

REPORTS

The Effects of the Sea Empress Oil Spill on the Plankton of the Southern Irish Sea

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This study investigates the effects of the Sea Empress oil spill on the local plankton communities which are an important component of the marine ecosystem. The Continuous Plankton Recorder survey has monitored the plankton in this area since 1970 giving an extensive time series for comparison with post-spill samples. The analytical procedures applied and results obtained are presented and reveal that, with some exceptions, no significant effects were evident. Barnacle larvae were not recorded post-spill and the spring zooplankton community was somewhat different to the previous year. A long-term trend is apparent in the community but the most common taxa showed no significant changes, suggesting a minor shift in species composition rather than a dramatic change. The number of zooplankton taxa in the autumn was significantly higher than in other years. The study emphasizes the importance of monitoring programmes which routinely collect samples so that any effects can be determined. © 1998 Elsevier Science Ltd. All rights reserved

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Introduction

On the evening of Thursday 15th February 1996 the *Sea Empress*, a 147273 dwt crude oil tanker carrying approx. 131000 t of Forties crude oil destined for the oil refinery at Milford Haven ran aground on St. Anne's Head at the entrance to the Haven (MPCU, 1996). The tanker was moved within a week further up the Haven, to shelter from the winds and waves, but in the meantime an estimated total of approximately 72000 t of oil, the majority being crude oil, but also a

quantity of heavy fuel oil, leaked from the holed tanker, most of which was not recovered (SEEEEC, 1996). This was the third largest oil spill to have occurred in UK waters, exceeded only by the *Torrey Canyon* in 1967 and the *Braer* in 1993, and a larger spill than Alaska's *Exxon Valdez*. A total of 8 t of demulsifier and 445 t of dispersant were deployed between the 18th and the 22nd February from aircraft (SEEEEC, 1996), and dispersants were also used in the clean-up of the recreational beaches.

The purpose of this study is to assess the effects, if any, of the spill and the subsequent clean-up measures on the plankton of the area. Whilst plankton may have some motile ability they are dependent on currents and tides for their location, and are thus unable to avoid unfavourable water conditions. Recovery from any effects is likely to be relatively rapid, given recruitment from other areas and their wide distribution and short generation times, but this may depend on the timing of the disturbance in relation to their life cycle. The Continuous Plankton Recorder (CPR) survey collects and monitors the plankton across the North Sea, and North Atlantic and began in the 1930s (Warner and Hays, 1994). The CPR survey has operated regular routes in the southern Irish Sea since 1970 and up to the present day.

Little work has been published which utilizes historical plankton information comparing community trends before and after an oil pollution incident. Work has generally been limited to only one or two taxa or species, not considering effects at a community level, with little or no historical data to act as a viable comparison. However, reactive changes have been found in different species of the marine planktonic community, manifested as alterations of biomass, abundance, and ecophysiological effects. Reductions in photosynthesis of up to 36% were reported by

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Tomajka (1985) and 40% by Goutz *et al.* (1984). *Skeletonema costatum* decreased in the presence of hydrocarbons (Anon., 1982). Algal growth was inhibited by high, and stimulated by low, concentrations with *Prorocentrum micans* displaying more growth inhibition than other species (Goutz *et al.*, 1984). Work by Elmgren *et al.* (1980) revealed that dominant phytoplankton species were relatively insensitive to oil, however, stress was indicated by an increase in biomass and changes in species composition. Samain *et al.* (1980) carried out an ecophysiological survey on the North coast of Brittany following the *Amoco Cadiz* oil spill and identified biochemical succession of population groups over a one year period. Samain *et al.* (1981) showed that the species *Anomalocera patersoni* (a neustonic copepod) was particularly perturbed even at residual hydrocarbon levels. Mackie *et al.* (1978) found aromatic hydrocarbon contents within the zooplankton near the wreck of the *Amoco Cadiz*. Presence of ingested oil was also found by Gajbihiye *et al.* (1995) on zooplankton after the *Murud* oil spill in the Bombay region and some species of copepods showed signs of increased mortality as a result. Planktonic heterotrophic ciliates appear to be affected by oil; they disappeared from water contaminated with 0.45–0.728 mg of oil per litre (Dale, 1987) and a bloom of tintinnids occurred in water with added oil and nutrients. Overall the addition of nutrients decreased the negative effects of oil on heterotrophic ciliates, (Dale, 1988a). It was suggested that the disappearance of ciliates was a result of their migration to a deeper layer (Dale, 1988b) and their loss was exacerbated in samples with added dispersants. Heterotrophic components of the plankton appear to be more sensitive to oil pollution than the phytoplankton (Skjoldal and Thingstad, 1987). Petroleum pollution experiments (Lacaze, 1983) showed phytoplankton and microzooplankton (ciliates) to have a high level of resistance, while zooplankton, especially copepods, were greatly affected. Enclosed planktonic ecosystem experiments with Ekofisk crude oil showed that growth of diatoms and copepods was inhibited, but an increase in tintinnid ciliates was observed (Dahl *et al.*, 1983).

A significant number of previous studies have concentrated on the effects on benthic species. A comprehensive review is not possible here but some studies have relevance to this work. Le Campion-Alsumard *et al.* (1984) studied benthic microalgal populations (cyanophytes and diatoms) in an attempt to estimate both short and long-term effects of the *Amoco Cadiz* oil spill. A sharp response was found; populations were completely destroyed in 1978 and 3 yr later, marsh soils were still much less densely populated. Gray *et al.* (1990) also utilized marine benthos as an indicator of the initial effects of oil pollution from the Ekofisk and Eldfisk oil fields. Stress was indicated by a reduction in the number of species and diversity. Site groupings were also distinguished

related to oil activities using statistical analysis. Since previous research shows that benthic species generally show a measurable response to pollution incidents it might be expected that planktonic larvae of benthic species will mirror these effects. The CPR collects and measures several taxa that would be appropriate as indicators of benthic perturbations, for example echinoderm larvae.

In summary, work on zooplankton has focused on a range of species, all of which are recorded by the CPR. Literature suggests that changes are more readily identified in heterotrophs rather than autotrophs, however a reduction of photosynthetic capability might also be reflected in long-term trends, such as with CPR material. Effects of contamination may be expected to be manifest as a change in the species composition of the plankton. More specifically, this may be as a decline or increase in one or more species or taxonomic groups, a change in the ratio of holo- to meroplankton (since it might be expected that the benthos, and hence larval stages of benthic fauna, will be affected to a greater degree) or a change in the variability of all, or a part, of the plankton community that may indicate a more perturbed system.

No conventional control sites were available for this study as differing hydrological regimes and plankton communities away from the southern Irish Sea would have made comparisons difficult. This study instead used pre-spill CPR data to determine the typical plankton community of the study area and the degree of natural variability in the plankton. This 'natural' variability also included any anthropogenic effects resulting from the shipping, industrial and leisure activities occurring in the area and any meteorological effects as well as fluctuations which were entirely the result of biological interactions. Attempts were made to determine any effects solely the result of the oil spill and any other trends were judged as 'natural' variations.

Methods

CPR sampling

CPRs are towed in the surface mixed layer at a depth of about 7 m (Hays and Warner, 1993) by commercial 'ships of opportunity' on their regular routes of passage. The use of commercial ships is economical and ensures that sampling is evenly spread throughout the year and is not biased towards the more clement months, as is often the case with research ship programmes. Water enters the front of the CPR through a 1.27 cm square aperture, passes along a tunnel and through a silk filtering mesh (mesh size 270 µm) before exiting at the back of the machine. The movement of the CPR through the water turns an external propeller which, via a drive shaft and gearbox, moves the filtering silk across the tunnel at a rate of approximately 10 cm per 18 km of tow. As the filtering

silk leaves the tunnel it is covered by a second band of silk so that the plankton are sandwiched between these two layers. The silk and plankton are then wound on into a storage chamber containing formaldehyde. On return to the laboratory, the silks are processed in a set manner (Colebrook, 1960). The deployment and recovery positions of the recorder are used to determine and mark the 18 km samples and alternate samples are analysed for the presence of plankton. Phytoplankton are counted in a semi-quantitative manner since the mesh size of the silk only quantitatively catches the largest phytoplankton species. Small zooplankton species are counted by viewing a subsample of the silk (1/50) and identifying and counting all taxa encountered. Larger zooplankton taxa (> 2 mm) are removed from the sample and individually identified and counted with no sub-sampling. Identification is carried out to the highest practicable taxonomic level. Although CPR sampling is continuous, individual samples are allocated a position according to the latitude and longitude of the mid-point of the sample. An area of study was defined in the southern Irish Sea that encompassed the area potentially affected by the oil spill. Figure 1 shows the study area and all CPR samples (1944) collected between 1970 and the oil spill, and the 63 samples taken between the oil spill and the end of October 1996. With the exception of 1978, sampling was gener-

ally of the order of 50–100 samples per year in the affected area.

Southern Irish Sea analysis

Seasonal means were calculated from the individual sample data to enable realistic comparisons between pre- and post-spill data according to the following rationale. (1) Post-spill samples are limited in number compared to pre-spill so to perform any statistical test the number of comparable samples must be maximized; (2) Interannual differences in meteorological conditions may mean that April of a given year, for example, may not be directly comparable with April of another year, it may in fact be more similar to the March or May. Seasonal means reduce this interannual variability; (3) The mean planktonic seasonal cycle for this area (Fig. 2) suggests that four distinct biological periods occur in synchrony with the seasons. During winter, levels of both phytoplankton (represented by phytoplankton colour, a visual estimate of the amount of phytoplankton per sample) and zooplankton (represented by total copepod abundance) are very low. During spring levels of both rise sharply to a peak, which decline through summer. During autumn, the phytoplankton continue to fall but the zooplankton show a second distinct peak in abundance.

The seasons were defined as follows; Winter = December, January, February; Spring = March, April,

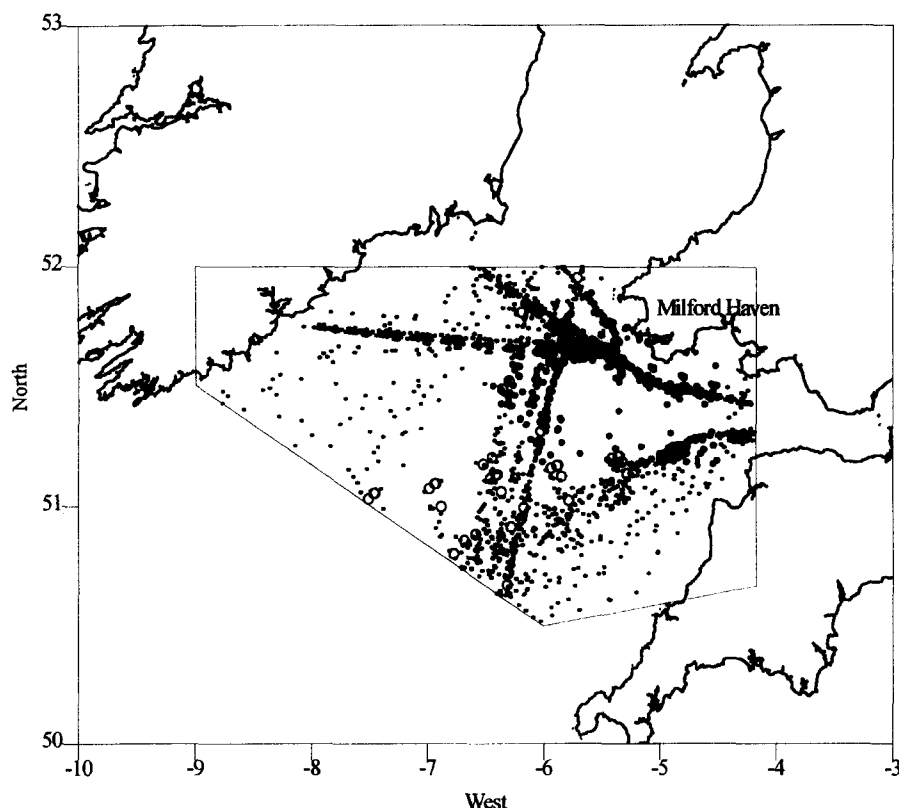


Fig. 1 The study area (within solid line) and position of CPR samples (small dots = pre-spill samples, circles = post spill samples).

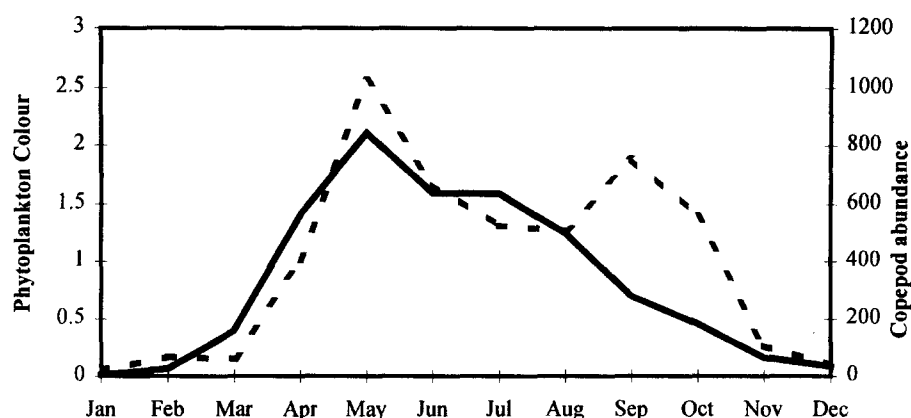


Fig. 2 Mean monthly phytoplankton colour and copepod abundance per sample for all pre-spill samples collected within the study area. Solid line is phytoplankton colour, dashed line total copepod abundance.

May; Summer = June, July, August; Autumn = September, October, November. CPR samples collected post-spill in February 1996 were taken at the very end of the month. They have, therefore, been included in the spring average rather than the winter.

Individual taxa analyses

Plankton abundance data were extracted for all of the 1944 samples shown in Fig. 1 from 1970 to 1995. The taxa were ranked according to the number of samples they had been recorded on (percentage incidence) and the ten most frequently occurring taxa (10 phyto- and 10 zooplankton) were examined for post-spill changes. Other taxa that might display changes were also investigated, including groups suggested by the literature to be susceptible and meroplankton not included in the ten 'most common' list and cyst stages of phytoplankton. Holo- and meroplankton abundance totals were also calculated and their ratio calculated.

Community analyses

Changes in diversity have long been recognized as potential indicators of a disturbed environment and many different analytical procedures exist to determine diversity. The simplest expression of diversity is to determine the proportion of species in a sample, although this will be dependent on the total number of individuals and so is not ideal. The most frequently used index of diversity, which measures the degree of uncertainty involved in predicting the species identity of a randomly selected individual, is the Shannon-Weiner information function H (Shannon and Weaver, 1963). Such univariate methods provide a single value for each sample, an advantage because it allows the use of simple statistical tests to determine change, however, two separate samples may have the same diversity without having any species in common. Multivariate techniques compare the similarity of every pair of samples and an analysis configures the samples so

that the distance between them is a reflection of the dissimilarity in their species composition. A commonly used multivariate ordination technique is non-metric multi-dimensional scaling (MDS) (Kruskal and Wish, 1978) which is often employed in pollutant investigations. Three separate analyses of diversity were carried out on the southern Irish Sea data.

1. The number of taxa recorded per sample in routine CPR analysis. This is a simple indication of the diversity of plankton recorded on a sample. Although a single CPR taxonomic entity may be a group of several species, the same distinctions have been made on all historical CPR samples, thus comparisons are valid. Phytoplankton and zooplankton are analysed separately throughout, mainly because of the differing methods of abundance determination, but also because of their trophic separation. Numbers of taxa recorded on each sample were calculated (including taxa recognized only as having a 'presence') and also the number of individuals (zooplankton only).
2. Shannon-Weiner diversity per sample. This requires that all individuals are identified to the same taxonomic level, generally to species. This is not the case in CPR analysis where some organisms are identified to species but many only to genus or even phyla level. It was necessary, therefore, to combine data to produce numbers of individuals of each phyla present per sample, and to calculate H at the phyla level. This was completed for the zooplankton but not for phytoplankton, as abundances are only relative.
3. MDS of zooplankton and phytoplankton seasonal abundances (by year). Data were combined into seasonal means (as previously described) for each year of sampling. Winter values were not considered any further, firstly because plankton abundance is very low in the winter, making comparisons difficult, and secondly because the post spill-data began in spring 1996 and ended in autumn 1996 so that there

was no winter post-spill data with which to compare. Phytoplankton and zooplankton data were analysed separately but in each case the entire suite of taxa was included in the analyses (even taxa only recorded once in the 26 yr). Zooplankton data were first transformed to reduce the bias caused by high numbers of common species and to observe patterns within the whole community. The transformation used was $\log(x+1)$. It was not necessary to transform the phytoplankton data as the method of estimating abundance in routine CPR analysis is a type of transform in any case. MDS analysis was performed using the statistical package PRIMER (Plymouth Routines In Multivariate Ecological Research).

Spatial analysis

Although none of the CPR data were collected in close proximity to the site of the spill it was thought necessary to determine if there were any differences in species composition as a result of geographical position, whether as a result of distance from the spill or habitat changes within the study area. Any gradients of community change within the study area would bias the other analyses. Individual post-spill samples were analysed for each season using MDS. The number of phytoplankton taxa recorded per sample was too low for a valid analysis, therefore, only zooplankton have been analysed and transformations were carried out as previously described. The latitude and longitude of the mid-point of each sample was used to determine its distance from Milford Haven.

Results and Interpretation

Individual taxa

It should firstly be stated that no new taxa were recorded in the post-spill samples, all plankton had previously been found in the study area. A simple visual examination of the 'top ten taxa' revealed that none of the taxa showed post-spill levels either higher or lower than those found in previous years. In some cases peaks were evident in 1996, however, these peaks began during the autumn or winter of 1995/1996 and so cannot solely be an effect of the spill. The plots of potentially susceptible taxa similarly showed no unusual increases or declines with the possible exception of cirripede (barnacle) larvae. Barnacle larvae were not recorded at all post-spill, but have been recorded every previous year except on three occasions (1970, 1975, 1991). Interestingly, barnacle larvae are most abundant in CPR samples in spring, whereas another littoral taxon also recorded in CPR samples, the larvae of bryozoa, have highest abundances in summer and autumn and were recorded in 1996. A spring spawning organism is more likely to have been affected by the spill than a summer spawning organism. A rocky shore study in south Pembrokeshire, however,

did encounter a good spatfall of *Semibalanus balanoides* in May/June 1996 (John Moore, pers. comm.). Other barnacle species, *Chthamalus* spp., which spawn later, in the summer, showed a patchy recruitment and reduced densities in 1996 whilst *Elminius modestis*, which spawns throughout the year also showed good recruitment in 1996. It is likely that the species predominantly caught by the CPR is *S. balanoides*, given the normal spring peak in larval abundance, however, it is not known which littoral populations contribute to the larvae sampled by the CPR and it is possible that some populations were affected. It is also possible that if the larvae were present in the plankton for only a short space of time, the CPR sampling may have missed their occurrence. That the rocky shores of south Pembrokeshire received a good recruitment is encouraging, however, and suggests that this was not a serious effect.

Spatial analysis

Figure 3 shows the MDS plots for the post-spill samples (zooplankton only) with distance indicators superimposed (the larger the circle the greater the distance of the sample from Milford Haven). It is clear that there are no distinct clusters of samples with a particular distance from Milford Haven. It is, therefore, reasonable to assume that geographical position within this particular study area has not determined the zooplankton community composition, and any trends seen in other analyses are the result of other factors.

Community analyses

Figure 4 shows the pre-spill seasonal cycles in the number of taxa and in diversity H (zooplankton). It should be noted that the means displayed are geometric means, rather than arithmetic, because the data were transformed [again $\log(x+1)$] before calculating the mean and 95% confidence limits because the data are not normally distributed.

It can be seen that very few taxa are recorded throughout the winter. The zooplankton show a high level throughout the spring and summer, which following the spring rise in copepods is probably maintained by the arrival of meroplanktonic forms. Phytoplankton taxa show a single narrow peak in mid-summer whilst the phytoplankton colour seasonal cycle shown in Fig. 2 suggests an earlier spring bloom. This demonstrates that the spring bloom is composed of high numbers of relatively few species and that the species succession (and hence number of taxa) reaches a climax in the summer.

The zooplankton diversity gradually increases through the spring to a peak in summer. When contrasted with Fig. 4(a) which shows high numbers of taxa in spring as well as summer it emphasizes that the response to the phytoplankton spring bloom occurs mainly in copepods and crustacean larvae (1 phylum) and that the diversity peak in summer is the result of

juvenile stages of benthic and littoral taxa (echinodermata, bryozoa, mollusca etc.). This is the most likely period for any effects of the oil spill to be evident, since the high summer plankton diversity is enhanced by inputs from a wide range of habitats, which may have been impacted to a greater extent than that of the holoplankton.

The proportion of the community composed of holoplankton and meroplankton are displayed in Fig. 4(d). The proportions have been calculated such that -1 indicates a community totally composed of holoplankton, +1 a community totally composed of meroplankton and 0 a community with an equal number of individuals of both. It is clear that during winter the population is almost entirely holoplanktonic and that there are three successive waves of meroplankton. Early contributions come from barnacle larvae and fish eggs, the late spring and early summer

peak is comprised of young fish, echinoderm larvae and decapod larvae and the late summer peak mainly bryozoan larvae, molluscan larvae and pre-settling echinoderms.

Figure 5 shows the results of the MDS analyses. The stress value gives an indication of how good this 2-dimensional representation of the data is. The lower the value the better the representation and for values above 0.3 (not present in this study) further dimensions should be examined. The interpoint distances correspond to the dissimilarities of the samples (in this case years) so that those closest together are the most similar in their community composition.

The MDS results show that the phytoplankton community throughout 1996 was not noticeably different, i.e. although it may have been different from any one given year, the distance between 1996 and 1995 is no greater than the distance between other

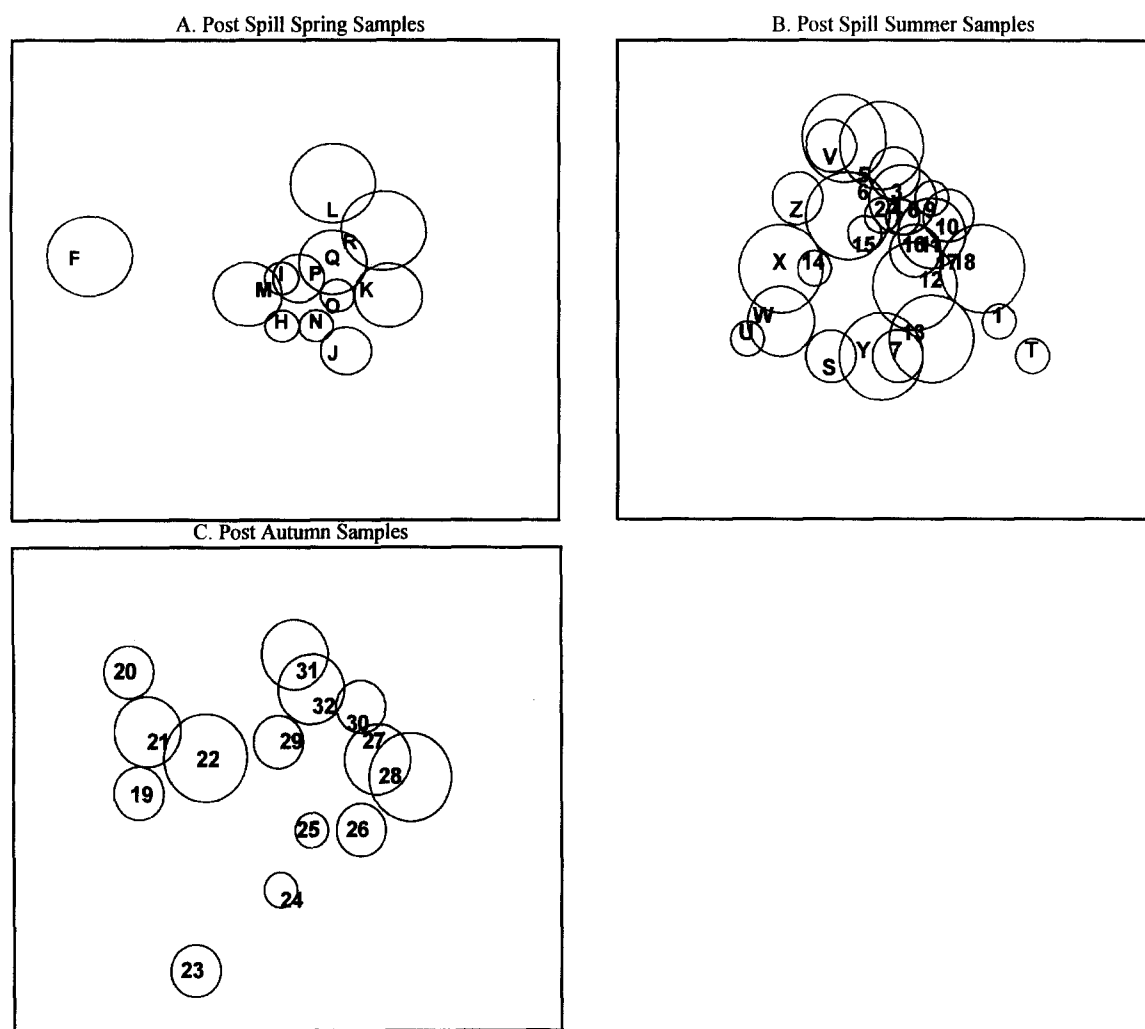


Fig. 3 MDS plot of 1996 post-spill samples, by season, with distances from Milford Haven superimposed. The larger the circle the greater the distance (minimum distance = 45 km, maximum = 182 km). (A) Spring, samples A-R, stress = 0.10; (B) Summer, samples S-Z and 1-18, stress = 0.20; (C) Autumn, samples 19-32, stress = 0.11. Some samples not evident because too few taxa for analysis or overlapped by another sample.

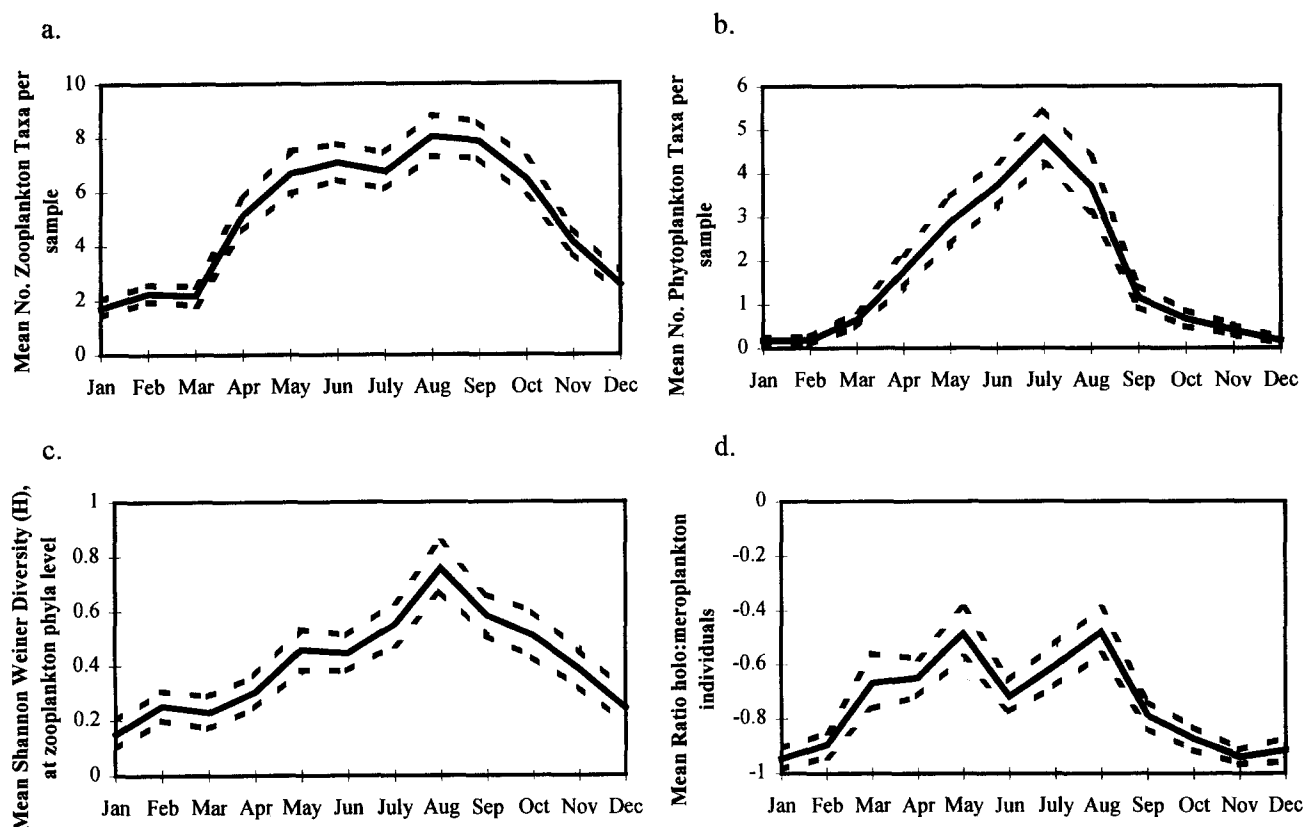


Fig. 4 Monthly mean (geometric) and 95% confidence limits for numbers of taxa, diversity and ratio of holo- and meroplankton per sample, for pre-spill samples collected in study area between 1970 and 1995.

pairs of years. The same can be said of the summer and autumn zooplankton communities, however, there is some evidence to suggest that the spring community was dissimilar. 1996 plots on its own, at a greater distance from 1995 than distances between most other sequential years. It is possible to determine whether 1996 results were significantly different from pre-spill years using the ANOSIM procedure. The *P* values ranged from 0.12 (spring zooplankton) to 0.42 (spring phytoplankton) so in no case was there a significant difference between pre- and post-spill communities. What is extremely apparent from these plots, however, is that there has been a gradual change in the communities from the start of the time series in 1970, to the time of the oil spill. It is more noticeable in the zooplankton than in the phytoplankton but in all plots the 1970s tend to be one side of the plot, with the 1990s opposite and the 1980s in between, so that the greatest difference in communities exists between the earliest and the latest years.

In order to determine if a climatological change could be causing this trend, given that recent years have shown generally increased temperatures in the British Isles, a time series of sea temperature was constructed. Two sources of data were available; a series from the Severn Estuary and one from the northern Irish Sea. Seasonal mean temperatures were calculated as described for the plankton data but only

data from the outer Severn Estuary was used, so that the influence of the land was minimized. The period of overlap of the two datasets showed a significant positive correlation, therefore, it was possible to use the northern Irish Sea dataset to complete the missing periods of the Severn Estuary series (although some gaps still existed in the later years). Figure 5 also shows the temperature data, superimposed on the MDS plots (the larger the circles the warmer the temperature).

These results indicate that the observed trends in community composition are not solely a response to temperature as no clear-cut correlations exist. The summer zooplankton may be a possible exception as it appears that warm, cool, and intermediate years form clusters, however in this number of analyses some random correlations might be expected. Recent published research suggests that climatic factors do affect the plankton. Taylor (1996) comments on the relationship between zooplankton and the position of the Gulf Stream (determined by ocean-atmosphere interactions), and Frid and Huliselan (1996) extend this relationship to zooplankton community structure changes. It is probable that the trends observed in the southern Irish Sea are also related to these published observations but it is beyond the scope of this study to further investigate pre-spill trends.

The MDS plots indicate that there is a trend in the time series of data, therefore, to compare 1996 data

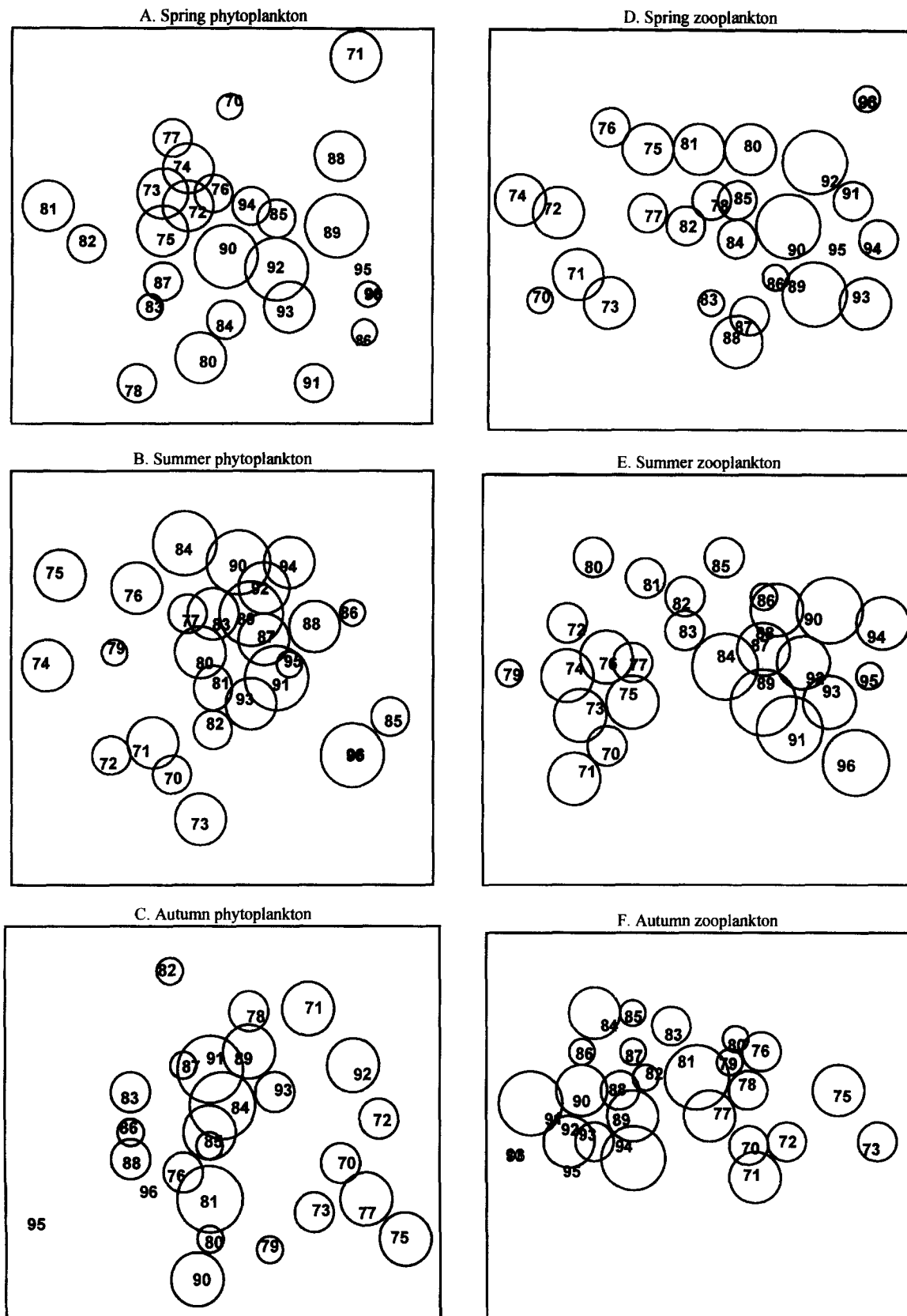


Fig. 5 MDS plots by year, with sea temperature superimposed (the larger the circle the warmer the temperature). Stress values: a = 0.23, b = 0.21, c = 0.22, d = 0.19, e = 0.15, f = 0.12. No circle indicates missing temperature data.

with the entire pre-spill time series may give an unsatisfactory result. For this reason the time series was divided into 5 yr sections (6 yr for the first section) and 1996 seasonal data was compared with seasonal data from each section. Individual sample results were used and the number of taxa, number of individuals, phyla diversity, and the proportions of holo- and meroplankton compared pre-and post-spill. The non-parametric Mann-Whitney U test was used to compare pre-and post-spill data and Table 1 shows the P values resulting from the tests. A significance level of 1% was chosen.

These analyses show that the post-spill spring samples did not differ significantly from any of the pre-spill periods for the categories compared. Some significant differences were noted in the summer, but only in the number of taxa recorded. Post-spill autumn data, however, showed many significant differences from pre-spill data, particularly in the number of taxa. It should be noted that with this number of analyses one or two results would be significant purely by chance, however the differences between post- and pre-spill taxa in autumn are so striking that they must be seriously considered. It was thought possible that because the 1996 data contained no November samples, whilst the pre-spill data was based on September, October and November, a bias might have been introduced. Repeating the analyses with only pre-spill September and October data, however, did not change the results, they were all still significant bar the 1986–90 test which was only just outside the range ($P = 0.012$).

Examination of the raw data revealed that the number of taxa recorded per sample in autumn 1996 was significantly *higher* than in previous years. One possible explanation could be that the windier autumnal weather re-suspended particles from the benthos which had a beneficial effect; autumn 1996 was

particularly windy and recurrences of oil on beaches was noted. Organic matter, including crude oil, has been reported as having a stimulatory effect on certain benthic organisms (Spies *et al.*, 1988). It is also possible that some factor completely unconnected with the oil spill was responsible, but as yet no other explanation is available. It should also be considered that the autumn zooplankton MDS plot did not show any noticeable changes for 1996. Since this analysis also considers the spread of individuals amongst the taxa it is a better indicator of the community changes. Nevertheless this significant result must be noted.

Conclusions

The long term trend in the data has, to some extent, complicated the before versus after analyses. It is possible that any impact from the spill might have increased the divergence of the 1996 community from the preceding years or actually buffered the natural temporal changes. An identical time series from a comparable control site would be necessary to conclusively rule out an impact. The majority of the analyses performed in this study revealed no detectable differences between the plankton that were sampled between February and October 1996 and previous years. We believe that the communities present in 1996 were not significantly impacted and were at one end of a temporal trend, however, some unusual events were noted which are summarized here,

1. Barnacle larvae were not recorded in the post-spill samples which, although this has happened in some previous years, could be a possible consequence of oil/clean-up operations on beaches close to the spawning time. Evidence from shore studies suggests that good recruitment of some barnacle species was apparent in 1996. It is possible that the larvae recorded by the CPR originate from other beaches,

TABLE 1

Values of P obtained when 1996 data were compared with each of the listed periods. Numbers in bold indicate significant results ($P < 0.01$)

	Zooplankton					Phytoplankton				
	70–75	76–80	81–85	86–90	90–95	70–75	76–80	81–85	86–90	90–95
Spring										
Number of taxa	0.451	0.391	0.725	0.867	0.846	0.795	0.35	0.333	0.042	0.952
Number of individuals	0.742	0.493	0.156	0.143	0.076					
Diversity	0.338	0.835	0.16	0.529	0.46					
Holo:meroplankton	0.277	0.426	0.399	0.939	0.464					
Summer										
Number of taxa	0.002	0.007	0.085	0.072	0.002	0.002	0.026	<0.001	0.147	0.409
Number of individuals	0.194	0.744	0.828	0.959	0.536					
Diversity	0.038	0.034	0.104	0.232	0.122					
Holo:meroplankton	0.983	0.831	0.968	0.887	0.283					
Autumn										
Number of taxa	<0.001	<0.001	<0.001	0.001	<0.001	0.011	0.048	0.467	0.336	0.029
Number of individuals	<0.001	0.014	0.02	0.021	0.004					
Diversity	0.311	0.206	0.267	0.48	0.485					
Holo:meroplankton	0.051	0.036	0.178	0.119	0.002					

perhaps in north Devon, or that the period of larval presence in the plankton was so short in 1996 that it was missed by the CPR

2. The post-spill spring zooplankton MDS analysis shows that the 1996 community may have been different to the previous year. The absence of barnacle larvae will have contributed to this result. Similar differences were noted between other years and as a long-term trend is apparent in the community, and the most common taxa showed no significant changes, this is not a dramatic change, rather a minor shift in species composition which may be attributable to another factor.
3. The number of zooplankton taxa recorded per sample in the autumn was significantly higher than in other years. A possible explanation has been offered, a re-suspension of benthic material by the autumn storms which was exploited by some groups, but again this could be an event unconnected with the spill.

In summary then, it would appear that the *Sea Empress* oil spill had no significant effects on the plankton of the southern Irish Sea. All of the common taxa showed normal levels of abundance, some taxa suggested by the literature to be susceptible showed no marked changes, and no striking changes were noted in the phytoplankton and zooplankton communities as a whole.

Whilst it is always hoped that an incident on the scale of the *Sea Empress* oil spill is never repeated, it must be expected that so long as similar cargoes are transported by ship the risk is ever present. Whilst the impact of an oil spill is visually apparent, as oil on beaches and oiled seabirds and mammals, often the consequences to invertebrate life are much less visible. The only way to determine any effects and monitor recovery is to know what the community was like before the incident, therefore, the importance of routine monitoring cannot be over-stressed. Whilst some areas of the British Isles are more at risk than others, in effect any part of the coastline could experience a similar incident, therefore, large-scale monitoring is essential. As these analyses have demonstrated, ongoing 'natural' trends in communities can give the wrong impression of change if communities at opposite ends of the trend are compared without the intermediate data. Long-term monitoring and data-banks are the only way that such information can be built up.

The collection and routine analysis of the CPR samples used in this study was supported by the UK Department of the Environment, and the Ministry of Agriculture, Fisheries and Food. This study was carried out for the Sea Empress Environmental Evaluation Committee with project guidance from the Environment Agency (Welsh Office). The authors are grateful to all past and present members of the CPR survey team and the ships' captains and crew for their contributions to this valuable dataset.

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