

## Recent Foraminifera from the North Sea (Forties and Ekofisk areas) and the continental shelf west of Scotland

JOHN W. MURRAY

Department of Geology, University of Exeter, Exeter, U.K.

**ABSTRACT**—The regions studied are all of mid continental shelf depth (70–145 m) and have bottom waters of normal marine salinity. The North Sea has lower bottom water temperatures than those to the west of Scotland. However, the major difference between the two regions is one of tidal and/or wave energy: the northern North Sea is a low energy environment of muddy sand deposition whereas the sampled part of the continental shelf west and north of Scotland is a moderate to high energy environment of medium to coarse biogenic carbonate sedimentation.

The physical differences between the two main areas are reflected in the living and dead foraminiferal assemblages. The northern North Sea is a region of free-living species whereas the continental shelf west of Scotland has immobile and mobile attached species living on firm substrates. The northern North Sea is very fertile and has high standing crop values.

The dead assemblages are small in size and very abundant. To the west of Scotland the sea is less fertile, standing crop values are low, the dead assemblages are moderate to large in size and reasonably abundant due to the slow rate of dilution by sediment.

### INTRODUCTION

The North Sea is an extensive epicontinental area opening northwards into the Norwegian Sea. The Forties sampling area (approx. Long. 57° 44' N; Lat. 00° 54' E) extends over a depth range of 100–130 m. The Ekofisk sampling area (approx. Long. 56° 32' N; Lat. 03° 13' E) has a depth of approximately 70 m and is further removed from the influence of the open ocean (Fig. 1).

The two North Sea areas have similar bottom water characteristics. Ekofisk has a mean temperature in the winter of 5.5°C and in the summer of 7.0°C. For Forties, the values are 6.5° and 7.0°C respectively. Likewise, the values for bottom salinity are 35.0‰ and 34.0‰ for winter and summer at Ekofisk and 35.1‰ throughout the year at Forties (Lee & Ramster, 1981). In both areas, the surface waters develop thermohaline stratification during the summer months. Ekofisk has a slightly muddy fine sand substrate with 3.6–6.5% fines < 63 µm and a median particle diameter of 130–144 µm (Addy *et al.*, 1979). Forties is characterised by a higher proportion of fine fraction, generally in the range 10–39% (Hartley, 1979).

Forties is fished commercially for the pink shrimp (*Pandalus borealis*) and for scampi (*Nephrops norvegicus*) which digs extensive dwelling burrows in the cohesive sediment (Lee & Ramster, 1981).

The continental shelf of the Fair Isle Channel and to the west of Scotland is a region of carbonate sedimentation. This reflects the meagre supply of terrigenous material thereby permitting the gradual accumulation of biogenic debris (Wilson, 1979, 1982). The mean bottom temperature is 7°C in the winter and 11°C in the summer for the Fair Isle Channel sampling area and ~9° for the summer for the shelf to the west of Scotland (no details

available for the winter; Lee & Ramster, 1981). The bottom water salinity values are 35.1‰ throughout the year in the Fair Isle Channel sampling area and 35.0 to > 35.25‰ to the west of Scotland (Lee & Ramster, 1981). The area develops thermohaline stratification in the summer months. Tidal current velocities are small to the west of Scotland (rippled sand), but are powerful in the Fair Isle Channel (gravel sheet; Wilson, 1982). All areas are subject to vigorous wave activity (35 m, 30 m, for West Scotland, Fair Isle Channel; and 28 m for Forties and Ekofisk – 50 year wave height, Lee & Ramster, 1981).

In summary, all four areas are of mid-shelf depth and normal salinity and they differ only in lower bottom temperatures and terrigenous sedimentary substrate (North Sea) and higher bottom temperatures and a bioclastic sediment substrate (Fair Isle Channel and West Scottish Shelf).

### MATERIAL AND METHODS

Three samples from the Forties area of the North Sea were collected in June 1978 and a further 17 in June 1981. Five samples were collected from the Ekofisk area of the North Sea in August 1981. All were taken with a Day grab. Once on the ship, a plastic ring enclosing an area of 45 cm<sup>2</sup> was pressed into the sediment surface and the contents scooped out to a depth of 1 cm. The samples from west and north of Scotland were collected in 1979 and 1981 using a Murray grab which takes a sample 100 cm<sup>2</sup> in area and 1 cm thick (Table 1).

All samples were preserved in alcohol. In the laboratory, they were washed on a 240 mesh (63 µm aperture) sieve, stained with rose Bengal, washed again on a 240 mesh sieve, and dried in an oven at 60°C. When

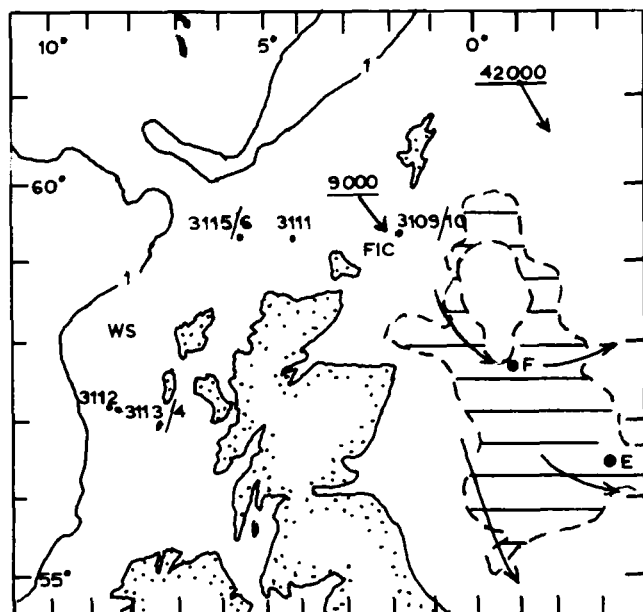


Fig. 1. The sampling areas. Arrows indicate surface currents, and inflow of Atlantic water ( $\text{km}^3/\text{yr}^{-1}$ ) (from Eisma, 1981); shaded area – *Bulimina fusiformis*, *B. marginata*, *Anomalina balthica* association of Jarke (1961). F = Forties, E = Ekofisk, FIC = Fair Isle Channel, WS = west of Scotland.

dry and cold, the foraminifera were floated off in trichloroethylene. The flotation was weighed and a portion of known weight picked for both living and dead assemblages. The standing crop was calculated to a standard area of  $30\text{ cm}^2$ .

Material finer than  $63\ \mu\text{m}$  was collected in a dish, decanted into a filter paper and dried. Small pieces of the dried material were mounted on stubs, coated with gold, and examined in a Philips S.E.M. 501B. Searches for nanoplankton were carried out at magnifications of  $\times 5000$  or  $\times 2500$ .

For taxonomy and illustrations, see Murray (1971) and Murray *et al.* (1983).

## LIVING ASSEMBLAGES

### North Sea

Diversity, measured by the  $\alpha$  Index of Fisher, Corbett & Williams (see Williams, 1964; Murray, 1973), ranges from  $1\frac{1}{2}$ – $2\frac{1}{2}$  (Ekofisk) and 1–5 (Forties). All assemblages have a high dominance of *Rotaliina* with only a small *Textulariina* component and very rare *Miliolina* (Fig. 2).

The standing crop values are generally high (Table 2 and Figs. 3, 4) The pattern of abundance at Forties shows no clear relationship with either depth or sediment grain size. Biomass values are also high and they show considerable variation (Table 2). The biomass distribution pattern at Forties also shows no clear correlation with depth or sediment grain size (Fig. 5). However, the abundance of the tiny species *Fursenkoina fusiformis*

and the generally low numbers of larger species mean that there is a reasonable correlation between biomass and standing crop (Fig. 6).

The living assemblages consist almost exclusively of free-living foraminifera (*sensu* Sturrock & Murray, 1981) (Fig. 8). In all assemblages, the single most abundant species is *Fursenkoina fusiformis*. This makes up 83–95% of the living assemblage at Ekofisk, 90–93% at Forties (1978 samples) and 40–96% at Forties (1981 samples). Accessory species at Ekofisk include *Epistominella vitrea* (0.5–4.1%), *Cassidulina obtusa* (1.2–4.8%) and *Reophax scottii* (0.6–4.5%). All these have small tests, generally  $< 300\ \mu\text{m}$  in diameter or length. At Forties, accessory species include *Nonionella* sp. (0.7–17.9%), *Bulimina marginata*

Table. 1. Sample Details

Station no.	Samples
2894	= Hartley (1979) F3
2895	= " " F6
2896	= " " F8
3109	= J. B. Wilson (1979) 9/11
3110	= " " 9/14
3111	= " " 10/1
3112	= " " 21/3
3113	= " " 22/1
3114	= " " 22/3
3115	= " (1981) 9/5
3116	= " " 9/6
3117	= Addy <i>et al.</i> (1979) E15
3118	= " " E16
3119	= " " E17
3120	= " " E18
3121	= " " E19
3122	= Hartley (1983) F1
3123	= " " F2
3124	= " " F3
3127	= " " F6
3130	= " " F9
3131	= " " F10
3133	= " " F12
3135	= " " F14
3136	= " " F15
3138	= " " F17
3140	= " " F19
3141	= " " F20
3142	= " " F21
3143	= " " F23
3144	= " " F24
3145	= " " F25
3146	= " " F26

E = Ekofisk

F = Forties

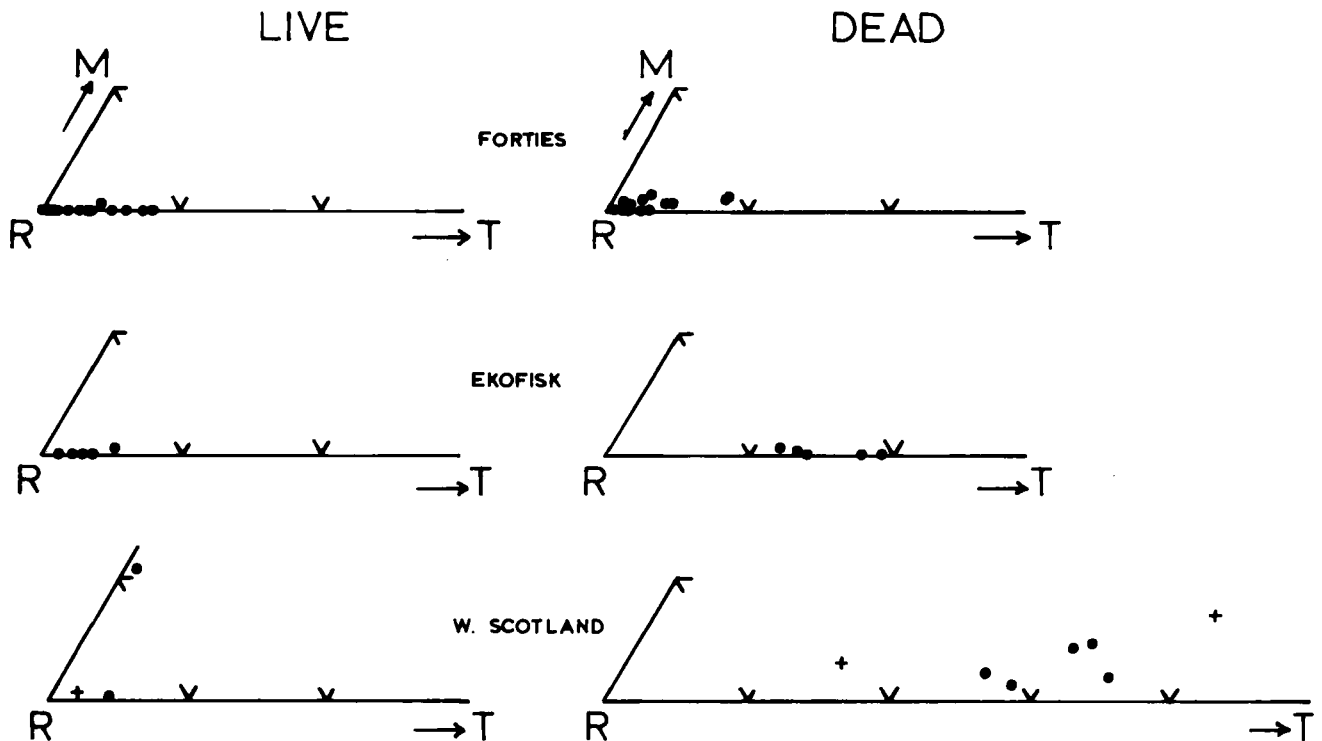


Fig. 2. Triangular plots of Rotaliina (R), Miliolina (M) and Textulariina (T). V = 10% contours. + = Fair Isles Channel.

Table 2. Summary of assemblages (\* on firm substrates)

	Ekofisk	Forties 1981	Forties 1978	Fair Isle Channel	West of Scotland
<i>Living assemblages:</i>					
$\alpha$ index range	1½–2½	1–5	3–3½	2*	1–2
$\alpha$ index average	2	3½	3	2*	2½
Standing crop per 30 cm <sup>2</sup>	1217–6646	958–5988	2620–2784	–	2–560
Standing crop average	3829	3308	2702	–	–
Biomass mm <sup>3</sup> per 30 cm <sup>2</sup>	1.466–12.981	1.511–8.988	3.598–4.565	–	–
Biomass average	5.733	4.910	4.081	–	–
<i>Fursenkoina fusiformis</i> %	83–95	40–96	90–93	–	–
<i>Cibicides lobatulus</i> %	–	–	–	35	84–88
<i>Rosalina anomala</i> %	–	–	–	58	4–8
<i>Dead assemblages:</i>					
$\alpha$ index range	3½–5½	5½–8	5½–7½	2–2½	6–8
$\alpha$ index average	4½	7½	6	2½	7
<i>Fursenkoina fusiformis</i> %	45–65	29–54	41–49	–	–
average	52	44	46	–	–
<i>Cassidulina carinata</i> %	–	4–22	–	–	2–19
<i>Cibicides lobatulus</i> %	0–1	0–7	–	1–12	14–41
<i>Cibicides refulgens</i> %	–	–	–	16–36	1–14
<i>Eponides repandus</i> %	–	–	–	18–44	0–2
<i>Trifarina angulosa</i>	–	0–14	–	–	3–18
<i>Textularia sagittula</i>	–	0–4	–	–	23–32
<i>Gaudryina rudis</i>	–	–	–	15–36	0–9

(1.1–41.3%), *Cassidulina carinata* (0.2–5.4%), *Hyalinea balthica* (0.2–6.5%), and *Trifarina angulosa* (0.2–4.7%). Species sometimes found include *Melonis barleeanus* (0.5–4.1%) and *Saccamina spherica* (0.5–4.1%). Although many of the tests are small, large forms are also present.

The distribution of *Fursenkoina fusiformis* at Forties is shown both as a percentage and as standing crop in Fig. 7. The results appear quite different and neither shows any clear correlation with depth or substrate.

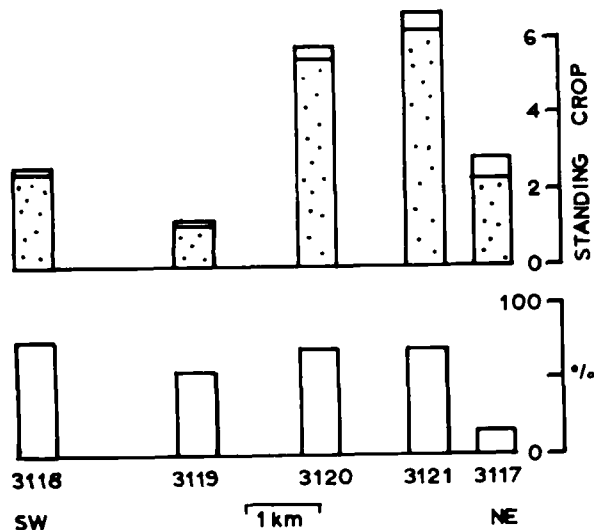


Fig. 3. Ekofisk. Traverse towards the oil installation (near station 3117). Dotted area of standing crop = that of *Fursenkoina fusiformis*. Standing crop in thousands per 30 cm<sup>2</sup>. Lower histogram = % living *F. fusiformis*.

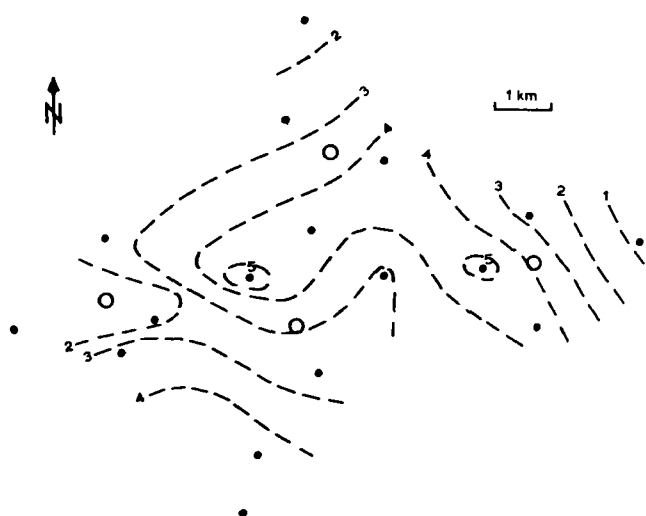


Fig. 4. Forties. Standing crop per 30 cm<sup>2</sup>. Contours in thousands of individuals. Open circles represent oil installations.

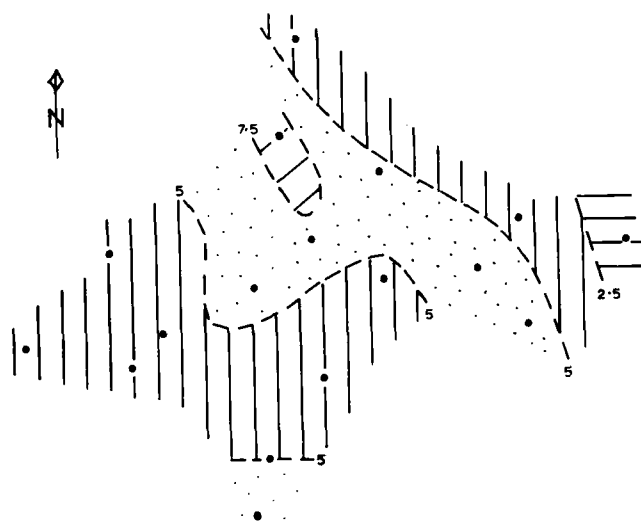


Fig. 5. Forties. Biomass mm<sup>3</sup>/30 cm<sup>2</sup>.

#### Continental Shelf west and north of Scotland

The sediment samples contain very few living foraminifera. Those samples with large shells or shell fragments, pebbles, or attached epifauna such as hydroids, have a fauna of attached immobile or mobile individuals (*sensu* Sturrock & Murray, 1981) (Fig. 8). Station 3109 (Fair Isle Channel) has an assemblage of *Cibicides lobatulus* (35.0%) and *Rosalina anomala* (57.9%), mainly on hydroids. The diversity is low ( $\alpha 1$ ). Stations 3111, 3113 and 3114 (Shelf west of Scotland) have *Cibicides lobatulus* – dominated assemblages on fragments of *Ditrupa* tubes (polychaete worm). Station 3115 has bivalve shell debris with a sparse fauna dominated by tiny *Trochammina*. In each case, the diversity is low. Standing crop values could be determined only from samples 3114 to 3116 as the remainder were of unknown area. The results are 560 per 30 cm<sup>2</sup> on *Ditrupa* tubes in sample 3114, 7 and 2 per 30 cm<sup>2</sup> bivalve shell debris for samples 3115 and 3116 respectively. In general, these assemblages are dominated by *Rotaliina* (Fig. 2).

#### DEAD ASSEMBLAGES

##### North Sea

These are more diverse than the living (Table 2) but some of the values are still low for a shelf sea. These assemblages fall in field 1 of the classification proposed by Murray (1984). The *Rotaliina* dominate the two areas but the proportion of *Textulariina* is between 12 and 19% at Ekofisk in comparison with <10% at Forties (Fig. 2).

*Fursenkoina fusiformis* is generally the dominant species (Table 2). Other common species at Forties include *Bulimina marginata* (4.5–22.0%), *Cassidulina carinata* (0.7–22.3%), *C. obtusa* (1.2–14.3%), *Hyalinea*

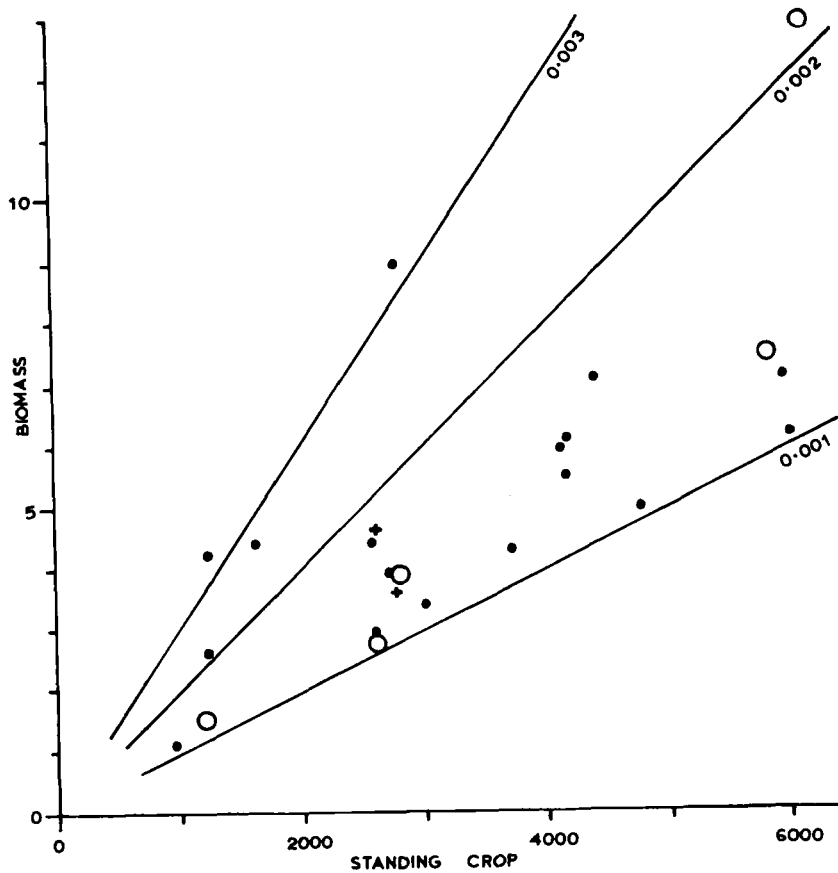


Fig. 6. North Sea. Biomass  $\text{mm}^3/30\text{cm}^2$ . Standing crop per  $30\text{cm}^2$ . Contours = average biomass per individual, • = Forties 1981, + = Forties 1978, ○ = Ekofisk.

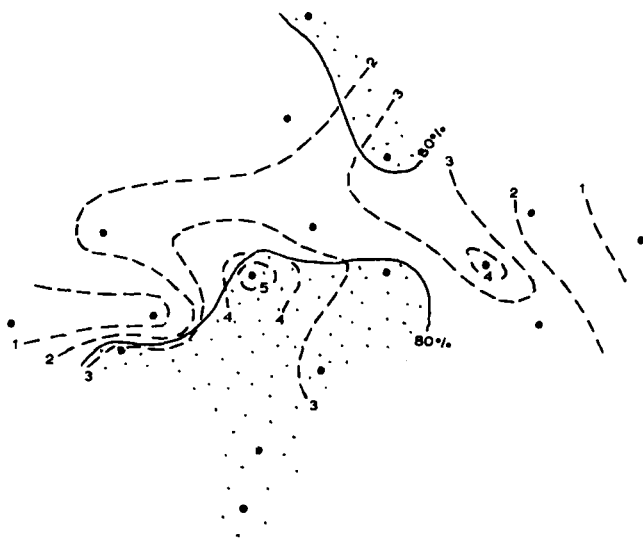


Fig. 7. Forties. Living *Fursenkoina fusiformis*. —% (stippled areas >80% -- thousands per  $30\text{cm}^2$ ).

*balthica* (1.4–19.8%), *Nonionella turgida* (1.0–3.3%) and *Trifarina angulosa* (0.3–14.3%). *Saccammina spherica* is present at most stations and fragments of *Astrorhiza arenaria* are present at a few stations.

The abundance of foraminifera, both benthic and planktonic, can be expressed by the weight of the flotation. This shows a fairly good correlation in the Forties area with the sediment grain size; muddy samples yield a greater weight of flotation. This suggests that the muddy areas are either more productive or that small tests are being deposited there from elsewhere. In view of the pattern of distribution of the standing crop (Fig. 4) and the small size of many of the dead tests, the latter interpretation is favoured.

*F. fusiformis* is invariably dominant at Ekofisk. The accessory species are *Reophax scottii* (3.7–10.2%), *R. subfusiformis* (1.9–6.3%), *Cassidulina obtusa* (7.9–16.1%), *Bulimina marginata* (0.8–7.9%), *Epistominella vitrea* (3.8–12.7%) and *Hyalinea balthica* (0.8–8.5%).

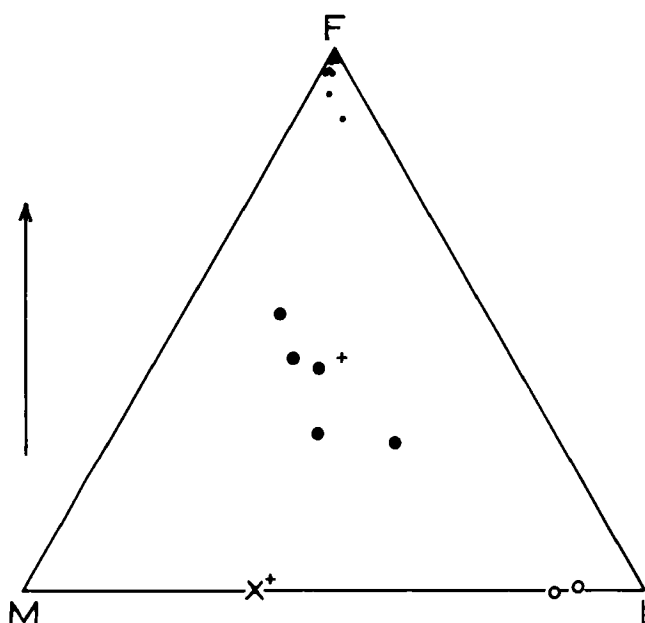


Fig. 8. I, M, F diagram. I = Immobile attached, M = mobile attached, F = free. Arrow indicates decrease in energy. Fair Isle Channel: X = living, + = dead; W. Scotland: open circles = living, large black dots = dead; Ekofisk and Forties: small dots = living and dead.

At Ekofisk, individuals of *H. balthica* in particular, and to a lesser extent *C. obtusa* and *B. marginata*, have opaque, white tests which appear to have been etched through dissolution. In some cases, the tests are so fragile that they crumble to dust. In the Forties area, some tests of *H. balthica*, *C. carinata* and *Melonis pompilioides* have etch-pits made by boring organisms. These seriously weaken the tests and cause them to break.

#### Continental shelf west and north of Scotland

The assemblages fall into two groups: stations 3109 and 3110 from the Fair Isle Channel gravel sheet (in fields III/IV of Murray, 1984) and stations 3111–3116 from the western shelf rippled sands (fields I/III of Murray, 1984).

The Fair Isle Channel sediment samples are coarse shell sands and gravel. All the foraminifera are large: few are smaller than 500  $\mu\text{m}$  and many are > 1 mm. Diversity is low,  $\alpha_2$  to 2½. The dominant species are *Eponides repandus* (18–44%), *Cibicides refulgens* (16–3%), *Cibicides lobatulus* (1–12%) and *Gaudryina rudis* (15–36%). These assemblages are a mixture of attached immobile and mobile forms (Fig. 8).

The assemblages from west of Scotland are sands with some < 63  $\mu\text{m}$  fraction. The foraminifera are small to medium in size. Diversity is  $\alpha$  6–8. The dominant

species are *Cassidulina carinata* (2.5–19%), *Cibicides lobatulus* (14–41%), *C. refulgens* (0.4–14%), *Trifarina angulosa* (3–18%) and *Textularia sagittula* (23–32%). All are attached immobile or mobile forms (Fig. 8). With the exception of station 3115, *Eponides repandus* and *Gaudryina rudis* are absent from these assemblages.

Although some specimens are damaged through abrasion, none shows any effects of dissolution.

#### PLANKTONIC: BENTHIC RATIO

Only one planktonic test (150  $\mu\text{m}$  in diameter) was observed in the Ekofisk samples whereas in the Forties samples the planktonic: benthic ratio is between 19: 81 and 46: 54. In general, the muddier sediments have the higher planktonic values. The maximum size of planktonic tests varies from 300–500  $\mu\text{m}$  but the average size is in the range 110–150  $\mu\text{m}$  and this reflects the dominance of thin-walled juvenile tests.

Planktonic forms are absent in the Fair Isle Channel samples. On the shelf to the west of Scotland, the ratio is 10: 90 to 45: 55. The maximum size varies from 420–660  $\mu\text{m}$ .

#### COCCOLITHS

Whole and fragmented coccoliths are present in all the samples examined but they are more abundant at Forties than they are at Ekofisk. The dominant species is *Emiliana huxleyi*. At Ekofisk, only one or two species are present in each sample and the second species is either *Coccolithus pelagicus* or *Coronosphaera mediterranea*. At Forties, three to five species are present, the additional forms being *Calcidiscus leptoporus*, *Gephyrocapsa oceanica* and *Helicosphaera carteri* (Table 3).

Table 3. Occurrence of nannoplankton in the sediment fraction < 63  $\mu\text{m}$ .

	<i>Calcidiscus leptoporus</i>	<i>Caneosphaera mollisii</i>	<i>Coccolithus pelagicus</i>	<i>Coronosphaera mediterranea</i>	<i>Emiliana huxleyi</i>	<i>Gephyrocapsa oceanica</i>	<i>Helicosphaera carteri</i>	Coccospheres	Number of species
West of Scotland	✓	✓	✓	✓	✓	✓	–	✓	3–5
Orkney/Shetland	–	–	✓	✓	✓	–	–	–	2–3
Forties	✓	–	✓	✓	✓	✓	✓	–	3–5
Ekofisk	–	–	✓	✓	✓	–	–	–	1–2

This pattern of distribution resembles that of the English Channel (Murray *et al.*, 1983), in showing a decrease in diversity with increase in distance from the ocean. It is also consistent with the known movement of oceanic water into the area (Fig. 1). The occurrence of *Emilina huxleyi* as the dominant species accords with the observation by Braarud *et al.* (1953) that this is the characteristic species of Atlantic water masses entering the North Sea through the Faeroe-Shetland Channel.

The shelf to the west of Scotland comes under the influence of Atlantic water. Whole and fragmentary coccoliths are generally abundant and *Coccospheres* (of *Emiliana huxleyi*) are present at some stations. The coarse sediments from the Fair Isle Channel have a very small proportion of the  $< 63 \mu\text{m}$  component and this has only 2–3 species of coccoliths (Table 3).

## DISCUSSION

In the early part of this century, Heron-Allen and Earland wrote a series of papers on individual species of foraminifera present in samples from the northern North Sea collected by the Scottish Fisheries Board cruiser "Goldseeker". The first assemblage study was that of Stephen (1923) who described the 'Foraminifera community' based on the abundance of foraminifera  $> 1.5 \text{ mm}$  in size on muddy bottoms from 100 m and deeper. *Astrorhiza arenarea*, *Saccammina sphaerica* and *Psammosphaera fusca* were present together with the bivalve *Thyasira flexuosa*. Thorson (1957) considered this community to have a small standing crop and low productivity, which is at variance with the results reported here.

The Fladen Ground, studied by McIntyre (1961), yielded 983 *Saccammina sphaerica* per  $\text{m}^2$  sea floor ( $> 1.3 \text{ mm}$  sieve). However, examination of 1000 tests showed that only 267 contained the animal and 636 were dead. Other species recorded by McIntyre were *Alveolophragmium crassimargo* and *Reophax scorpiurus*, but he also looked at the  $< 1.3 \text{ mm}$  size fraction and commented on the great abundance of small foraminifera. In a further paper (1976) he stained the samples with rose Bengal and looked at the  $> 76 \mu\text{m}$  fraction. *Bulimina* (which may include *Fursenkoina* as used here) and *Cancris* were said to be present in abundances of 2000–105,000 per  $\text{m}^2$  (= 6–315 per  $30 \text{ cm}^2$ ) in samples from the Fladen Ground and Loch Nevis on the west coast of Scotland. These values are significantly lower than those recorded here, perhaps partly because of the use of a  $76 \mu\text{m}$  rather than a  $63 \mu\text{m}$  sieve.

In the classification of marine communities proposed by Jones (1950), the northern North Sea is a boreal deep mud association.

Previous studies of assemblages of foraminifera from the whole North Sea include those of Jarke (1961) and Gabel (1971). These authors used a  $63 \mu\text{m}$  sieve and

concentrated the foraminifera by the carbon tetrachloride technique. However, they did not distinguish between living and dead faunas. The Ekofisk area lies within the *Bulimina fusiformis*, *B. marginata*, *Anomalina balthica* assemblage of Jarke (1961) and the *Bulimina fusiformis*, *B. marginata* assemblage of Gabel (1971). This is consistent with the present results. (*Bulimina fusiformis* = *Fursenkoina fusiformis*; *Anomalina balthica* = *Hyalina balthica*).

The living assemblages of the mid-shelf off Northumberland (depth 85 m) were studied by Collison (1980). He took core samples having a surface area of  $3.9 \text{ cm}^2$ , and examined 1 cm thick slices down to a depth of 11 cm below the sediment/water interface. *Fursenkoina fusiformis* was the dominant species at every station. It formed an average of 57% of the living assemblages from all cores, but only 21% of the assemblage in the top 1 cm (average of 5 cores). In core 1, it formed 6% in the top 1 cm but reached a peak of 96% at 5–6 cm. (Absolute abundance 10 and 205 respectively). The other five species discussed, *Bulimina marginata*, *Hippocrepina* sp., *Reophax subfusiformis*, *Ammonia batavus*, and *Quinqueloculina* sp. were most abundant in the top 2 cm although they also occurred in small numbers below this depth.

The results from Forties and Ekofisk show some differences from shelf seas in general (see Murray, 1973, for a review). In particular, the living assemblages show high dominance by one species and low diversity. Both of these features are more characteristic of marginal marine environments. It is possible that the high abundance of *Fursenkoina fusiformis* might be a seasonal feature as most of the samples were collected in June (as also were those by Collison, 1980). Three samples from the Celtic Sea had living assemblages with *F. fusiformis* forming 58, 67 and 92% and these were collected in October 1970 and July–August 1972 (Murray, 1979). A seasonal blooming would also help to account for the reduced abundances in the dead assemblages (Table 2). Alternative explanations are the selective post-mortem loss of this species or the introduction of tests of other species not normally resident in the area. The latter process probably takes place anyway as the dead assemblages are somewhat more diverse. These results are in marked contrast to those for the living macrofauna. In the 1978 (Hartley, 1979) and 1981 (Hartley & Ferbrache, 1983) sampling surveys, the Forties area was found to be rich in species and low in species dominance.

The standing crop and biomass values range from average to very high in comparison with other shelf seas and this indicates that the area is very fertile. The range previously recorded for shelf seas is 0–4.230  $\text{mm}^3/30 \text{ cm}^2$  biomass (Murray, 1973, 1979) thus the values for the North Sea are especially high.

The living assemblages are composed entirely of free forms (*sensu* Sturrock & Murray, 1981). This is true also

of the dead assemblages although these include rare attached immobile forms (*Cibicides lobatulus*). This is consistent with a low-energy area of fine grained sediment accumulation.

Both Forties and Ekofisk come under the influence of Atlantic water which flows into the North Sea at the surface. The evidence for this is recorded in the sediment by the planktonic: benthic ratio and by the coccoliths. Planktonic tests are present at Forties but most are small juveniles. They are virtually absent from Ekofisk. This accords with the model for determining the proximity of marginal seas to an ocean put forward by Murray (1976). Similarly, the coccoliths show a reduction in diversity from Forties to Ekofisk.

The samples studied were originally taken during surveys to monitor the effects of pollution from oilfield development. The macrobenthos of the Ekofisk oilfield underwent changes between 1975 and 1977 with a modified area extending to ~3 km away from the central storage and production complex in 1977. Although some species were reduced in number in the central area, others (*Chaetozona setosa* and *Arctica islandica*) were most abundant there. Unfortunately, no studies of living foraminifera were undertaken prior to the development of the oilfield. However, the results presented here suggest that there has been no detrimental effect on living assemblages.

Few studies have been made of foraminifera from the west coast of Scotland. Brady (1865) discussed the Shetland fauna and Heron-Allen and Earland (1916) the continental shelf. Recently, Edwards (1982) reported on the faunas of the North Minch Channel. None of these studies differentiated between living and dead, although a few of the samples studied by Heron-Allen and Earland were preserved in alcohol. McIntyre (1961) made a study of the fauna >1.3 mm on the muddy bottom of Loch Nevis and found *Crithrionina granum* to be abundant. There appears to be no previous studies of the mid-shelf region.

In this study, it has been shown that the faunas of the North Sea are very different from those of the Scottish shelf. The latter have a modest proportion of free-living forms and a dominance of attached forms, both immobile and mobile. This is indicative of the higher-energy environment to the west of Scotland, where, although the tidal currents are weak (Wilson, 1982, p. 165), it is possible that wave energy disturbs the sea floor especially during storms. The highest energy area is that of the Fair Isle Channel where tidal currents are powerful (Wilson, 1982, p. 163). The living assemblages resemble those of the English Channel and Celtic Sea (Groups 1 and 3 of Sturrock & Murray, 1981). The dead assemblages differ markedly from the living due to transport. This causes mixing of assemblages from adjacent micro-environments and winnowing away of small mobile attached species which live on firm sub-

strates. The abundance of the dead faunas is thought to be controlled mainly by the slow rate of dilution by sediment.

## CONCLUSIONS

The mid continental shelf muddy bottom living foraminiferal assemblages from the northern North Sea have a high standing crop, low diversity, and are generally dominated by *Fursenkoina fusiformis*. This contrasts with the high diversity, low dominance macrofauna of the same area. The dead foraminiferal assemblages are more diverse, probably due to the introduction of small tests winnowed from elsewhere but are nevertheless very similar to the living assemblages. Both are made up of free-living species.

Living assemblages from the mid continental shelf west of Scotland are largely confined to attached forms on hard substrates such as bivalve shells, bryozoa or hydroids. The dead assemblages are made up of large tests and they differ significantly from the living due to post-mortem transport effects.

## ACKNOWLEDGEMENTS

The North Sea samples were collected by Dr. J. P. Hartley of the Oil Pollution Research Unit. Thanks are due to British Petroleum plc and Phillips Petroleum (Norway) Ltd. who funded the field sampling and have permitted publication of the results. Those from the Scottish shelf were collected by Dr. J. B. Wilson of the Institute of Oceanographic Sciences. The manuscript was read by Drs. J. P. Hartley, S. Sturrock and J. B. Wilson and I am grateful for their helpful comments. Mrs. V. Ellis kindly typed the manuscript.

## REFERENCES

- Addy, J.M., Levell, D. & Hartley, J. P. 1979. Biological monitoring of sediments in Ekofisk Oilfield. Proc. Conf. 'Assessment of ecological aspects of oil spills', Keystone, Colorado, June 1978. *Amer Inst. Biol.*, 514-539.
- Braarud, T., Gaarder, K. R. & Grøntved, J. 1953. The phytoplankton of the North Sea and adjacent waters in May 1948. *J. du Conseil*, 113, 1-87.
- Brady, H.B. 1865. Contribution to the knowledge of the Foraminifera - On the Rhizopodal fauna of the Shetlands. *Trans. Linn. Soc.*, 24, 463-475.
- Collison, P. 1980. Vertical distribution of Foraminifera off the coast of Northumberland, England. *J. foramin. Res.*, 10, 75-78.
- Edwards, P.G. 1982. Ecology and distribution of selected foraminiferal species in the North Minch Channel, north-western Scotland. In: Banner, F.T. & Lord, A.R. (Eds.), *Aspects of Micropalaeontology*, George Allen & Unwin, London, pp. 111-141.
- Eisma, D. 1981. Supply and deposition of suspended matter in the North Sea. *Spec. Publ. int. Ass. Sediment.*, 5, 415-428.
- Gabel, B. Die Foraminiferen der Nordsee. *Helv. wiss. Meeresuntersuch.*, 22, 1-65.



- Hartley, J. P. 1979. Biological monitoring of the seabed in the Forties Oilfield. *Proceedings of the Conference on Ecological Damage Assessment*, 215–253. Society of Petroleum Industry Biologists.
- Hartley, J. P. 1983. Biological monitoring of the Forties Oilfield. *Proceedings of the 1983 Oil Spill Conference*, 407–414, Texas.
- Hartley, J. P. & Ferbrache, J. 1983. Biological monitoring of the Forties Oilfield (North Sea). *Proc. 1983 Oil Spill Conf.*, San Antonio, Texas, 407–414.
- Heron-Allen, E. & Earland, A. 1916. The Foraminifera of the west coast of Scotland collected by Prof. W. A. Herdman, F.R.S., on the cruise of the S.Y. "Runa", July–Sept. 1913. Being a contribution to "Spolia Runiana". *Trans. Linn. Soc.*, (2), 11, 197–300.
- Jarke, J. 1961. Die Beziehungen zwischen hydrographischen Verhältnissen, Faziesentwicklung und Foraminifernverbreitung in der heutigen Nordsee als Vorbild für die Verhältnisse während der Miocen-Zeit. *Meyniana*, 10, 21–36.
- Jones, N. S. 1950. Marine bottom communities. *Biol. Rev.*, 25, 283–313.
- Lee, A. J. & Ramster, J. W. 1981. Atlas of the seas around the British Isles. Ministry of Agriculture, Fisheries and Food, Lowestoft, England.
- McIntyre, A. D. 1961. Quantitative differences in the fauna of boreal mud associations. *J. mar. biol. Ass. U.K.*, 41, 599–616.
- McIntyre, A. D. 1964. Meiobenthos of sub-littoral muds. *J. mar. biol. Ass. U.K.*, 44, 665–674.
- Murray, J. W. 1971. *An atlas of British Recent Foraminiferids*. Heinemann Educational Books, London, 274 pp.
- Murray, J. W. 1973. *Distribution and ecology of living benthic foraminiferids*. Heinemann Educational Books, London, 244 pp.
- Murray, J. W. 1976. A method of determining proximity of marginal seas to an ocean. *Mar. Geol.*, 22, 103–109.
- Murray, J. W. 1979. Recent benthic foraminiferids of the Celtic Sea. *J. foramin. Res.*, 9, 193–209.
- Murray, J. W. 1984. Benthic Foraminifera: some relationships between ecological observations and palaeoecological interpretations. *Benthos '83; 2nd Int. Symp. Benthic Foraminifera (Pau, April 1983)*, 465–469.
- Murray, J. W., Weston, J. F. & Sturrock, S. 1983. Sedimentary indicators of water movement in the Western Approaches to the English Channel. *Continental Shelf Research*, 1, 339–352.
- Stephens, A. C. 1923. Preliminary survey of the Scottish waters of the North Sea by the Petersen grab. *Sci. Invest. Fish. Scot.*, 3, 1–21 (for 1922).
- Sturrock, S. & Murray, J. W., 1981. Comparison of low energy and high energy marine middle shelf foraminiferal faunas; Celtic Sea and western English Channel. In: Neale, J. W. & Brasier, M. D. (Eds.), *Microfossils from Recent and fossil shelf seas*. Ellis Horwood Ltd., Chichester for British Micropaleontological Society, pp. 250–260.
- Thorson, G. 1957. Bottom communities (sublittoral or shallow shelf). *Mem. geol. Soc. Amer.*, 67(1), 461–534.
- Williams, C. B. 1964. *Patterns in the balance of nature*. Academic Press, London, 324 pp.
- Wilson, J. B. 1976. Biogenic carbonate sediments on the Scottish continental shelf and on Rockall Bank. *Mar. Geol.*, 33, M85–M93.
- Wilson, J. B. 1982. Shelly faunas associated with temperate offshore tidal deposits. In: Stride, A. H. (Ed.), *Offshore tidal sands*. Chapman & Hall, London, pp. 126–171.