflats. Station numbers are given. A - River Avon, C - Chemical effluent channel, G - Grangeburn and O - Oil refinery channel* ■—■ *- diversity,* ▲- - -▲ *- evenness,* ⬢- -⬢ *- species richness and* ●—● *- density.*

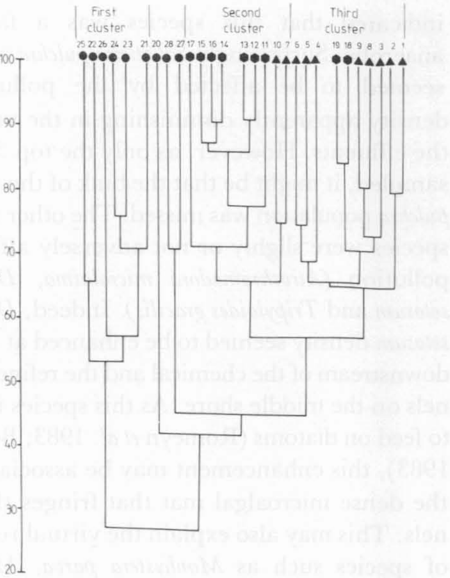

Fig. 8: *Dendrogram illustrating the similarity of the stations at approximately Mean High Water Neap (MHWN), Mid Tide Level (MTL) and Mean Low Water Neap (MLWN), based on density (no. ind. 10 cm^{-2}) of nematode and Harpacticoid species at Grangemouth mudflats.* ● *MHWN,* ⬢ *- MTL and* ▲ *MLWN.*

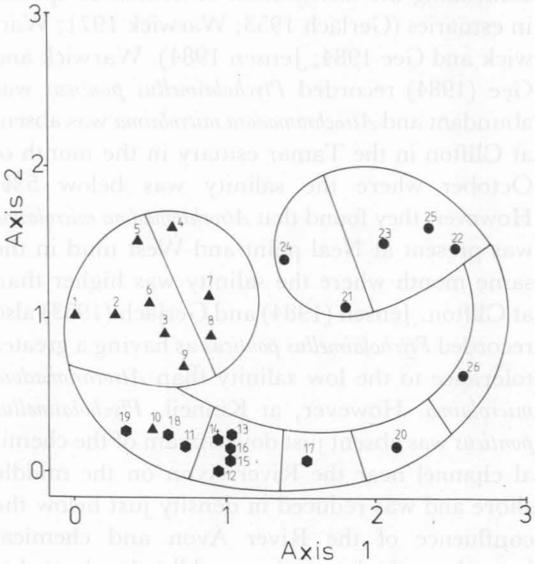

Fig. 9: *Detrended correspondence analysis of nematode and harpacticoid species at 26 stations on Grangemouth mudflats. The diagram shows the ordination of sites in the space of first two vectors. The sites are located at approximately* ● *- MHWN,* ⬢ *- MTL and* ▲ *- MLWN.*

the chemical channel on the middle shore. Similarly, Bouwman *et al.* (1984) found *Ptycholaimellus ponticus* to be absent in the vicinity of potato flour industry outfall in the EMS-Dollart estuary, but was one of the dominant species at more than 100 metres from the outfall. In contrast, Alongi *et al.* (1983) found *Ptychloimellus ponticus* to be one of the earliest species to colonize sediments experimentally sprayed with oil.

Sabatieria pulchra is another dominant species at Grangemouth. It has frequently been recorded as dominant in pulluted sediments (Tietjen 1977; Bouwman 1978; Tenore *et al.* 1982) and the remarkable eurytolerance of *Sabatieria pulchra* has been observed and demonstrated repeatedly. Jensen (1981) found *Sabatieria pulchra* to be the only mesohaline comesomatid and one of the few metazoans thriving in the extremely oxygen-depleted sediment in the Baltic sea and he classified it as an inhabitant of the RPD layer in European sediment, suggesting an ability to tolerate sulphides and to utilize the higher microbial densities in this layer. Warwick and Price (1979) indicated that this species was a facultative anaerobe. Surprisingly *Sabatieria pulchra* at Kinneil seemed to be affected by the pollution, its density apparently diminishing in the vicinity of the effluents. However, as only the top 3 cm was sampled, it might be that the bulk of the *Sabatieria pulchra* population was missed. The other common species were slighly or not adversely affected by pollution *(Atrochromadora microlaima, Daptonema setosum* and *Tripyloides gracilis).* Indeed, *Daptonema setosum* density seemed to be enhanced at sites just downstream of the chemical and the refinery channels on the middle shore. As this species is known to feed on diatoms (Romeyn *et al.* 1983; Bouwman 1983), this enhancement may be associated with the dense microalgal mat that fringes the channels. This may also explain the virtual restriction of species such as *Monhystera parva, Monhystera anophthalma* and *Diplolaimella ocellata* to the vicinity of the effluent channels. Hence the nematode species in the area seem to show a variety of responses to the discharges ranging from intolerance to stimulation

It is known that salinity is one of the factors controlling the distribution of nematode species in estuaries (Gerlach 1953; Warwick 1971; Warwick and Gee 1984; Jensen 1984). Warwick and Gee (1984) recorded *Ptycholaimellus ponticus* was abundant and *Atrochromadora microlaima* was absent at Clifton in the Tamar estuary in the month of October where the salinity was below 5%. However, they found that *Atrochromadora microlaima* was present at Neal point and West mud in the same month where the salinity was higher than at Clifton. Jensen (1984) and Gerlach (1953) also recorded *Ptycholaimellus ponticus* as having a greater tolerance to the low salinity than *Atrochromadora microlaima.* However, at Kinneil, *Ptycholaimellus ponticus* was absent just downstream of the chemial channel near the River Avon on the middle shore and was reduced in density just below the confluence of the River Avon and chemical hannels on the lower shore, whilst *Atrochromadora microlaima* was present in moderate density at both sites. This suggests that the density of *Ptycholaimellus ponticus* was influenced by pollution rather than by any salinity effects.

Findings on the reaction of benthic harpacticoid copepods to the presence of oil are contradictory in the literature. Several studies have found that the presence of oil pollution did not affect the copepod community (Naidu *et al.,* 1978; Fleeger & Chandler 1983; Alongi *et al* 1983; Decker & Fleeger 1984; Boucher 1984), while others have recorded an effect (Giere 1979; Wormald 1976; Bonsdorff 1981). The difference in results might be caused by the differences in habitat, level of pollution, types of oil used, period of studies and tolerance of the copepod species. The benthic harpacticoid copepods at Kinneil were virtually absent at sites close to the discharges on the top shore. Only *Harpacticus gracilis* was found sporadically distributed among the stations at the top of the shore. This contrasts strongly with the situation at similar tidal level at Skinflats, where *Stenhelia palustris, Platychelipus littoralis* and *Microarthridion fallax* were common. Thus, the absence of these species at the top shore at kinneil clearly implicated pollution as a causative factor.

Over the rest of the shore at Kinneil the copepod species display a range of response to pollution with *Amphiascoides limicola* apparently reduced by both refinery and chemical effluents, *Stenhelia palustris* by the chemical discharge whilst *Platychelipus littoralis* appears to be enhanced in the vicinity of the refinery channel on the middle shore. *Mesochra lilljeborgi,* generally absent, flourishes just downstream of the chemical channel on the middle shore, presumably as a consequence of the enhanced alga flora, as this species is usually commonest in phytal habitats.

In this area, species richness seems a better measure of pollution impact than species diversity or evennes. Nematode and harpacticoid species richness seems to be clearly influenced by the discharges on the top and middle shore. The area displaying depressed species richness on the top shore extended at least 200 metres upstream and 870 metres downstream of the oil channel and, on the middle shore, at least 563 metres upstream and 938 metres downstream of the oil channel. There was no clear impact of pollution on species richness at the bottom of the shore. Species diversity was of little value as a pollution indicator on all transects. It is clear that the species richness of both harpacticoid copepods and nematodes were affected on the top and middle of the shore. However, the harpacticoid species richness is more strongly affected than that of the nematodes on the top of the shore. Species diversity and evenness are again unsuitable measures for both copepods and nematodes on the top and middle shores, although there was a big change in nematode diversity near the chemical effluent on the middle shore. On the lower shore, nematodes seemed unaffected by pollution but copepods suffered a drastic reduction in species richness, diversity and evenness near the River Avon and chemical effluent confluence. It seemed that species diversity was not really suitable as a measure of pollution impact in the area due to the drastic reduction of all species, leading sometimes to relatively high diversity in the most polluted sites as a result of high evenness.

When the totality of species distributions are considered, two controlling factors seem dominant, intertidal height and pollution. Cluster analysis of the stations clearly showed the separation of sites on the upper, middle and lower shore. However, on the upper shore, the sites close to the discharges, which can be considered as polluted (from the evidence of hydrocarbon value and RPD depth; Mohd Long (1987), were grouped together and separated from the site near the River Avon, where some recovery of meiofauna occurred, and the sites at Skinflats which were considered as clean. On the mid and lower shore, cluster analysis were not very helpful in separating effects of pollution from those of natural factors. The ordination of stations was also strongly influenced by intertidal height, although pollution seemed to play the second major role in controlling species composition. The polluted sites on the upper shore were again isolated from the recovery site near the River Avon and clean sites at Skinflats. The mid shore site just downstream of the chemial channel was isolated from the other mid shore sites, indicating a pollution effect. On the lower shore, sites immediately upstream and downstream of the refinery channel and the sites just below the confluence of the Riven Avon and the chemical channel were isolated from the others. This was also possibly caused by the effects of the refinery and chemical discharges.

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REFERENCES

ALONG, D.M., D.F. BOESCH and R.J. DIAZ. 1983. Colonization of Meiobenthos in Oil Contaminated Subtidal Sands in the Lower Chesapeake Bay. *Marine Bio.* **72:** 325-335.

BONSDORFF, E. 1981. The Antonio Gramsci Oil Spill Impact on the Littoral and Benthic Ecosystems. *Mar. Pollut. Bull.* **12:** 301-305.

BOUCHER, G. 1980. The Impact of Amoco Cadiz Oil Spill on Intertidal and Sub-littoral Meiofauna. *Mar. Pollut. Bull.* **11:** 95-101.

BOUCHER, G. 1985. Long Term Monitoring of Meiofauna Densities after the Amoco Cadiz Oil Spill. *Mar. Pollut. Bull.* **16:** 328-333.

BOUWMAN, L.A. 1978. Investigations on Nematodes in the Ems-Dollart Estuary. *Ann. Soc. V. Zool. Beig - T.* **1-2:** 103-105.

BOUWMAN, L.A. 1983. A Survey of Nematodes from the Ems Estuary, Part 2: Species Assemblages and Associations. *Zool. Jb. Syst.* **110:** 345-376.

BOUWMAN, L.A. K. ROMEIJN and W. ADMIRAL. 1984. On the Ecology of Meiofauna in an Organically Polluted Estuarine Mudflat. *Estuar. Coastal. Shelf. Sci.* **19:** 633-653.

DALLA VENEZIA, L. and V.U. FOSSATO. 1977. Characteristics of suspensions of Kuwait Oil and Corexit 7664 and their Short and Long-term Effects on *Tisbe bulbisetosa* (Copepoda: Harpacticoida). *Marine Bio.* **42:** 233-237.

DECKER, C.J. and J.W. FLEEGER. 1984. The Effect of Crude Oil on the Colonization of Meiofauna into Salt Marsh Sediments. *Hydrobiol.* **118:** 49-58.

FLEEGER, J.W. and G.T. CHANDLER. 1983. Meiofauna Responses to an Experimental Oil Spill in a Louisiana Salt Marsh. *Mar. Ecol. Prog. Ser.* **11:** 257-264.

FRICKE, A.H:, H.F.K.O. HENNIG and M.J. ORREN. 1981. Relationship between Oil Pollution and Psammolittoral Meiofauna Density of Two South Africa Beaches. *Mar. Environ. Res.* **5:** 59-77.

GERLACH, S.A. 1953. Die biozonotische gliederung der nematoden fauna an den deutschen kusten. *Z. Morph. U. Okol. Tiere* **41:** 411-512.

GIERE, O. 1979. The Impact of Oil Polution on the Intertidal Meiofauna. Field Studies after the La Caruna - Spill, May 1976. *Cah. Biol. Mar.* **20:** 231-251.

GOURBAULT, N. 1984. Fluctuations des peuplements de nematodes du chenal de la baie de Morlaix. 1. Resultats a moyen terme, apres pollution par les hydrocarburers. *Cah. Biol. Mar.* **25:** 169-180.

JENSEN, P. 1981. Species Distribution and a Microhabitat Theory for Marine Mud-dwelling Comesomatidae (Nematode) in European Waters. *Cah. Biol. Mar.* **22:** 231-241.

JENSEN, P. 1984. Ecology of Benthic and Epiphytic Nematodes in Brackish Waters. *Hydrobiol.* **108:** 201-217.

MOHD LONG, S. 1987. The Impact of Pollution on the Meiofaunal Densities of an Estuarine Mudflat. *Pertanika* **10:** 197-208.

MOORE, C.G. 1983. A BASIC Program for the Investigation of Species Diversity. *Wat. Pollut. Control.* 102-106.

NAIDU, A.A., H.M. FEDER and S.A. NORRELL. 1978. The Effect of Prodhoe Bay Crude Oil on a Tidal Flat Ecosystem in Port Valdez, Alaska. In *10 Offshore Tech. Conf.* p. 94-104. Houston, Texas.

ROMEYN, K, L.A. BOUWMAN and A. ADMIRAAL. 1983. Ecology and Cultivation of the Herbivorous Brakish Water Nematode *Eudiplogaster pararmatus. Mar. Ecol. Prog. Ser.* **12:** 145-153.

TENORE, K.R. et al. 1982. Coastal Upwelling in the Bajas, N.W. Spain: Contrasting the Benthic Regimes of the Rias de Arosa and de Muros. *J. Mar. Res.* **40:** 701-772.

TIETJEN, J.H. 1977. Population Distribution and Structure of the Free-Living Nematodes of Long Island Sound. *Marine Bio.* **43:** 123-136.

TIETJEN, J.H 1980 Population Structure and Species Composition of the Free-living Nematodes Inhabiting Sands of the New York Bight Apex. *Estuar. Coastal Mar. Sci.* **10:** 61-73.

USTACH, J.F. 1979. Effects of Sublethal Oil Concentrations on the Copepod *Nitocra affinis*. *Estuaries,* **2:** 272-276.

WARWICK, R.M. 1971. Nematode Associations in the Exe Estuary. *J. Mar. Biol. Ass. U.K.* **51:** 439-454.

WARWICK, R.M. and R. PRICE. 1979. Ecological and Metabolic Studies on Free-Living Nematodes from an Estuarine Mudflat. *Estuar. Coastal Mar. Sci.* **9:** 257-271.

WARWICK, R.M. and J.M. GEE. 1984. Community Structure of Estuarine Meiobenthos. *Mar. Ecol. Prog. Ser.* **18:** 97-111.

WISHART, D. 1978. CLUSTAN. User Manual, 3rd edn. Program Library Unit, Edinburgh University. University.

WORMALD, A.P. 1976. Effects of a Spill of Marine Diesel on the Meiofauna of a Sandy Beach at Picnic Bay Hong Kong. *Eviron. Pollut.* **11:** 117-130.

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