ISSN 0142-2499

MINISTRY OF AGRICULTURE FISHERIES AND FOOD

DIRECTORATE OF FISHERIES RESEARCH

AQUATIC ENVIRONMENT MONITORING REPORT

Number 17

Irish Sea Status Report of the Marine Pollution Monitoring Management Group

R.R. Dickson
Editor

Lowestoft 1987

MINISTRY OF AGRICULTURE, FISHERIES AND FOOD
DIRECTORATE OF FISHERIES RESEARCH

AQUATIC ENVIRONMENT MONITORING REPORT
NUMBER 17

Irish Sea Status Report of the Marine Pollution Monitoring Management Group

R. R. DICKSON (Editor)

LOWESTOFT 1987

R. R. Dickson, MA PhD, is a Grade 6 Officer (Senior Principal Scientific Officer) in the Aquatic Environment Protection Division, Section 3, of the Directorate of Fisheries Research. He is based at the Fisheries Laboratory at Lowestoft.

Aquat. Environ. Monit. Rep., MAFF Direct. Fish. Res., Lowestoft, (17) 83 pp.

CONTENTS

Introduction and Summary

R. R. Dickson (Chairman)

Ministry of Agriculture, Fisheries and Food
Directorate of Fisheries Research
Fisheries Laboratory
Lowestoft, Suffolk NR33 OHT

(a) Introduction

At its meeting in March 1985, the UK Marine Pollution Monitoring Management Group (MPMMG) agreed that a review should be undertaken of 'the state of knowledge on the Irish Sea in relation to the impact of pollution, monitoring information and monitoring needs'. Some other guidelines were also laid down which supplemented and, in one important way, changed these terms of reference. The review was not to consider radioactive pollutants since a separate Monitoring Management group has responsibility for those. Contributors were to be from the UK only at present but with the intention of expanding the review into a full international study at some later stage following review by the ICES Advisory Committee on Marine Pollution, the Working Group on Shelf Seas Hydrography, the Working Group on Irish Sea/Bristol Channel Fisheries, and others. The review was to be structured along the guidelines recommended by Bewers *et al*. (1982) for the preparation of regional assessments, which had the effect of broadening the terms of reference to include not only pollution but past, present and prospective anthropogenic effects on physical oceanography, pollution and biology. No specific deadline was laid down but it was suggested that the first draft should be available in about a year.

Most of these terms of reference have been met in compiling this report. However, there are some differences. In contrast with Bewers 'guidelines' we stressed completeness rather than brevity for its own sake and leave it to subsequent reviewing groups to recommend deletions as well as additions. Second it is not, in the usual sense of the word, an 'assessment' but a status report; the difference is of course that the former implies that adequate knowledge exists to make the assessment whereas the latter makes no such claim and may merely, for example, identify remaining areas of ignorance. The study is *not* an attempt to summarise all that we know about the Irish Sea, but to summarise relevant present knowledge in the three main subject-areas of physical oceanography, pollution and biology and to identify uncertainties and gaps in our knowledge. By 'relevant' we mean that a knowledge of one subject area is important to the understanding of another, in a way that provides some measure, however qualitative, of the anthropogenic contribution in any one of these subject areas. Needless to say, if a particular worrysome trend or fluctuation can be shown to be entirely natural, then that too quantifies the anthropogenic contribution (as zero).

Anthropogenic effects are, therefore, the key reason for the present study and a summary of our conclusions in each subject area is given below.

(b) Summary

(i) *Physical effects* While the physical environment is of great relevance to the observed distribution of pollutants and biological productivity, direct anthropogenic effects on physical oceanography are understandably slight. The principal potential effect is via the influence on the density field (and hence on the density-driven circulation) of the various coastal barrage schemes that have been mooted in the past, since these could significantly lower the freshwater input at the coast. None of these schemes is proceeding at the present time and even if they were, it is unlikely that all would go ahead together.

(ii) Biological effects Under the 'general biology' heading the anthropogenic effects may be summarised as follows. For general phytoplankton and zooplankton we have no reason to suppose that the observed fluctuations and trends are anything but natural. For what are currently described as 'abnormal plankton blooms' anthropogenic influences have been claimed from time to time, but we describe these claims as unconfirmed or speculative at present. When we consider the benthos, anthropogenic effects become both obvious and significant but are of restricted distribution, close to urbanised estuaries, dredging and dumping grounds; more widespread changes in the benthos have of course been noticed, and although regional variations may include an anthropogenic contribution (directly, through intensive fishing activity at certain locations and times for example, or indirectly through the changes in the level of predation on benthos due to fishing activity) there is no evidence that the observed variations are due to anything other than natural changes in the environment. As in other areas of the shelf the Irish Sea has sustained its share of significant, demonstrable and widespread anthropogenic effects on fish stocks through commercial fishing. It can be shown that although all the major demersal fish are being exploited at levels of fishing mortality greater than is needed to take the maximum yield per recruit, there is no compelling evidence that total yields have diminished as a result of heavy fishing. Due to their low fecundity, high age at first maturity and large size at hatching, skates and rays serve as a sensitive indicator of overfishing; though the common skate has been fished to local extinction in the Irish Sea, the ray species have, encouragingly, maintained a high, steady catch rate. Fish disease prevalence is often held to be an indicator of environmental stress. In multi-aim cruises up to 1985 the prevalence of disease appeared to be no higher in the Irish Sea than in the North Sea, but these opportunistic cruises were not sufficiently standardised to comment usefully on trend. The first dedicated fish disease cruise in the area in 1986 did deploy a sufficiently focussed observing effort to resolve the prevalence of a limited range of epidermal diseases in a limited range of species unambiguously. However, even if and when a series of such cruises have been mounted, it will be extremely difficult to distinguish natural temporal and spacial changes from the percentage incidence that may be due to pollution. The anthropogenic contribution to fish disease in the Irish Sea is therefore best described as unknown at present and may be unknowable. The few available analyses of seal carcasses (found dead) suggest that the Irish Sea seal populations are accumulating heavy metals and other persistent contaminants but not at concentrations likely to cause death. Seal culls do not take place. Finally, the text describes a range of potential or actual anthropogenic effects suffered by various components of the bird population at various places and times, ranging from fatalities attributed to lead pollution, eggshell thinning possibly due to PCB's, mass mortalities of auks due to oil spills, botulism attributed to refuse-feeding, and the potential restriction of habitat if any of the barrage schemes go ahead. Though many of these incidents have been both dramatic and alarming, they have so far presented a temporary rather than a permanent threat to the affected bird populations.

(iii) Chemical contamination and inputs While anthropogenic effects and influences of various kinds have been identified in (i) and (ii) above, they have, by and large, been of relatively minor importance or if more serious, their effects have been either localised and/or temporary. Section B describes a further range of anthropogenic effects in listing a wide range of pollutant inputs to the Irish Sea. Accepting that any sea area has an assimilative capacity for almost any potentially harmful substance, many of these inputs are more properly described as contaminants rather than pollutants and fall into much the same non-serious/localised/temporary category as others listed above.

However, Section B also includes the case of Liverpool Bay where the effects of contaminant inputs are anything but localised and temporary. There are two grounds for concern there: first the general concern that multiple-loading by individually - 'harmless' contaminants may still result in the type of environment that we rather vaguely describe as 'under stress'. Second, and more particularly, Liverpool Bay does support concentrations of mercury in fish which are close to the Environmental Quality Standard laid down under EEC Directive 82/176/EEC which states that "the concentration of mercury in a representative sample of fish flesh chosen as an indicator must not exceed 0.3 mg kg^{-1} wet flesh".

The various components of 'the mercury problem' are as follows.

- First, this Greater Liverpool Bay area is a relatively shallow, relatively non-dispersive 'backwater' of the Irish Sea, the area with the longest flushing time, floored in places by muddy sediments with a high adsorptive capacity for contaminants and with an estuarine (coastward) deep mean circulation tending to return dumped material to its source rather than export it out of the region.

- At the coast the most heavily urbanised and industrialised sector of the Irish Sea coastline contributes mercury through industrial and sewage discharges to the estuary (where they adsorb onto sediments), through river discharge and dumping of dredge spoil (which, transfers these sediments to the Bay), and through direct offshore dumping of sewage sludge, which short-circuits the river-route.

- Since these industrial and urban practices have been in operation for decades, the 'flywheel' effect of the accumulated mercury 'reservoir' in sediments of the Bay must represent a further source of exposure to fish that would persist even if the present coastal inputs were stopped completely.

- The spin-down time for this flywheel effect is unknown, though major reductions in all controllable mercury inputs to the Bay since the early 1970's have been accompanied by a reduction in the mercury body-burdens of fish. So over this period the reservoir has contributed to, but does not appear to have dominated, mercury uptake.

- The reduction of Hg in fish flesh from the vicinity of the dumpsite follows the decline in the totality of Hg inputs to Liverpool Bay. Mercury body-burdens are, therefore, assumed to reflect exposure from the totality of inputs to the Bay plus the reservoir effect of Bay sediments. However, we do not know how the observed fish body burdens are partitioned in terms of the various sources and if we reduce a particular input or source we do not know how much of the problem we are dealing with.

- To some extent this is academic since (a) mercury body-burdens are close to the EQS and (b) there is limited scope for further reductions in inputs in the short term if port and industrial facilities are to be maintained. In such a situation you reduce where you can.

- Successive stepwise reduction of 0.8, 1.4 and ultimately 4.2 kg d^{-1} in the long-term (10 years) outlook period are both possible and desirable to increase the margin of safety between the levels in fish and the EQS limit, and even if reductions in inputs are maximised the reservoir already present will ensure that the decline of Hg levels in fish will be slow.

- If in fact industrial or urban expansion prevents the achievement of maximal reductions in inputs, some relocation of part of these inputs may be necessary to a site which lies outside the present contaminated zone, whose own characteristics would neither permit the physical or biological transfer of mercury back to Liverpool Bay nor permit mercury levels to approach the EQS at the second site itself.

- In this context it is instructive to note that the 'present contaminated zone', as defined by the most important single criterion (mercury levels in fish), is not restricted to the vicinity of the dumpsites but occupies the whole of the area south and east of the Isle of Man, presumably because the fish affected range freely over this area, though concentrations decrease somewhat towards the north.

This summary has emphasised the Liverpool Bay mercury problem simply because - within our restricted terms of reference - it is arguably the most important single problem in the Irish Sea under any of the three subject areas considered here. Evidence for the secondary concern that Liverpool Bay is showing more general signs of environmental stress is of course much less tangible and the conclusion itself much more subjective. The point worth making here is that any measure of what constitutes 'environmental stress' should include consideration of radioactive as well as non-radioactive contaminants. While the reasons for our present, more restricted, brief are understood and accepted by the group, it nevertheless recommends that due consideration be given to organising this complementary study.

SECTION A. PHYSICAL OCEANOGRAPHY

R. R. Dickson[1], J. A. Durance[1], M. J. Howarth[2] and E. Hill[3]

1. Ministry of Agriculture, Fisheries and Food
Directorate of Fisheries Research, Fisheries Laboratory,
Lowestoft, Suffolk NR33 OHT

2. Institute of Ocanographic Sciences, Bidston,
Birkenhead, Cheshire L43 7RA

3. University College of North Wales
School of Biological Sciences
Menai Bridge, Anglesey, Gwynedd LL59 5EH
North Wales

1. General description

1.1 Volume and bathymetry

For the purpose of the present study, the term 'Irish Sea' is taken to mean the semi-enclosed sea area bounded by latitudes 52° and 55°N or from St Davids Head to the Mull of Galloway (Figure 1). West of ~ 4.5°W this sea area forms a deep channel 300 km in length and 30-50 km in width, with a minimum depth of 80 m and a maximum of > 275 m at Beauforts Dyke in the North Channel (Figure 1). The deep trough of the western Irish Sea is open-ended, connected to the Celtic Sea via St George's Channel in the South and the Malin Shelf via the North Channel in the north; it receives Atlantic water influences and inputs through both entrances. To the east, the deep channel is fringed by two relatively shallow embayments of depth < 50 m - Cardigan Bay in the south and the Eastern Irish Sea in the north. The width of the Irish Sea varies between 75 and 200 km but decreases to 30 km in the North Channel. The total volume of the Irish Sea, thus defined, is 2 430 km^3 equivalent to only 6% of the volume of the North Sea; 80% of this volume lies west of the Isle of Man.

1.2 Inputs and outputs

'Oceanic' inflow to the Irish Sea via St George's Channel is variable in time; our first estimate of this is due to Bowden (1950) who deduced a net northward transport of 2.2 km^3 d^{-1} from the salinity distribution in the western Irish Sea (Figure 2).

We have a wider range of estimates of net outflow via the North Channel. Based on Bowden and Hughes' 1961 study, telephone-cable estimates for the period 1970-81 suggest that the net flow through the North Channel was as often inward as outward. More modern estimates are based on analyses of Cs distributions and their changes with time. Jefferies, Steele and Preston (1982) deduce a net northward flux of 2.7 km^3 d^{-1} from November, 1974-January 1976 but rising thereafter 3-fold to the ~ 8 km^3 d^{-1} in 1977-78, which is similar to the 7.8 km^3 d^{-1} suggested by McKay and Baxter (1985) for the period 1978-81.

While these Cs-based estimates and the broadscale distribution of Cs to the west of the British Isles give confidence that the long-term net transport through the North Channel is unambiguously 'outward', they cannot provide information on the separate outward and inward components of flow which exist side by side within the North Channel. Craig (1959) suggests 5 km^3 d^{-1} outward compared with 0.5 km^3 d^{-1} inward along the Irish coast, but the first actual measurements were those by MAFF in 1984-85. The successive 11- and 6-mooring deployments over 45 days in March-June 1985 (Figure 3) provided figures of 'out' = 10.3 km^3 d^{-1}; 'in' = 3.0 km^3 d^{-1}; 'net outward' = 7.3 km^3 d^{-1}. While these are in good agreement with the Cs-based estimates quoted above, it must be stressed that these are relatively short-term measurements and that a 99-day single-mooring deployment in July-November 1984 showed a predominantly southward flow through the deep Beaufort Dyke in the east-central part of the Channel suggesting a large-amplitude, short-term variability in addition to the long-term inter-annual variability described above.

In the absence of sufficient long-term measurements, it is tentatively concluded that the net transport through the North Channel is of the order of 2-8 km^3 d^{-1} in the long-term mean but that much of the throughput may occur in short-periodic bursts of outflow peaking especially during winter; i.e. a variable outflow through the deep east side of the Channel is partially balanced by a more steady and directionally very stable (but lesser) inflow along the Irish Coast.

In the modelling of residence time to be described below the values for the northward water flux through the Irish Sea are assumed to be 3.0 km^3 d^{-1} pre-1976 and 6.6 km^3 d^{-1} post-1976.

For an estimate of coastal freshwater input, Bowden (1955) suggests a total river discharge of 6.2 km^3 yr^{-1} and 24.9 km^3 yr^{-1} along the western and eastern margins of the Irish Sea respectively, coupled with a direct addition (precipitation minus evaporation) of 10.6 km^3 yr^{-1} to give a net freshwater input of 41.7 km^3 yr^{-1}. Since the main river discharges are grouped along the English coast (Dee, Mersey, Ribble and Solway Firth) the lowest salinities (~ 32-32.5^0/oo) are found along the eastern Irish Sea (Figure 2). More recent values of annual discharge for the main river inputs are provided in ICES Cooperative Research Report No. 77 (Anon., 1978) for each sector of the Irish Sea coastline and are annotated in Figure 2. These more recent estimates are in broad agreement with Bowden's (1955) figures but suggest a smaller relative influx along the English and Welsh coasts and a larger relative influx along the Irish coast. As a result, the ratio of English and Welsh to Irish inputs falls from 4:1 (Bowden) to 2:1. [Table 12 contains the most recent discharge figures available but for only a part of the coastline (England and Wales). While these figures differ in detail from those listed in the ICES report, the total England and Wales discharge differs by only about 2% from that quoted by ICES, (Anon., 1978) so that the above statement remains valid].

1.3 Sediments

No consistent representation of surficial sediment-type is yet available for the whole area covered by this study. However the Institute of Geological Sciences (IGS), Continental Shelf Division, Keyworth, Nottingham have kindly provided published maps for three areas of the Irish Sea, an unpublished draft of a fourth area and the raw survey data for the fifth. In Figure 4, this detailed information has been simplified into 6 broader categories of sediment-type to provide a preliminary description of the whole area under review. These categories comprise the three end-members mud, sand, and gravel plus 'muddy' (sM, (g)M, (g)sM and gM) 'sandy' (mS, gS (g)S, (g)mS and gmS) and 'gravelly' (mG, msG and sG) sediment types.

Broadly speaking, the gravelly sediments extend from a widespread distribution in St George's Channel northwards through the central Irish Sea and tapering out in the North Channel. Sandy sediments flank the gravels to east and west, with the exception of two main areas of muddy sediments which extend south west of the Isle of Man and south from St Bees Head and which reflect both the weakness of tidal currents in these areas (Figure 5) and (in part) the availability of suitable source-material (glacial clays). A third area of muddy sediments in Liverpool Bay, not included in the IGS charts but identified by MAFF survey data, is of much smaller extent but great importance to the fate of metals arising from the dumping of sewage sludge and dredge spoil in that area.

The principal sand transport paths are illustrated in Figure 6 (from Stride, 1973). From bed load partings in the North Channel and in St George's Channel west of the Lleyn Peninsular, sediments transported into the Irish Sea and then eastward toward Liverpool Bay and the Solway are in good agreement with Pingree and Griffiths' (1979) description of the distribution of mean bottom stress due to M_2 and M_4 tidal currents. Particles fine enough to be brought into suspension will be transported as suspended sediment in the watercolumn rather than as bedload. A description of the mean residual current paths in the upper and lower water column is provided in Section 3.

Apart from the dumping of dredge spoil, (whose effects are described in Section B of this report) the primary anthropogenic effect on sediment is that of marine aggregate extraction, but in the Irish Sea this activity is confined to the Liverpool Bay area, takes place on a relatively small scale and is declining:

Year	ICES Areas A5 and A6 Aggregate extraction (tonnes)
1982	659 229
1983	623 582
1984	588 190
1985	484 965

Over the years these limited operations appear to have caused relatively little interference with fishery or environmental interests.

Of possible future significance to aggregate extraction in the eastern Irish Sea is the proposed construction of the Conwy Tunnel. Prospecting has been carried out and suitable material identified in the Conwy Bay area, but no extraction license has yet been applied for or issued.

2. Dynamics

Three primary forces are responsible for the movement of water within this sea area, the tides, the weather and water density differences (Bowden, 1980). In the Irish Sea, tidal movement with periods of a few hours to one day, is the most energetic. However, the amplitude of the tidal current has a large spatial variation (Figure 5) which determines many of the processes and distributions within the sea (mixing, fronts, sediment transport, sediment distribution). Dynamically, the weather causes four main responses, largely through the action of the wind - surface waves, with periods from 3 to 15 s, inertial currents, with a period of ~ 15 hours, storm surges, with periods of 2 to 10 days, and residual or long-period currents. The weakest response is to water density differences between the saline oceanic inflows and freshwater input by river discharge. Although the resulting currents are weak the density effects are persistent and produce a major contribution to the residual especially in the eastern Irish Sea (see Section 3).

2.1 Tides

The tide propagates into the Irish Sea from the Atlantic Ocean through the St George's and North Channels (Robinson, 1979). The two branches meet to form a standing wave to the south west of the Isle of Man which is, therefore, an area of very weak tidal currents (< 25 cm s^{-1}; Figure 5). As elsewhere in seas around the British Isles, the twice-daily tide is the dominant tidal component. This has an amphidrome just outside the North Channel between Islay and the Mull of Kintyre and a degenerate amphidrome near Courtown on the Irish side of St George's Channel. The occurrence of the degenerate amphidrome implies that the majority of the tidal energy flux into the Irish Sea is through the St George's Channel. This is largely dissipated in the St George's Channel, off Anglesey and off the Mull of Galloway. In all three areas tidal currents are strong - the mean spring amplitude exceeds 120 cm s^{-1}, compared with less than 40 cm s^{-1} to the south west of the Isle of Man. A reflection of the presence of the degenerate amphidrome is that the tidal range is less on the Irish side (Sager, 1963; Figure 7); the maximum range occurs on the Lancashire and Cumbrian coasts where the mean spring range is 8 m. The daily tides are small by comparison, current amplitudes are less than 10 cm s^{-1} everywhere, again with a minimum south west of the Isle of Man. Higher frequency tides are generated in shallow water and where there are sudden changes in bathymetry/topography. The largest component is the four-times-daily which has mean spring current amplitudes up to 15 cm s^{-1} to the east of the Isle of Man, but locally these high frequency currents can be enhanced near headlands, islands and estuaries.

2.2 Internal/inertial motion and stratification

For internal motion to exist, some degree of vertical density structure is necessary. Then energy can occur in the period range from the local inertial period (15 h) to a few minutes depending on the density structure. Thus, though the degree of stratification is relevant to many aspects of the present study, it is described here where we encounter its relevance for the first time.

Density structure is caused either by summer heating at the sea surface or by the input of fresh water from rivers in winter and spring. In most areas of the Irish Sea, tides are sufficiently energetic to mix in the density deficit and create a vertically homogeneous water column throughout the year. The main exception is the area south west of the Isle of man where increased water depth and weak tidal streaming prevent the generation of sufficient turbulent energy to maintain vertical mixing against the surface buoyancy flux in summer and a seasonal thermocline is established to a depth of 20-30 m between April and October. The horizontal transition between stratified and mixed water occurs over a frontal zone some 5-10 km wide, the location of which conforms well to the critical value of the parameter $s = \log_{10} \frac{h}{c_D u^3}$, where h is the mean water depth and u is the tidal stream amplitude (Pingree and Griffiths, 1978; Figure 8). A frontal system also exists in the shallow Cardigan Bay area in summer but is highly susceptible to destruction by wind mixing.

The eastern Irish Sea forms the second main region of significant stratification. In this case the haline contribution is the more important, so that the stratification is most marked in winter and spring, especially near the main rivers entering along the Lancashire and Cumbrian coasts. Thermal stratification may also develop in Liverpool Bay in summer but the location of the thermohaline front is not well predicted by the $\frac{h}{u^3}$ criterion. The frontal position is greatly affected by the local windstress but is always confined to a region east of 4°W (Foster _et al._, 1985).

In the main stratified patch south west of the Isle of Man in summer, both inertial currents and internal motion have been observed. In these measurements the inertial currents (rotary currents with inertial period) had near-surface speeds up to 20 cm s^{-1}. The internal motion was at the semi-diurnal and quarter-diurnal tidal frequencies and was manifest by vertical movement of the thermocline (Sherwin, 1983). Interest arises concerning the source of the internal motion, which must be local since the region is surrounded by vertically well-mixed water.

2.3 Surface waves

Surface waves depend on the duration and fetch of the wind. Since the Irish Sea is sheltered with only two relatively narrow 'windows', along the axes of the St George's and North Channels, the majority of waves are locally generated, of fairly short period and hence steep. The maximum 50-year return value of the mean zero-up-crossing period varies between about 10 s within the Irish Sea to about 15 s at its outer entrances. Similarly, the 50-year return value of the significant wave height varies between about 8 m within the Irish Sea to about 12 m at its outer entrances. The effect of waves on other processes will be significant during storms and especially on sediment movement, in the shallow areas of the eastern Irish Sea.

2.4 Surges

Surges are caused by storms, both through the action of wind stress at the sea surface piling up water at a coast and through the inverse barometer effect associated with atmospheric pressure variations. Once generated, storm surges propagate like tidal waves. Hence, Irish Sea surges have an external component, propagating via the St George's and North Channels, and a locally generated component, each of comparable significance (Heaps and Jones, 1979). Surges and tides can interact leading to oscillations with a twice-daily frequency in the tidal residuals. In the Irish Sea this interaction appears to be associated with the surge's external component. The largest surges are generally associated with storms tracking eastward between Inverness and Shetlands. Maximum surge levels of about 2 m are predicted to be on the Lancashire and Cumbrian coast, with surge levels between 1.25 m and 0.75 m predicted on the Irish coast and across the St George's Channel (Flather, in press). Since the Irish Sea is semi-enclosed the associated currents are weak, arising both directly from the wind drag at the sea-surface and also related to the sea-surface gradients. The former are limited to a surface layer of the order of 10 m thick, with a maximum speed at the surface of about 3% of the wind speed. The latter are predicted to have a maximum depth-mean current away from the coast of 50 cm s^{-1} (Flather, in press). Their direction is largely determined by topography not by wind. In the eastern Irish Sea the prevailing storms generate an anti-clockwise movement of water, in opposition to the longer period movement. Transport through the North Channel is at least partly correlated with the component of the wind blowing along the channel's axis whilst sea level variations there are correlated with the wind blowing perpendicular to this, parallel to the Scottish and Irish west coasts.

3. Residual circulation

The time-averaged circulation of the Irish Sea is relatively weak and with no particularly coherent directionality over large areas. It is driven by 4 main forces; meteorological (wind stress and atmospheric pressure gradients), spatial variations in sea-water density, oceanic or far field (transmitted by a pressure gradient), and non-linear tidal (Howarth, 1984). Since each of these forces may vary it is not surprising that the internal circulation of the Irish Sea will also vary according to which force is dominant, and this has in the past supported some controversy as to the nature of the mean circulation.

Numerical models (e.g. Heaps and Jones, 1977; Heaps, 1979; Proctor, 1981) are therefore necessary to resolve the importance of the different driving forces. The models show that the flows through the Irish Sea caused by 3 of the driving forces (non-linear tide, density and mean wind-stress) are each northward, of similar magnitude and each about the size of the total observed flow. Regarding the fourth driving force (elevation gradient), the models show that east-west gradients are not associated with flows through the Irish Sea, in contrast to north-south gradients where even a small gradient will produce a large flow.

In the tentative scheme of surface and bottom currents presented here (Figure 9) the time-averaged flow through the western Irish Sea is described as principally north-going, in agreement both with the above model results and with direct current measurements and radioactive tracers distributions which confirm a net 'outward' transport through the North Channel.

In Figure 9, a south-going residual is shown along the Irish coast. We know from measurements in the western side of the North Channel that this southerly coastal flow is extremely persistent (e.g. Figure 10) but it is not known how far this current penetrates into the Irish Sea before turning to join the main northwards flow. A narrow southward-flowing jet is expected, on dynamical grounds, to run along the western Irish Sea front, but attempts to confirm this feature from observations have so far failed.

In Figure 9, the eastern Irish Sea is shown to be characterised by a southward drift off St Bees Head and a two-layer circulation in Liverpool Bay. Our evidence for these features is as follows:

The first of these flows is characteristically suggested in maps of caesium distribution from Sellafield (e.g. Figure 11, for May 1978), and long-term current measurements by MAFF off Sellafield confirm its persistence (Figure 12). In Howarth's (1984) review of model experiments, this south-going flow along the Cumbrian coast is suggested to be derived from non-linear tidal forcing.

The circulation of the greater Liverpool Bay area is complex, variable and depth-dependent and has long been the subject of controversy. Essentially Williamson (1952) described a clockwise mean gyre in the surface layers of this area based on plankton distributions while Ramster and Hill (1969) suggested an anticlockwise circulation based on direct current measurements. These conflicting theories were later resolved by the model experiments of Heaps and Jones (1977) which showed that a weak but persistent, clockwise circulation is set up by density forcing whereas the anticlockwise circulation tends to be forced through the normal sequence of wind changes accompanying the passage of depressions. Accordingly, the clockwise flow is found during periods of light winds, but at windspeeds > 5-10 m s^{-1} the wind-induced anticlockwise circulation tends to dominate. The situation is further complicated by the presence of a two-layer estuarine flow-pattern in Liverpool Bay. Most direct current measurements, tracer studies and computations based on hydrographic data show that bottom currents flow dependably towards the coast whereas surface currents (if less dependable in the pattern of their circulation) tend to flow westwards away from the coast.

Thus, although the circulation patterns illustrated in Figure 9 are intended to represent merely the average tendency of a very variable circulation, these patterns do include elements of persistence and predictability. The greatest 'unknown' still concerns the controversial question as to whether the main northwards flow through the Irish Sea passes to the east or west of the Isle of Man. Early conclusions by Bassett (1910) suggested that the main flow passed to the east, but the basis of his conclusion (the distribution of isohalines) is not now regarded as a true indicator and such measurements and simulations as we now have suggest that the main flow passes to the west of the Isle of Man.

4. Flushing time

The large variation in the flow through the Irish Sea with the possibility of net southerly flow through the North Channel lasting for periods of months, makes the estimation of residence time unreliable. The fate of any short-term release of a contaminant is dependent on actual circulation conditions at the time of release and for a few months thereafter. In the Eastern Irish Sea the two-layer flow and dependence of the surface currents on variable wind influence makes the problem more difficult. Nevertheless, there is a considerable amount of data available on the flushing of the caesium effluent from Sellafield. Indeed, much of evidence for the long-term residual circulation described above originates from this data.

A simple box model has been used by MAFF to study the dispersion of caesium and the flows between boxes were adjusted to give the best fit to the observed distribution of caesium. The arrangement of these boxes is shown in Figure 13, together with the net flows between boxes which gave the best fit to observations for the years up to September 1976. After this date a greatly increased flow was required to achieve the best fit to the data, and this is also shown in the figure. Mixing between adjacent boxes has been ignored in the estimates of flushing time because its effectiveness as a means of removing contaminants depends on the concentration gradients of the contaminant. The inclusion of this mixing would not greatly reduce the residence times shown in the figure.

5. Anthropogenic effects

There are no existing large-scale effects on the physical oceanography which can be attributed to human activity. Dredging activities and the construction of ports may have produced local changes in the circulation but generally these works are on a scale too small to affect the large-scale water movements.

In the late 1960s and early 1970s a number of barrage schemes were studied. Freshwater storage schemes were proposed for the Solway, Morecambe Bay and the Dee and a tidal power generation scheme for the Mersey (Water Resources Board, 1966a, b, c; Jackson, 1977; Marinetech N.W., 1983). The largest schemes studied in the Solway and Morecambe Bay could abstract $7 \times 10^8\ m^3\ yr^{-1}$ of fresh water each, and since this represents a significant proportion of the fresh water run off in the area and would be exported to the industrial regions of south Lancashire, a small but detectable increase in the salinity of the north-eastern Irish Sea might be expected, possibly with changes to the density field and, hence, to the density-driven circulation.

Generally, the effects of barrages are to reduce tidal stream velocities in the vicinity and, hence, some silting of nearby harbours. Changes in tidal range need to be assessed for each scheme by the use of extensive numerical models. Predicting effects using models of the local area only can produce erroneous results.

In the case of one scheme <u>outside</u> the Irish Sea (The Severn Barrage), a considerable modelling effort showed that the barrier would affect tidal ranges not only close to it in the Bristol Channel, but also further afield in the Irish Sea (Owen, 1979; Heaps, 1982).

None of the schemes mentioned above is proceeding at the present time, though the Severn scheme is currently being reconsidered, and the feasibility of a barrage scheme across the Mersey itself is currently being examined.

SECTION B. CONTAMINANTS (NON-RADIOACTIVE)

J. E. Portmann[1], D. J. Harper[1], P. W. Balls[2], C. Pattinson[3], P. C. Head[4], J. G. Parker[5] and R. J. Ramsay[6]

1. Ministry of Agriculture, Fisheries and Food
   Fisheries Laboratory
   Burnham-on-Crouch, Essex CMO 8HA

2. Department of Agriculture and Fisheries for Scotland
   Marine Laboratory
   P.O. Box 101
   Aberdeen AB9 8DB
   Scotland

3. Welsh Water
   Tremains House
   Coychurch Rd
   Bridgend
   Mid-Glamorgan CF31 2AR

4. North-West Water
   Dawson House
   Great Sankey
   Warrington WA5 3LW

5. Department of Agriculture for Northern Ireland
   Fisheries Research Laboratory
   38 Castle Roe Road
   Coleraine
   County Londonderry
   (Present address: Shell Exploration and Production
   1 Altens Farm Rd
   Nigg
   Aberdeen)

6. DOE (NI)
   Environment Protection Division
   Calvert House
   23 Castle Place
   Belfast BT1 1FY

1. Introduction

Information on chemical quality of water, biota and sediments from the Irish Sea is limited in both quantitative and geographical coverage terms. This is surprising in view of its semi-enclosed nature, the number of marine institutes bordering it and the politically sensitive nature of some of the activities which influence the quality of the Irish Sea waters, sediments and biota. Most data relate to the north-eastern section and to Liverpool Bay in particular. Some data exist for Cardigan Bay but they are not recent and do not cover the area in sufficient detail to permit an accurate assessment of the present state of these areas. Few data exist for the western and southern sectors.

An important consideration when interpreting data on the distribution of chemical contaminants in the Irish Sea is the occurrence of lateral and vertical density discontinuities. The latter, especially, develop seasonally and can persist throughout the summer and autumn. These fronts hinder the offshore transport of contaminants and permit enhanced concentrations to develop on the inshore side, (Foster, 1984a; Foster et al., 1978, 1982); such effects are particularly noticeable on the eastern side in the Liverpool Bay area.

2. Nutrients and dissolved oxygen

Almost all the available information on dissolved oxygen (DO) levels indicate that the area is well oxygenated. Generally, when subsaturation levels have been encountered, these have been attributed to breakdown of algal blooms. Only very rarely have low levels been encountered in Liverpool Bay close to the sewage sludge dumping ground, and whether such occasional low levels arise as a consequence of dumping or algal blooms, or a combination of the two, with the former contributing to the occurrence of the latter, is not known. They have, however, only been recorded when the water column was strongly stratified and on only one occasion were low DO values found in bottom waters at the dumping ground.

To ascertain the general state of nutrient concentrations in a body of water the data used must refer to winter values when primary productivity is at a minimum. Most of these data apply only to the northern Irish Sea. However, despite being collected over a period of about 20 years they are broadly in agreement.

Irish coastal waters are relatively enriched in silicon whilst eastern waters are enriched with anthropogenically derived nitrogen and phosphorus (Foster, 1984b). In open waters, nitrate-nitrogen concentrations are relatively homogeneous at about 5 to 7 μg at NO_3 -N l^{-1} increasing to about 11 μg at NO_3 -N l^{-1} close to land, with even higher concentrations of 29 to 36 μg at NO_3 -N l^{-1} in areas such as Liverpool Bay and the mouth of the Mersey Estuary. A similar pattern is exhibited by phosphorus, 0.96-1.29 μg at PO_4 -P l^{-1} being the normal range with concentrations of up to 2.26 μg at PO_4 -P l^{-1} being recorded in Liverpool Bay and south of St Bees Head (Balls, in press; Jones and Folkard, 1971; Foster, 1984(a)(b)). The elevated levels of both nitrogen and phosphorus nutrients found in Liverpool Bay can be attributed to estuarine inputs, particularly those from the Mersey estuary, whereas the elevated phosphate levels off St Bees Head are almost certainly the result of discharges of phosphate from an industrial discharge.

Generally, good correlations are obtained for nutrient/salinity plots, although for nitrate two distinct mixing curves were apparent (Foster, 1984(a)(b)). Although winter nitrate concentrations can be as high as 40 μg at NO_3 -N l^{-1} in the inner reaches of Belfast Lough, levels in the outer Lough are usually close to those found in the open Irish Sea.

Somewhat wider variations are shown in silicate concentrations. Away from fluvial input the distribution of silicate is fairly constant at 5.3-7.4 μg at SiO_2 -Si l^{-1}. Concentrations show very marked elevations closer to riverine sources e.g. in the Solway Firth and Morecambe Bay (up to about 14 μg at SiO_2 -Si l^{-1} (Jones and Folkard, 1971)) and in Liverpool Bay (up to 25 μg at SiO_2 -Si l^{-1} (Foster, 1984(a)(b))).

In Liverpool Bay, seasonally averaged nutrient concentrations reveal the anticipated winter maxima and summer minima (Table 1). The effects of biological uptake are also evident in salinity/nutrient correlation coefficients (Table 2). An accumulation of nutrients has been observed to occur in winter inside the front separating Liverpool Bay and offshore waters.

3. Metals

Reliable data for trace metal concentrations in Irish Sea water are very limited. A selection of the published data is presented in Table 3 and it is evident that reported concentrations have declined over time. Few workers consider that the decline is real and most attribute the changes to markedly improved sampling and analytical techniques, brought about through the recognition of the need for ultra clean conditions to avoid contamination. A pattern is, however, now beginning to emerge from the most recent surveys conducted by MAFF and DAFS, viz, higher concentrations tend to occur in the eastern, less saline parts of the Irish Sea and in particular in Liverpool Bay and off the Lancashire coast.

In the following paragraphs, comments are made on the relative distribution of some of the metals; these comments are based primarily on data generated in the last two or three years by MAFF and DAFS scientists (D. J. Harper, in preparation; Balls, 1986) and refer to dissolved metal concentrations unless otherwise stated. Where data from other sources are used references are cited.

3.1 Cadmium

Typical concentrations of cadmium in the less contaminated areas appear to be of the order of 10-15 ng l^{-1} with levels increasing towards the coast and in the north east to 20-40 ng l^{-1}. Data reported by Preston (1973) suggest that average concentrations of cadmium were higher in the western sector of the Irish Sea than in the east, but there are no recent data to confirm this. Two areas appear to be subject to sources of anthropogenically derived cadmium. Unusually high concentrations of cadmium have been found in Liverpool Bay (30-140 ng l^{-1}) and a similar range of concentrations was encountered off St Bees Head. In the latter case, an industrial discharge in the vicinity of Whitehaven may be responsible. In the former, the influence of both the the River Mersey and the Ribble was very obvious along the offshore transects, although the highest concentrations were found over the dredge spoil site and it is known that some of the dredge spoils do contain unusually high concentrations of cadmium which is likely to be released, at least initially, on disposal.

3.2 Lead

For lead, a concentration in open waters of 15-20 ng l^{-1} seems to be normal; closer to land however, and in the north-eastern sector, concentrations rise to 30-40 ng l^{-1}. Concentrations in Liverpool Bay (50-70 ng l^{-1}) were higher than those found offshore. They were not, however, as high as those encountered just south of the Irish Sea in the Bristol Channel. Here, exceptionally high levels (100-1000 ng l^{-1}) were recorded.

3.3 Mercury

The concentration of dissolved, reactive mercury in open waters appears to be between 0.5 and 1.5 ng l^{-1}. In Liverpool Bay the levels of dissolved, reactive mercury are in the range 1.0 to 2.0 ng l^{-1}. Total, dissolved mercury data are only available for Liverpool Bay and concentrations of 2 to 4 ng l^{-1} have been found here. Recently, Campbell et al. (1986) have reported concentrations as high as 40 to 75 ng l^{-1} in the Mersey Estuary and somewhat lower levels in Liverpool Bay. The MAFF surveys have recently produced data for total (i.e. reactive, dissolved and particulate) mercury concentrations in seawater. In Liverpool Bay concentrations of 3.0 to 24 ng l^{-1} were found, the highest levels being found around dredge spoil dumping ground, site Z, over the Burbo Bight and off the mouth of the Ribble.

From the data obtained so far, trends in the distribution of mercury around areas of expected inputs have been apparent on the basis of analyses of unfiltered seawater. This suggests that the distribution of mercury in coastal waters is governed by particulate loading.

3.4 Copper

Although concentrations have been reported for various areas in the Irish Sea the only reliable data on copper available refer to the north eastern Irish Sea (van den Berg, 1984) and the unpublished MAFF and DAFS work. These suggest typical concentrations of around 0.3 to 0.4 µg l^{-1} rising to more than 1 µg l^{-1} off the Cumbrian coast. At present, there do not seem to be any reliable data on copper in Liverpool Bay. The most recent publications (Norton et al., 1984a; Balls, 1986) have reported inverse trace metal/salinity relationships for Cu, Cd, Zn and Ni. This suggests that freshwater sources (i.e. rivers) are the major sources of these elements.

3.5 Metals on particulate material

A summary of the elemental composition of suspended particulate matter from the Irish Sea is given in Table 4. For the north-eastern Irish Sea the percentages of the total load carried in the particulate phase for Cd, Cu and Pb are ca. < 5, 10 and 75 respectively. The corresponding percentages for Cd, Cu, Zn and Ni in Liverpool Bay are ca. < 5, 20, 30 and 70 respectively. Suspended particulates are enriched in metals relative to bottom sediments from the north-eastern Irish Sea (see footnote to Table 4). This is attributed to the dominance of fine clay material in suspension.

The distributions of particle-reactive elements such as lead and mercury are dominated by uptake onto suspended solids. For this reason, dissolved lead and mercury, unlike, for example, copper, are not expected (or observed) to behave conservatively. For lead, atmospheric inputs may be the principal source to offshore waters.

3.6 Metals in sediments

The main areas of the Irish Sea for which recent data are available are the north-western sector especially Belfast Lough, and Liverpool Bay. In the Belfast Lough studies the data relate to whole sediments and there are some uncertainties about the absolute values obtained for chromium and lead. The results are summarised in Table 5. In Liverpool Bay the studies undertaken were concentrated around sewage and dredge spoil dumping grounds, although the surveys of Liverpool Bay were extended northwards with samples taken as far north as the north of the Isle of Man (Rowlatt et al., 1984). The data refer only to trace metals. Because the majority of sewage sludge particulates are < 90 μm and therefore most of the sewage derived contaminants are likely to be held on < 90 μm fraction of the sediment, most of the data are for this fraction only.

The range of values found in the north-eastern Irish Sea are shown in Table 6. The geographical distribution is dominated by a sharp drop in concentrations in the north-western part of the area. This correlates to a change in sediment type from muddy to sandy (Banner and Culver, 1979). It coincides with the drop in concentrations of total metals found in seawater and suggests that deposition is marked by a fairly sharp boundary (Rowlatt, et al., 1984).

Liverpool Bay presents a complex system as it is a highly dynamic area with a number of significant sources of contamination. The Mersey and Ribble Estuaries and the sludge and spoil dumping grounds all act as a source of metals to the sediment in the Bay. Although the distribution alters from year to year, it is clear that sewage sludge is a major contributor of metals to the sea bed near the dumping ground (Figure 14) (Norton et al., 1984a, b; Rowlatt, et al., 1984). From the scale of input it is apparent that the disposal of dredge spoil must have a similar impact on the dredge spoil dumping grounds, but this is still under investigation.

4. Petroleum hydrocarbons

4.1 Petroleum hydrocarbons in water

On three occasions (1979, 1982 and 1983) surveys have been carried out in the Irish Sea in which subsurface (1 m) water samples have been analysed for hydrocarbons (by fluorescence spectroscopy). In 1979, samples were taken from 9 stations in St George's Channel and the eastern Irish Sea. Total hydrocarbon concentrations (THCs all expressed as Ekofisk crude oil equivalents) were all in the range 2.1 to 74 $\mu g\ l^{-1}$. The highest THC's, 12 and 74 $\mu g\ l^{-1}$, were found near Morecambe Bay and off the entrance to the River Mersey respectively (Law, 1981). The two later surveys were confined to the eastern Irish Sea, centering on the Morecambe Bay gas field development but covering a large part of the eastern Irish Sea (see Figure 15 which shows most of the area sampled). Ninety stations were sampled in 1982, including some off Ramsey Bay (Isle of Man). THCs were found to range from 0.9 to 8.1 $\mu g\ l^{-1}$ with mean values of 4.5 $\mu g\ l^{-1}$ to the south east and 2.3 $\mu g\ l^{-1}$ to the north west. The 1983 survey included 128 stations and took in Liverpool Bay and the coast of North Wales in addition to the gas field development. The THCs found were 1.7 to 40 $\mu g\ l^{-1}$, with all the concentrations greater than 10 $\mu g\ l^{-1}$ (9 stations) being found in the extreme south east and south of the survey area (R. J. Law et al., in preparation).

4.2 Petroleum hydrocarbons in sediments

THCs in surface sediments were determined using samples taken during the three surveys mentioned above. During the 1979 survey, sediment samples were obtained from 7 of the 9 stations at which water samples were taken (Law, 1981). THCs in 6 of the 7 were within the range 4.9 to 29 $\mu g\ g^{-1}$ dry weight with the seventh sample from the muddy sediments at the Mersey entrance containing 340 $\mu g\ g^{-1}$. Samples taken in 1982 and 1983 gave THCs from 1.2 to 410 $\mu g\ g^{-1}$. High THCs were associated with fine sediments (Figure 15) and concentrations were markedly lower in sandy deposits (Bedborough, Blackman and Law, in press).

These results indicate that the Irish Sea is quite heavily contaminated by hydrocarbons. The distribution shows no clear gradient to a source. Hence, it seems likely that the high concentrations arise from a wide variety of sources, including river and atmospheric inputs, sea disposal of wastes, shipping operations, etc. Much of the transport of hydrocarbons within the sea area seems likely to occur in association with sediment particles.

5. Contaminants in biota

The levels of contaminants in fish and shellfish are examined regularly in areas which are known to be most heavily contaminated and less often in other areas. Most of the recent studies have concentrated on areas such as Liverpool Bay, Morecambe Bay, St Bees Head/north-eastern Isle of Man and Belfast Lough. As it is reasonable to assume some influence from man's activities in these areas, results will be compared with data from the Western Channel, which, for the purposes of this investigation, is considered to be uncontaminated.

The pattern that emerges from studies of trace metal concentrations in both fish and shellfish is that, compared with samples from the Western Channel, elevated levels of some contaminants are to be found in Liverpool Bay, and Morecambe Bay (Table 7), the concentrations of zinc in shellfish and mercury in both fish and shellfish being highest in Liverpool Bay and, in the case of mercury, in Morecambe Bay. Chlorinated hydrocarbons followed a different pattern with low levels being found in the St Bees Head/north-eastern Isle of Man area with all other areas showing relatively high values (Table 7). These differences in levels of contamination by chlorinated hydrocarbons probably reflect the relatively small inputs from land-based sources from the Isle of Man and Cumbrian coasts.

In 1977/78, MAFF undertook a mussel-watch survey of contaminant levels in coastal waters around the whole of England and Wales. The results of that part of the study undertaken for the Irish Sea are summarised in Table 8. A more detailed investigation was undertaken by Welsh Water Authority in 1978/79 in the waters for which they have a statutory responsibility. That study included samples from the south coast of Wales and used _Fucus vesiculosis_, _Mytilus edulis_, _Patella_ sp and _Littorina littorea_ and samples were taken from 57 sites. The results for biota generally confirm those found by MAFF. A similar mussel watch study was undertaken in Northern Ireland in 1981/82 and the results of that study are summarised in Table 9.

The investigation undertaken by the Welsh Water Authority included analyses of chlorinated hydrocarbons in sea water and selected results from one of those surveys are summarised in Table 10.

Generally, the results of these surveys confirm the findings of the offshore sampling of fish and shellfish, the waters around the highly populated and industrialised Lancashire coast clearly giving rise to higher levels of contamination than elsewhere. However, the more detailed survey results did reveal point sources of particular contaminants which might not otherwise have readily been detected.

6. Inputs

Inputs to the Irish Sea arise from the atmosphere, North Atlantic flow through the Irish Sea, from land-based sources and from dumping.

6.1 Atmosphere

There are no data which can usefully be used to assess inputs from this source. Data do, however, exist for North Sea sites and the nearby Firth of Clyde; these suggest that the atmosphere may be an important source of contaminants, particularly lead, to coastal waters (Cambray, Jefferies and Topping, 1979).

6.2 North Atlantic inflow

Details of the probable input, in order of magnitude terms, for most of the metals and some organochlorines and petroleum hydrocarbons are given in Table 11. These are based on information on typical North Atlantic/South-Western Approaches water concentrations and the data of water transport into the area, across the southern boundary, given in Section A.

6.3 Land-based sources

Information has been obtained for inputs from rivers, direct discharges and sewage discharges, for the coasts of the relevant parts of England plus Wales and in less detail for Northern Ireland. These data are summarised in Tables 12 and 13 respectively.

The data on which these figures are based are of variable quality and, in view of the uncertainties, in many cases it has been considered prudent to provide a worst and a best input value. One of the problems stems from the fact that flows, especially those of rivers, are very variable and it is unlikely that concentrations remain constant with change in flow. Consequently, assessment of inputs is very dependent on the combinations of concentration and flow data used. The problems are compounded by the fact that in many cases it has not been possible, with the analytical methods available, to actually measure the concentration present of some contaminants in some or all of the samples. In such situations, estimates have been made on the basis of local knowledge and there is, therefore, an obvious need to improve the data base and methods used in assessing river inputs of contaminants.

These limitations must be borne in mind if any attempt is made to relate input data to concentration distributions in the environment or to observed effects. It is likely that information on Cd and Hg inputs will improve in the next year or so as further efforts are made to quantify them in accordance with EEC Directives.

Where river inputs are given in Table 12 these are gross inputs to the estuaries measured at the fresh/salt water interface or some similarly convenient sampling point. They do not necessarily, therefore, represent inputs from the estuary to coastal waters. In the case of the Mersey Estuary, a serious attempt has been made to assess the flux of contaminants out of the estuary and into Liverpool Bay.

Estimates of the amounts of various potential pollutants discharged to the estuary are given under section E28 in Table 12. The figures are of the same order of magnitude as ICES estimates of discharges to other large UK estuaries such as the Tyne, Tees, Humber and Thames (Anon., 1978). The figures for BOD and nutrients are in general agreement with the ICES figures but the metal loads are lower, except in the case of lead, where better quantification of industrial discharge gives a figure three times larger than the ICES figure. In the course of the mixing between fresh and saline water which takes place in estuaries a considerable number of chemical and physical reactions can take place to alter the behaviour of material added from streams and discharges. The precise fate of inputs even to relatively simple estuarine systems cannot, as yet, be properly determined. However, it is probable that most estuaries represent a steady state in which inputs and exports are more or less in balance. Thus, assuming that the inputs have remained fairly constant for some years, if one can be measured reasonably reliably it will give the other. An examination of the metal data from the flux investigations shows that although the flux estimates only refer to a particular, very short time period, they are of the same order as the long-term input data, except for mercury, where only one net tidal transport estimate is available. Table 14 shows the net tidal transports of Zn, Ni, Cu, Cd, Hg and Pb calculated from the flux surveys in relation to the input data from Table 12. Given the fairly large errors involved in calculating both the inputs and the net transports and the fact that the former represent the average situation and the latter individual tides, the agreement between them might be taken as an indication that the input data gives at least an order of magnitude estimate of the average load exported from the estuary. The input data represent, on average, between 1% and 5% of the ebb tide transport.

6.4 Dumping

In terms of quality of data, those which are available on inputs via dumping are probably the most accurate and are certainly the most complete. The biggest quantity of material dumped is dredge spoil but it should be recognised that this is very largely simply a redistribution of sediment material, often of a transient nature, as the sediment is returned by currents to the dredged location.

The second largest input of dumped material is of sewage sludge which is dumped primarily in Liverpool Bay and Belfast Lough. Additionally, relatively small quantities of industrial wastes are dumped in Liverpool Bay and the Bristol Channel.

Table 15 summarises the inputs of these three types of materials to the main area of disposal i.e. Liverpool Bay.

7. Liverpool Bay. The mercury problem

7.1 Introduction

In the preceding sections, mention has been made on a number of occasions of elevated levels of certain contaminants being encountered in

Liverpool Bay. Whilst most of these instances would not on their own, give cause for special concern, taken together they indicate a stressed environment. It is apparent that some members of the local fish eating community are likely to exceed the FAO/WHO defined Provisional Tolerable Weekly Intake (PTWI) for mercury and that the average levels are only just below the Environmental Quality Standard (EQS) defined by the European and Paris Commissions (0.3 mg kg^{-1} as an average concentration in fish taken from the area and likely to be consumed). Whilst this does not mean that those persons are at risk, since the PTWI is set well below the level at which effects occur, it gives rise to concern, since the PTWI has been recommended as an internationally agreed limit, and the UK Committee on Toxicity has recently stated 'this limit has considerable international support. We consider it should be respected and that it would be prudent to endeavour to conform with it.' (MAFF, Food Science Laboratory, in press).

7.2 Inputs

Mercury is known to be discharged to the Mersey Estuary via a number of routes. Some of this may reach Liverpool Bay and the north-eastern Irish Sea through direct transport in the estuary outflow. Most, however, will be adsorbed onto estuarine sediments, at least initially, before being transported to the Bay either on suspended particulates or as dredged spoil in the course of port maintenance work. Additionally, some mercury is transported directly to the Bay in sewage sludge which is dumped from several sources in the North-West Water Authority (NWWA) area. The quantities of mercury discharged, or potentially mobilised, via these routes have recently been quantified and the figures for 1985 were:

	kg day^{-1}
Industrial discharges to the Estuary	3.8
Sewage sludge disposal in the Bay	1.1
Dredgings disposal in the Bay	6.6
Mersey River discharge to the Estuary	0.5
Sewage discharges to the Estuary	0.2-0.5.

Past inputs by all routes were higher, in some cases substantially higher, and steps are in hand to reduce inputs still further. A straight addition of the above figures would not provide an accurate estimate of the quantity of mercury reaching Liverpool Bay as it would obviously involve elements of double counting. However, some of the sediments in the Bay are known to contain elevated concentrations of mercury and these probably act as a source of mercury to the benthos and the overlying waters and in turn to the fish.

7.3 Concentrations in fish

The concentrations of mercury in fish have been monitored regularly since the early 1970s. Since 1980, the monitoring has been conducted according to a standardised procedure and the results have been submitted to both the Paris and European Commissions. During the latter part of 1984 and throughout 1985, an extensive sampling and analysis programme was conducted by MAFF and NWWA to establish the relative levels of mercury contamination in fish throughout the north-eastern Irish Sea. Figures 16 and 17 show the distribution found in the four most commonly sampled species and it is apparent from these that, although the highest levels are centred on Liverpool Bay, contamination is fairly general in the area south and east of the Isle of Man.

Figure 18(a-d) shows the levels of mercury in fish relative to inputs and to the EQS of 0.3 mg kg^{-1}. The differences between the panels are as follows. In Figure 18(a)(b), the time-variation of Hg in whiting and plaice is shown in the way which would best show up any link with the individual curves of mercury input (from A. Franklin and M. D. Nicholson in preparation). That is, in contrast to earlier analyses by MAFF or that by Cooper (1986), we have chosen to use a more selective data set in which the fish samples used are those from the vicinity of the Liverpool Bay dumpsites only, and the length-dependence of Hg in fish has been removed to establish a curve applicable to the actual mean length of fish in these dumpsite samples (28 cm for both species). In Figure 18(c) these curves have been recalculated to reflect the mean length of Irish Sea fish available to consumers (33.2 cm for whiting, 31.2 cm for plaice, 1981-83 means). Finally, Figure 18(d) compares the 'shopping-basket' estimates of Hg in fish with the EQS; such estimates are only available for years which follow the introduction of the EQS principle in 1980. It is clear that as inputs have fallen so have the levels in fish and, although in recent years the rate of decline has been slow, the mean Hg levels in fish from the inner-Bay area now lie just below the EQS. Leah (1986) provides a simple but robust statistical analysis of the detailed ICI data set of mercury in fish from the area, and also finds evidence of a relatively rapid decrease of Hg levels in fish in the 1970's, followed by a slower decrease since 1980.

7.4 Unknowns and expectations

It will be apparent, from the details of inputs of mercury given in sub-section 7.2 and from the changes in mercury concentrations in fish with time shown in Figure 18, that it is extremely difficult to attribute the high levels of mercury to any one source. It is equally difficult to attribute the decline in the levels of contamination found in the fish to the reductions in any one source of mercury or any particular combination of sources. A further problem is that although inputs have been quantified with varying levels of success since the early 1970s, no data of value exist prior to that, although it is certain that inputs were higher and that a considerable accumulation of mercury has occurred in the Liverpool Bay sediments. It is unlikely that the levels of mercury contamination in fish will decline significantly until this reservoir of mercury decreases which is only likely to occur if inputs, both direct and via the Mersey Estuary, can be further decreased. While steps are in hand which should reduce inputs in 1986 by about 0.8 kg day^{-1} and progressive reductions of a further 1.4 to 4.2 kg day^{-1} are reasonably assured in the longer term, it will, clearly, be some time before the Mersey Estuary sediments become decontaminated and dredge spoil inputs are eliminated or substantially reduced. The importance and impact of this actually happening is not clear since, as with inputs via sewage sludge, there is considerable uncertainty about how much of the mercury in the dredge spoil is 'available'. These are gaps in information which will require considerable further research effort if we are to identify the important inputs and/or sources which are likely to result in a significant decrease in mercury, which in turn is the pre-requisite for implementing controls on a priority basis. Meanwhile, monitoring of both inputs and levels in the fish will have to be maintained.

SECTION C. GENERAL BIOLOGY AND FISHERIES OF THE IRISH SEA

K. M. Brander[1], J. M. Colebrook[2], E. I. S. Rees[3], M. M. Parker[4] and D. Bucke[5]

1. Ministry of Agriculture, Fisheries and Food
   Directorate of Fisheries Research
   Fisheries Laboratory
   Lowestoft, Suffolk NR33 OHT

2. Institute for Marine Environmental Research
   Prospect Place
   The Hoe
   Plymouth PL1 3DH

3. University College of North Wales
   School of Ocean Sciences
   Menai Bridge
   Anglesey Gwynedd LL59 5EH
   North Wales

4. Ministry of Agriculture, Fisheries and Food
   Fisheries Laboratory
   Burnham-on-Crouch
   Essex CMO 8HA

5. Ministry of Agriculture, Fisheries and Food
   Fish Diseases Laboratory
   The Nothe
   Weymouth, Dorset DT4 8UB

1. Primary production, plankton and microbiology

Recent investigations of production in the planktonic ecosystem of the Irish Sea are reported in Fogg et al. (1985), Floodgate et al. (1981) and Richardson et al. (1985). There are great differences in biological activity between the various water masses within the Irish sea and it is impossible at this time to give an integrated estimate of primary production. It is evident that biological activity is highest in the large stratified water mass in the northwest Irish Sea and in particular along the front (Savidge, 1976) separating it from the mixed water further south (see Figure 1). Other areas which stratify to a greater or lesser extent occur off the Cumbrian and Lancashire coast, in Cardigan Bay and in bays and estuaries. This uneven distribution of plankton production clearly influences the distribution of all other marine life, including benthos, fish, sea birds, marine mammals and even fishermen.

1.1 Continuous Plankton Recorder survey data, 1971 to 1984

Continuous Plankton Recorder (CPR) surveys provide a means of making comparisons with plankton of other sea areas and of looking at time trends within the Irish Sea. The Irish Sea route runs from Liverpool to Dublin (see Figure 19) and can, therefore, only be taken as approximately representative of the mixed water plankton.

Figure 20 summarises the seasonal variations in the standing stock of phytoplankton in the Irish Sea compared with neighbouring areas. It is clear that in the mixed water of the Irish Sea the spring bloom is about a month later and the autumn decline nearly two months earlier than in the open shelf areas to the north and south. This has a marked impact on the abundance of zooplankton, represented by the seasonal variations in the total of all the copepod species (Figure 21). These graphs show that in the mixed water of the Irish Sea the numbers of copepods are less than half of those in the open shelf areas.

The main patterns of year-to-year variability in the abundance of the plankton of the Irish Sea over the last 14 years are presented in Figure 21. There are two distinct patterns, shown by the broken lines in the top two and bottom two rows of graphs and, in the figure, these are compared with the year-to-year changes in the abundance of eight of the more common species of zooplankton and phytoplankton. The first pattern, clearly associated with the copepods Pseudocalanus, Temora and Acartia appears to be restricted to the Irish Sea and the open shelf to the west of Scotland (area C4 in Figure 20), while the second pattern, associated with Calanus helgolandicus, Thalassiosira, Asterionella and Ceratium fusus, represents the general trend of decline and recovery found over the whole of the north-east Atlantic and the North Sea.

1.2 Abnormal algal blooms

The principal foci of exceptional algal activity in the Irish Sea are the three regions in which frontal systems develop, namely, (Figure 19) the north-western Irish Sea and Celtic Sea fronts (thermal) and in Liverpool Bay where more transient thermal or thermohaline fronts develop (Simpson and Hunter, 1974; Czitrom Baus, 1982). The latter has been particularly noted for many years (Burrows, 1975) as a region where exceptional blooms often occur though overall primary production is not high (Liverpool Bay Working Group, 1984); the blooms are sometimes associated in the literature with "eutrophication" due to anthropogenic inputs, including not only the nutrients (particularly of phosphates) but also the growth factors such as certain B vitamins (Burrows, 1975; Spencer, 1972); such suggestions remain unconfirmed or speculative at present. Synoptic data on nutrient distribution for the whole Irish Sea is not available but many workers have measured nutrient concentration in the north-eastern Irish Sea; relatively high levels inshore are associated with run-off, and decline seaward (Abdullah, 1975).

Studies of the other frontal systems suggest that they fit a recognised pattern in which high productivity is linked to the stability of water on the stratified side of the front and higher nutrient concentrations of the mixed side. Very rapid cycling of scarce nutrients via microbial and flagellate pathways occurs in summer and sustains high production even when the standing stock of nutrients is very low (Turley and Lochte, 1985).

Early in the year, diatom bloom patches of various species are often observed in Liverpool Bay, originating along the North Wales coast. These are followed in the late spring or early summer by blooms of Phaeocystis pouchetti usually in association with Nitzchia spp and subsequently in later summer, in some years, Noctiluca or Gyrodinium aureolum (Spencer, 1972; Lancashire and Western Sea Fisheries Committee, 1976-79; Jones and Haq, 1963). The two latter appear to be mutually exclusive, perhaps because Noctiluca preys on Gyrodinium. Mass mortalities and lesser effects including reductions in DO, increased mortality of shellfish larvae in hatchery conditions and appearance of unsightly/smelly decaying organic matter on beaches have been noted with Phaeocystis and Gyrodinium blooms (Helm et al., 1974). Though the appearance of Gyrodinium in European waters is a relatively new phenomenon (Tangen, 1977), Phaeocystis and Noctiluca blooms are thought to have a long history in this area (Burrows, 1975; Jones and Haq, 1963).

Aside from generally enhanced primary production, no particularly exceptional blooms have been associated with the north-western Irish Sea front. The Celtic Sea front is a centre for the development of Gyrodinium (or, in some years, Noctiluca) blooms, but these affect areas outside the Irish Sea proper (the Irish South Coast and Cornwall) (Parker, 1981).

Paralytic shellfish poisoning (PSP) (due to Gonyaulax tamarensis/excavata) has been recorded only from Dublin Bay in 1890 (Cameron, 1890); in more recent years, the dinoflagellate has been recorded there, but only rarely (K. Roden, personal communication), while positive PSP tests have been recorded in Belfast Lough, which is also frequently the location of small diatom blooms (Parker, 1981; Maxwell, 1978). Unusually in 1985, Phaeocystis bloomed extensively along the Irish coast from Dublin to Wexford, causing a significant nuisance to tourist interests though no other damage, and a prolonged bloom of Prorocentrum minimum occurred in Wexford Harbour, without any of the toxic effects normally associated with this species; neither of these two species have been recorded from the Irish east coast before that date, nor have other blooms been reported before from these well-mixed, turbulent waters (Parker, 1981; J. Doyle, personal communication).

2. Benthos

In broad terms, the benthic associations of the Irish Sea can be categorised according to the annual range of temperature fluctuations experienced at the bottom. Figure 22 shows the distribution of the benthic étages using the classification of Glemarec (1973), the most important division being between the mixed water areas and the stratified water of the western basin. Within these broad divisions the complex mosaic of sediment types determines the detailed distribution of the benthic associations. The main ones are shown in Figure 22(b), but in many places the scale of the mosaic is such that the details cannot be shown on this map. The most notable feature is the occurrence of pockets of muddy sand deposits in the bays round the margin of the sea. Onshore near bed residual currents result in the selective deposition of organic detritus in these pockets, thus supporting benthic populations an order of magnitude greater than those of adjoining areas (Rees, Eagle and Walker, 1976). In addition to the muddy communities of the western basin, another extensive area of muddy deposits lies off the coast of Cumbria. The margins of these mud areas have much denser macrobenthos populations than the mud in their centres. Localised areas with particularly rich benthos occur near the western Irish Sea front, (Holme and Rees, 1986) but, as in the North Sea (Creutzberg, et al., 1984), it is not clear whether pelagic enhancement or marginal deposition on the tidal current gradients is responsible.

Anthropogenic influences affecting small areas in or adjacent to the urbanised estuaries are obvious, but such influences on a larger scale are more difficult to detect. Virtually all of the estuaries round the Irish Sea have been modified in some way by man's activities. The Liffey in Dublin is a classic case, where nearly all of the types of changes come together to produce the full sequence of polluted benthic communities culminating in azoic conditions (Crisp, Hoare and Seymour, 1974; Seymour, 1976). Inland, the drainage of peatlands amplifies the load of humic material carried by the river and a hydro-electric dam diminishes the spates that would otherwise flush the inner estuary. The estuary itself has had the tidal prism reduced by the construction of quays and breakwaters. Dredging of the port has resulted in a bed profile that is not in equilibrium in a section where there is strong stratification. Thermal influences from an oil-fired power station serve to amplify the salinity-derived stratification. Into this basin, with a particularly poor capacity for mixing and re-oxygenation, the city and its industries discharge a fairly heavy load of organic wastes. Belfast Lough has similar features and even in the estuaries on the eastern side, where the tide range is bigger, the construction of training banks has frequently disrupted the natural sedimentation patterns of the estuaries, creating traps for any excess organic detritus and the persistent contaminants frequently associated with it. A good example of this can be seen to the south west of the trained channel to the Mersey. This has cut off an embayment in the sand banks which happens to lie in the direct path of sewage sludge being dispersed from an offshore dumping ground by near bed residual currents. This dumping ground in Liverpool Bay does not show the usual effects of over enrichment whereas the Garroch Head dumping ground in the Clyde does show such effects (Pearson, 1986). The benthic species that dominate Liverpool Bay are mainly ones that are often associated with organic pollution, but they do not occur in excessively high numbers. Much of the central part of Liverpool Bay has a rather sparse fauna, but it is not clear whether dumping is a factor in this or whether it is mainly due to natural sediment mobility. As some species that are common in the rest of the eastern Irish Sea, such as Echinocardium cordatum, are virtually absent from the sector of the bay which includes the Mersey and the dumping ground, the vigorous mixing may lead to broad effects.

On several occasions, patchy local mortality of the shallow water and intertidal benthos has been observed, following the collapse of intense plankton blooms. Nearbed currents tend to concentrate senescent plankton in nearshore pockets, where the benthos is thus enriched. These shallow coastal waters tend to be rather turbid and the amount of particulate material may well be increasing. Accelerated soil erosion from land use changes in the surrounding catchments coupled with river management schemes for flood relief and the construction of sea walls enclosing salt marshes have increased the load of fines in coastal waters. In the Menai Strait, where records of water clarity go back to the early 1950's, there are signs of a decline in the occurrence of periods of clear water and the lower depth limit of the Laminarian weeds seems to have decreased.

In Cardigan Bay, off a coast where the human population is small and agricultural intensification has been less, there is an area where quantitative benthos samples were taken in 1921 (Laurie and Watkin, 1922). This was not long after Petersen's (1918) classic studies off Denmark. Recent resampling of Petersen's Danish stations showed widespread changes, indicative of general eutrophication of coastal waters (Pearson, Josefson and Rosenberg, 1985). However, samples taken at the Cardigan Bay locality in 1981 showed a remarkably high degree of similarity with those taken sixty years earlier.

Elsewhere in the eastern Irish Sea, the year to year variations in the benthos are often considerable. This is particularly so in the inshore muddy sand pockets where populations of some species that intensively rework the sediment are sufficiently high to inhibit recruitment of other species. Variations in wind stress driven residual water movements also influence the mix of larvae available for recruitment. Repopulation of the sparsely inhabited sediments of Liverpool Bay is more likely when the residual in the bay is clockwise and carries larvae from the richer populations to the north.

Additional, localised effects on the benthos occur where there is gravel dredging in southern Liverpool Bay, where dredge spoil has been dumped at site Z in Liverpool Bay (Rowlatt, Rees and Rees, 1986), where slag has been dumped on the foreshores of Cumbria (Perkins, 1977), and on a miniscule scale so far, round the gas platforms of the Morecambe Field. The mud zone off Cumbria is of special interest because of the proximity of the outfalls from the Sellafield nuclear reprocessing plant. Deep bioturbation by benthic organisms coupled with bed disturbance from trawling means that particulate nuclides would not remain completely buried even if the mud were accumulating, which is unlikely. Extrapolating from the limited experiments done elsewhere on the effects of scallop dredges and heavy beam trawls, it is likely that in places the intensity of fishing is at times sufficient to significantly affect the sessile epifauna. Where the populations of large fish such as cod that are predators on benthic organisms have been reduced by fishing, there are probably consequences for the benthos. Mathematical modelling suggests that fishing cod at an intensity beyond the level where the maximum sustainable yield is taken could benefit the Nephrops fishery (Brander and Bennett, 1986).

3. Fish and fisheries

The Irish Sea supports a diverse fish fauna similar to other sea areas around the British Isles, but the fish yield per unit area is lower than in other areas (see Table 16 and Brander and Dickson, 1984). The only commercially important pelagic fishery is for herring. The decapod crustacean Nephrops norvegicus, with average annual landings of around 9000 t, is the most valuable component of the Irish Sea mixed demersal fishery (Figure 23(b)).

The biomass of the main commercial demersal fish species are given in Table 17 (from Brander 1981a). From trawl survey data it is evident that other, non commercial, species make up a small proportion of total fish biomass, although sprat, poor cod and Norway pout are fairly abundant. Compared with the North Sea demersal fish fauna (also given in Table 17), the main differences are the small proportions of saithe and haddock and the large proportion of rays. About 85% of the Nephrops landed from the Irish Sea come from the mud patch west of the Isle of Man and this area also yields much of the cod and whiting. The flatfish catches come mainly from the eastern Irish Sea. The sole fishery in March and April attracts visiting beam trawlers from Belgium, Holland and south-west England, but otherwise most vessels fishing in the Irish Sea are based around its shores.

The main spawning areas are in the stratified water masses west of the Isle of Man and off the Cumbrian coast and spawning generally occurs slightly later than in the North Sea. Larvae are distributed over nursery areas in most coastal regions of the Irish Sea, with juvenile flatfish occurring mainly on the east side (Figures 24 and 25). The flatfish nursery areas are in shallow water in areas which are closest to sources of pollution and which are also subject to small mesh shrimp fisheries. There have been extensive surveys of the inshore nursery areas in several years (Riley, Symonds and Woolner, 1986) and these provide a means of comparing different parts of the Irish Sea and also other coastal areas of England and Wales.

Tagging of young plaice, sole and cod shows that although most recaptures occur close to the tagging area, there is good evidence of extensive seasonal migration. Young cod and plaice tagged off North Wales were often recaptured in the southern Irish Sea and the Celtic Sea. Young cod tagged in Belfast Lough were recaptured to the north and west of Ireland. Older cod, plaice and sole tagged on their spawning areas were recaptured over a much wider area during the summer and autumn but appeared to return to the same spawning areas the following spring. Adult whiting tagged off Northern Ireland were recaptured throughout the Irish Sea, but other species appear not to migrate across the Irish Sea in either direction as adults.

3.1 The effects of exploitation on fish stocks

The total yield of demersal fish from the Irish Sea has fluctuated between 30 and 55 kt over the past ten years. This is a higher level than at any time since records began (Brander, 1977) and although it can be shown that all the major demersal fish (cod, whiting, plaice and sole) are being exploited at levels of fishing mortality greater than is needed to take the maximum yield per recruit, there is no compelling evidence that total yields have been diminished as a consequence of heavy fishing. On the other hand, the disappearance of the common skate Raia batis from the Irish Sea is one of the clearest examples of a species being fished to (local) extinction (Brander, 1981(b)).

Trends in the yields of the four main demersal species in the Irish Sea (cod, whiting, plaice and sole) over the past ten years are given in Table 18 and shown in Figures 26-29 respectively. The figures also show the trends in fishing mortality, which are an indication of the level of exploitation and the trends in spawning stock biomass and in recruitment. Although the spawning biomass of both flatfish stocks has shown some decline, there is no evidence that reduced recruitment has resulted and both are expected to benefit from recent good year classes. Tables 19 and 20 show UK (England and Wales) otter trawl and beam trawl catch-per-unit-effort for eight major demersal species in the Irish Sea, which gives an indication of biomass trends. It is encouraging to note, from Table 18 that the ray species (principally Raia clavata, R. montagui, R. brachyura and R. naevus) have maintained a steady high catch rate, since they have a life history similar to R. batis and might be expected to decline under heavy fishing pressure.

Fishing removes 30-60% of adult demersal fish from the Irish Sea every year and a rough calculation of the total area swept by trawls in 1978 shows that the whole area of the Irish Sea was trawled over, on average, 2½ times (Brander, 1980). Given the enormous effect of fishing on the fish stocks, it would be very difficult to detect any other anthroprogenic impact at the population level.

The main pelagic fishery in the Irish Sea is for herring and this has declined very sharply since 1974 when nearly 40 kt were taken. Overfishing certainly played a part in the decline, but the present level of catches, which average around 4 kt is probably closer to the long-term average level for the Irish Sea.

3.2 Historical note on diseases of fish in the Irish Sea

Diseases of fish from the Irish Sea are not a new revelation, probably because the area has had the benefit of having a marine biological station in its midst and in the past there has been opportunity to examine diseases and abormalities of marine organisms in more detail. Early recordings of diseases included descriptions of lymphocystis, epidermal ulcers and hyperplasia, tumours, deformities as well as parasitic infestations (Woodcock, 1904; Johnstone, 1905, 1910, 1923, 1924, 1925). However, these early investigations are little more than case studies of disease in a small number of fish and are not capable of determining disease prevalence levels. Because of observations by fishermen and others of epidermal diseases in flat fish in this area, surveys of demersal fish were made later (Perkins, Gilchrist and Abbot, 1972; Shelton and Wilson, 1973), when lymphocystis $< 14.6\%$ and epidermal ulcers $< 4\%$ were recorded, particularly in flounders but also in dabs and plaice.

3.3 Current status of fish and shellfish diseases in the Irish Sea

In the Irish Sea, more recent surveys of fish stocks for evidence of diseases have been conducted in 1982 (Bucke, Feist and Rolfe, 1983), in November 1985 and in April 1986. In common with earlier surveys, the 1982 and 1985 investigations took place as shared cruises with multiple aims and the 1986 cruise was the first dedicated fish disease cruise that covered different areas of the Irish Sea systematically with trained observers.

The 1982 survey examined 13,218 fish of commercial species (whiting, mackerel, cod, dab, plaice, flounder, Dover sole and lemon sole). The diseases recorded were mainly epidermal, but included lymphocystis, epidermal hyperplasia, epidermal ulcers, skeletal deformities (Table 21), (some) liver nodules in dab (Table 22) and mycobacteriosis in mackerel. From this survey, the prevalence of epidermal diseases was reported to be similar to those recorded by others from surveys of fish in the North Sea (Dethlefsen, 1980; Möller, 1981; Wootten, McVicar and Smith, 1982; Mellergaard and Nielsen, 1984) and less than in previous fish disease surveys in the Irish Sea (Perkins, Gilchrist and Abbot, 1972; Shelton and Wilson, 1973). The results of the 1985 survey appear to show about the same general level of epidermal disease prevalence as in 1982. From these and earlier cruises of this 'opportunistic' type, it would be difficult to attribute significance to the observed changes in disease prevalence with time since important variables (season, locality, fish size, etc.) were not standardised but at least no general upward trend seems to have been apparent.

The survey carried out by the dedicated 1986 cruise was much more rigorous in character, focussing on dab and plaice as the target species, on epidermal diseases, and on four contrasting areas of the Irish Sea - Point of Air (Liverpool Bay), St Bees, Dundrum Bay and Cardigan Bay. Though still under analysis, results show that only epidermal hyperplasia, lymphocystis and ulcers were present in sufficient numbers to justify statistical analysis, and this analysis shows two main conclusions (Bucke and Nicholson, 1987). Firstly, the general prevalence of fish epidermal disease encountered was significantly higher than on earlier cruises, including the 1985 survey, only 5 months earlier; until supported by future surveys of an equally rigorous type, this increasing disease-prevalence in the observations is not regarded as conclusive evidence of a real increase in disease incidence among the wild population, but rather as the expected result of fielding an increased and more-focussed observing effort. The second result may well prove to be more significant from the view point of anthropogenic effects; that is, the statistically demonstrable result that of the four areas surveyed, the dab showed it highest disease prevalence off Point of Air (Liverpool Bay), the plaice off St Bees and for all six categories considered (2 spp. x 3 disease-types) the (supposed) control site in northern Cardigan Bay showed the lowest disease prevalence.

As the first and only cruise of its type, the 1986 survey does provide statistically reliable 'benchmark' values for the limited range of diseases and species considered but, even if a 'time-series' of such surveys eventually becomes available, it will still remain to be demonstrated whether an anthropogenic contribution to the observed changes can be convincingly separated from the natural spatial and temporal variations which must undoubtedly exist in fish disease incidence.

4. Marine mammals and seabirds

Although the list of Cetacean species that have at some time been stranded on Irish Sea coasts is quite long (Fraser, 1974), only a few are seen live regularly (P. G. H. Evans, 1980). Porpoises are fairly common inshore in summer but are at risk from drowning in monofilament nets. Bottlenosed dolphins still penetrate to Liverpool Bay, but anecdotal evidence suggests that there are fewer than formerly. Most of the other species seem not to penetrate far from the entrance narrows, though in recent years occasional minke whales and small schools of common dolphins have been seen in the richer stratified waters of the western Irish Sea (Hope Jones, 1984).

One of the main breeding areas of the south-western British stock of grey seals is on the Pembroke coast at the southern entrance to the Irish Sea (Hewer, 1974). Smaller numbers pup on the Saltee and Lambay Islands on the Irish side and at several localities on the north Wales coast. Away from the pupping beaches they can be found almost anywhere around the sea. The most favoured haulout sites are on offshore rocks such as Bardsey and Ynys Dulas, off Anglesey, at each of which up to about eighty whales can be seen at times. There is also a major haul out on the Hoyle Banks, off the Dee Estuary, of seals feeding in Liverpool Bay (Craggs and Ellison, 1960). Individuals can sometimes be seen feeding in the Queens Channel at the mouth of the River Mersey. These individuals must be at risk of accumulating heavy metals and other persistent pollutants. The few analyses from the carcasses of dead seals showed the presence of the expected contaminants, but not at concentrations likely to cause death (Holden, 1978). Seal populations in the Irish Sea do not seem to have increased as much as those off north-western Scotland and the Farnes. It is most likely that this is due to the habit of the south-western British stock, of pupping on storm beaches in caves and remote coves where the pups are often washed away (Hewer, 1974). Conflicts between seals and fisheries have been relatively few. Common seals are limited to a small population centred on Strangford Loch, but wanderers sometimes join the major grey seal haulouts as at Bardsey.

The Irish Sea is surrounded by a chain of estuaries with very extensive intertidal flats. Large populations of wildfowl and waders use these estuaries in winter on a regular basis and as a hard weather refuge (Prater, 1981; Owen, Atkinson-Willes and Salmon, 1986). The Irish Sea estuaries have a milder climate than continental estuaries and invertebrate food remains more available (Reading and McGrorty, 1978; P. R. Evans, 1980). In some bird species very significant parts of the total north-western European populations use the Irish Sea estuaries, for example, over half the knot (Prater, 1981). Although several barrage schemes, which would restrict the available habitat, have been proposed in recent years, none has come to fruition. Many of the estuaries are scheduled as being of conservation importance because of their bird populations (Ratcliffe, 1977). During the late 1970s abnormal levels of bird mortality occurred on the Mersey Estuary, which was attributed to lead from an anti-knock compound manufacturing plant (Prater, 1981).

Scoter sea ducks concentrate at times in flocks of up to several thousand off shallow sandy coasts on both sides of the Irish Sea (Owen, Atkinson-Willes and Salmon, 1986). The concentrations seem to move from season to season, probably depending upon the erratic occurrence of single age cohort patches of benthic bivalves.

The largest breeding populations of seabirds are concentrated at the two entrances to the Irish Sea, such as at Rathlin Island in the north and the Pembrokeshire islands in the south (Cramp, Bourne and Saunders, 1974). The latter have been particularly vulnerable to oil tanker accidents. In spite of intermittent oil pollution incidents, the populations of auks at Irish Sea colonies seem to have risen slightly in the last 15 years, though at a much slower rate than North Sea and Shetland colonies (Harris, Wanless and Rothery, 1983). From time to time there have been mass mortalities of auks in late summer. The incident in 1969 provoked considerable alarm, because of the high levels of PCBs found in the bird corpses (Holdgate, 1971). At this season the whole population, probably including some from colonies outside the Irish Sea, concentrates to feed in a few favoured feeding areas, where they moult and tend the still flightless young. It has recently been found that over 75% of razorbills and guillemots go to limited areas off the east coast of Ireland, the North Channel and Sound of Jura (Rees and Hope Jones, 1985). After the 1969 incident, chemical analyses of cormorant eggs showed the presence of PCBs and some coastal peregrines, habitually feeding on shorebirds, also suffered eggshell thinning. In mid-summer, in recent years, there have often been abnormal numbers of adult gulls dying with disease symptoms. This has been attributed to botulism from feeding on refuse dumped in plastic sacks (Sutcliffe, 1986).

SECTION D. REFERENCES

ABDULLAH, M. I. (1975). Nutrients and trace metals in Liverpool Bay. pp. 37-39. In: Liverpool Bay - an Assessment of Present Knowledge. Liverpool Bay Study Group. Publ. Nat. Environ. res. Coun., Ser. C, (14), 72 pp.

ABDULLAH, M. I., ROYLE, L. G. and MORRIS, A. W. (1972). Heavy metal concentrations in coastal waters. Nature, Lond., 235, 158-160.

ANON. (1978). Input of pollutants to the Oslo Commission area. Coop. Res. Rep., int. Coun. Explor. Sea, (77), 1-57.

BAKER, C. W. (1977). Mercury in surface waters of seas around the United Kingdom. Nature, Lond., 270, 230-232.

BALLS, P. W. (1986). Composition of suspended particulate matter from Scottish coastal waters - geochemical implications for the transport of trace metal contaminants. Sci. Total Environ, 57: 171-180.

BALLS, P. W. (in press). Dispersion of dissolved trace metals from the Irish Sea into Scottish coastal waters. Submitted to Continental Shelf Research.

BANNER, F. T. and CULVER, S. J.(1979). Sediments of the north-western European shelf. pp. 271-300. In: Banner, F. T. Collins, M. B. and Massie, K. S. (Eds), The North-west European Shelf Sea: the Sea Bed and the Sea in Motion. I. Geology and Sedimentology. Elsevier, Amsterdam, Oxford and New York, 300 pp.

BASSETT, H. Jnr. (1910). The flow of water through the Irish Sea. Rep. Lancs Sea-Fish. Labs, for 1909, 18, 148-157.

BEDBOROUGH, D. R., BLACKMAN, R. A. A. and LAW, R. J. (In press). A survey of inputs to the North Sea resulting from oil and gas developments. Phil. Trans. R. Soc. Lond. (B).

Van Den BERG, C. M. G. (1984). Organic and inorganic speciation of copper in the Irish Sea. Mar. Chem., 14, 201-212.

BEWERS, J. M., JENSEN, A., McINTYRE, A. D., PARKER, M. M., PEARCE, J. B., and PORTMANN, J. E. (1982). Guidelines for the preparation of regional environmental assessments. ICES CM 1982/E:22, 9 pp. (mimeo).

BOWDEN, K. F. (1950). Processes affecting the salinity of the Irish Sea. Mon. Not. R. astr. Soc. geophys. Suppl., 6 (2), 63-90.

BOWDEN, K. F. (1955). Physical oceanography of the Irish Sea. Fishery Invest., Lond., Ser II, 18 (8), 1-67.

BOWDEN, K. F. (1980). Physical and dynamical oceanography of the Irish Sea. pp. 391-413. In: Banner, F. T., Collins W. B. and Massie, K. S. (Eds.), The North-west European Shelf Seas: the Sea Bed and the Sea in Motion. II. Physical and Chemical Oceanography and Physical Resources. Elsevier, Amsterdam, Oxford and New York, 301-638 pp.

BOWDEN, K. F. and HUGHES, P. (1961). The flow of water through the Irish Sea and its relation to wind. Geophys. J. R. astr. Soc., 5 (4), 265-291.

BRANDER, K. (1977). The management of Irish Sea fisheries - a review. Lab. Leafl., MAFF Direct. Fish. Res., Lowestoft, (36), 1-60.

BRANDER, K. (1980). Fisheries management and conservation in the Irish Sea. Helgoländer Meeresunters., 33, 687-699.

BRANDER, K. (1981a). On the application of models incorporating predation in the Irish Sea. ICES CM 1981/G:29, 11 pp. (mimeo).

BRANDER, K. (1981b). Disappearance of common skate Raia batis from Irish Sea. Nature, Lond., 290 (5801), 48-49.

BRANDER, K. M. and BENNETT, D. B. (1986). Interactions between Norway lobster (Nephrops norvegicus) and cod (Gadus morhua) and their fisheries in the Irish Sea. pp. 269-281. In: G. S. Jamieson and N. Bourne (Eds.), North Pacific Workshop on Stock Assessment and Management of Invertebrates. Can. Spec. Publ. Fish. Aquat. Sci., (92), 430 pp.

BRANDER, K. and DICKSON, R. R. (1984). An investigation of the low level of the fish production in the Irish Sea. Rapp. P.-v. Rêun. Cons. int. Explor. Mer, 183, 234-242.

BUCKE, D., FEIST, S. and ROLFE, M. (1983). Fish disease studies in Liverpool Bay and the north-east Irish Sea. ICES CM 1983/E:5, 9 pp. (mimeo).

BUCKE, D. and NICHOLSON, M. D. (1987). Fish disease investigations in the Irish Sea. ICES CM 1987/E:19, 7 pp. (mimeo).

BURROWS, E. M. (1975). Phytoplankton studies in Liverpool Bay. pp. 44-45. In: Liverpool Bay - An Assessment of Present Knowledge, Liverpool Bay Study Group. Publ. Nat. Environ. res. Coun., Ser. C, (14), 72 pp.

CAMBRAY, R. S., JEFFERIES, D. F. and TOPPING, G. (1979). The atmospheric input of trace elements to the North Sea. Mar. Sci. Communic., 5 (2), 175-194.

CAMERON, C. A. (1890). Note on poisoning by mussels. Br. Med. J., 2, 150.

CAMPBELL, J. A., CHAN, E. Y. L., RILEY, J. P., HEAD, P. C. and JONES, P. D. (1986). The distribution of mercury in the Mersey Estuary. Mar. Pollut. Bull. 17 (1), 36-40.

COOPER, V. A. (1986). Mercury in sea water, sediments and fish from Liverpool Bay and other areas. Rep. Wat. res. Coun., Medmenham, U.K., (1105-M/1), 1-20, + 8 figs (mimeo).

CRAGGS, J. D. and ELLISON, N. F. (1960). Observations on the seals of the (Welsh) Dee Estuary. Proc. zool. Soc. Lond., 135, 375-385.

CRAIG, R. E. (1959). Hydrography of Scottish coastal waters. Mar. Res. Scotl., 1958 (2), 1-30.

CRAMP, S., BOURNE, W. R. P. and SAUNDERS, D. (1974). The Seabirds of Britain and Ireland. Collins, London, 288 pp.

CREUTZBERG, F. WAPENAAR, P., DUINEVALD, G. and LOPEZ, N. L. (1984). Distribution and density of the benthic fauna in the southern North Sea in relation to bottom characteristics and hydrographic conditions. Rapp. P.-v. Rêun. Cons. int. Explor. Mer., 183, 101-110.

CRISP, D. J., HOARE, R. and SEYMOUR, A. G. (1974). River Liffey survey - estuarine area. Rep. mar. Sci. Lab., Menai Bridge, N. Wales, U.K., 65 pp. (unpublished).

CRONAN, D. S. (1970). Geochemistry of recent sediments from the central north-eastern Irish Sea. Rep. Inst. geol. Sci., (70/17), 20 pp.

CZITROM BAUS, S. P. R. (1982). Density stratification and an associated front in Liverpool Bay. PhD Thesis, University College of North Wales, Bangor, U.K., 97 pp.

DETHLEFSEN, D. (1980). Observation on fish diseases in the German Bight and their possible relation to pollution. Rapp. P.-v. Rêun Cons. int. Explor. Mer., 179, 110-117.

DOYLE, J. (1986). Personal communication. Fisheries Research Centre, Abbotstown, Co. Dublin, Ireland.

EVANS, P. G. H. (1980). Cetaceans in British waters. Mammal Rev., 10, 1-52.

EVANS, P. R. (1980). Migration and dispersal of shorebirds as a survival strategy. pp. 275-290. In: Jones, N. V. and Wolff, W. J. (Eds.), Feeding and Survival Strategies of Estuarine Organisms. Plenum Press, New York and London, 304 pp.

FLATHER, R. A. (in press). Estimates of extreme conditions of tide and surge using a numerical model of the north-west European continental shelf. Estuar. Cstl Shelf Sci.

FLOODGATE, G. D., FOGG, G. E., JONES, D. A., LOCHTE, K. and TURLEY, C. M. (1981). Microbiological and zooplankton activity at a front in Liverpool Bay. Nature, Lond., 290, 133-136.

FOGG, G. E., EGAND, B., FLOODGATE, G. D., HOY, S., JONES, D. A., KASSAB, J. Y., LOCHTE, K., REES, E. I. S., SCROPE-HOWE, S., TURLEY, C. M. AND WHITTAKER, C. J. (1985). Biological studies in the vicinity of a shallow-sea tidal mixing front: Papers I-VII. Phil. Trans. R. Soc. (B), 310, 407-571.

FOSTER, P. (1984a) Inhibitions to pollutant dissipation in the north-east Irish Sea. Mar. Pollut. Bull., 15, 222-225.

FOSTER, P. (1984b). Nutrient distributions in the winter regime of the northern Irish Sea. Mar. Environ. Res., 13, 81-95.

FOSTER, P., BEARDALL, J., VOLTOLINA, D. and SAVIDGE, G. (1985). The effects of wind, phytoplankton and density discontinuities upon ammonia distributions in Liverpool Bay. Estuar. Cstl Shelf Sci., 20 (4), 463-475.

FOSTER, P., HUNT, D. T. E., PUGH, K. B., FOSTER, G. M. and SAVIDGE, G. (1978). A seasonal study of the distributions of surface state variables in Liverpool Bay. II. Nutrients. J. exp. mar. Biol. Ecol., 34, 55-71.

FOSTER, P., VOLTOLINA, D., SPENCER, C. P., MILLER, I. and BEARDALL, J. (1982). A seasonal study of the distributions of surface state variables in Liverpool Bay. III. An offshore front. J. exp. mar. Biol. Ecol., 58, 19-31.

FRASER, F. C. (1974). Report on Cetacea stranded on British coasts from 1948 to 1968. British Museum (Natural History), London, 65 pp. + 9 maps.

GLEMAREC, M. (1973). The benthic communities of the European North Atlantic continental shelf. Oceanogr. mar. Biol., ann. Rev., 11, 263-289,

HARRIS, M. P., WANLESS, S. and ROTHERY, P. (1983). Assessing changes in the numbers of guillemots Uria aalge. Bird Study, 30, 57-66.

HEAPS, N. S. (1979). Three-dimensional modelling of the Irish Sea pp. 2671-2686. In: Proc. 16th Cstl Engng Conf., Hamburg, 1978, 3. American Society of Civil Engineers, New York, pp. 2069-3060.

HEAPS, N. S. (1982). Prediction of tidal elevations: model studies for the Severn Barrage. pp. 51-58. In: Severn Barrage. Proc. Symp. Instn. Civ. Eng., London, 8-9 October 1981. Thomas Telford, London, 240 pp.

HEAPS, N. S. and JONES, J. E. (1977). Density currents in the Irish Sea. Geophys. J. R. astr. Soc., 51, 393-429.

HEAPS, N. S. and JONES, J. E. (1979). Recent storm surges in the Irish Sea. pp. 285-319. In: J. C. J. Nihoul, (Ed.), Marine Forecasting. Elsevier, Amsterdam, 493 pp.

HELM, M. M., HEPPER, B. T., SPENCER, B. E. and WALNE, P. D. (1974). Lugworm mortalities and a bloom of Gyrodinium aureolum in the eastern Irish Sea, Autumn 1971. J. mar. biol. Ass. U.K., 54, 857-869.

HEWER, H. R. (1974). British Seals. Collins, London, 256 pp.

HOLDEN, A. V. (1978). Pollutants and seals. A review. Mammal Rev. 8, 53-66.

HOLDGATE, M. W. (1971). The seabird wreck in the Irish Sea, autumn 1969. Publ. Nat. environ. res. Coun., Ser. C, (4), 1-17.

HOLME, N. A. and REES, E. I S. (1986). An interesting deep-water community in the Irish Sea. Newsletter Challenger Soc., (22), 15.

HOPE JONES, P. (1984). Cetaceans seen in the Irish Sea and approaches, late summer 1983. Nature in Wales (New Series) 3, 62-64.
HOWARTH, M. J. (1984). Currents in the eastern Irish Sea. Oceanogr. mar. Biol., ann. Rev., 22, 11-54.
HUNT, G. J. (1980). Radioactivity in surface and coastal waters of the British Isles, 1978. Aquat. Environ. Monit. Rep., MAFF Direct. Fish. Res., Lowestoft (4), 1-37.
JACKSON, H. B. (1977). The Morecambe Bay, Dee Estuary and Wash feasibility studies of estuarial water storage in the United Kingdom. Central Water Planning Unit, Reading, England, 34 pp.
JEFFERIES, D. F., STEELE, A. K. and PRESTON, A. (1982). Further studies on the distribution of ^{137}Cs in British coastal waters. - I. Irish Sea. Deep Sea Res., 29 (6A), 713-738.
JOHNSTONE, J. (1905). Internal parasites and diseased conditions of fishes. Rep. Lancs. Sea Fish. Labs., 1904, (13), 98-120.
JOHNSTONE, J. (1910). Internal parasites of fishes from the Irish Sea. Rep. Lancs. Sea Fish. Labs., 1909, (18), 16-37.
JOHNSTONE, J. (1923). On some malignant tumours in fishes. Trans. L'Pool. Biol. Soc., 37, 145-157.
JOHNSTONE, J. (1924). Diseased conditions in fishes. Trans. L'Pool. Biol. Soc., 38, 183-213.
JOHNSTONE, J. (1925). Malignant tumours in fishes. Trans. L'Pool. Biol. Soc., 39, 169-200.
JONES, P. G. W. and FOLKARD, A. R. (1971). Hydrographic observations in the eastern Irish Sea with particular reference to the distribution of nutrient salts. J. mar. biol. Ass. U.K. 51, 159-182.
JONES, P. G. W. and HAQ, S. M. (1963). The distribution of Phaeocystis in the eastern Irish Sea. J. Cons. perm. int. Explor. Mer., 28, 8-20.
JONES, P. G. W. and JEFFERIES, D. F. (1983). The distribution of selected trace metals in United Kingdom shelf waters and the North Atlantic. Can. J. Fish. aquat. Sci., 40 (Suppl. 2), 111-123.
LANCASHIRE AND WESTERN SEA FISHERIES JOINT COMMITTEE (1976-79). Phytoplankton studies in the eastern Irish Sea. Sci. Rep., Lancs west. Sea Fish. jt. Comm. Section 1.3. (1975), 20-26; (1976), 21-23; (1977), 13-16; (1978), 30-34.
LAURIE, R. D. and WATKIN, E. E. (1922). Investigations into the fauna of the sea floor of Cardigan Bay. Aberyst. Stud., 4, 229-250.
LAW, R. J. (1981). Hydrocarbon concentrations in water and sediments from UK marine waters, determined by fluorescence spectroscopy. Mar. Pollut. Bull., 12, 153-157.
LEAH, R. T. (1986). Mercury in fish from the Irish Sea. Internal Rep., L'Pool Univ. Dept. Zool., 117 pp. (mimeo).
LIVERPOOL BAY WORKING GROUP (1984). Sewage sludge disposal in Liverpool Bay. Research into effects 1975-1977. Part 2. Appendices. DOE, Water Technical Division, London, 194 pp.
McKAY W. A. and BAXTER, M. S. (1985). Water transport from the north-east Irish Sea to western Scottish coastal waters: further observations from time-trend matching of Sellafield radiocaesium. Estuar. Cstl. Shelf Sci. 21 (4), 471-480.
MAFF, FOOD SCIENCE LABORATORY (In press). Survey of Mercury in Food: Second Supplementary Report. 17th Report of the Steering Group on Food Surveillance. HMSO, London.
MARINETECH NORTH WEST (1983). Mersey Barrage Pre-feasibility Study. 1. Executive Summary. 2. Research Report. Marinetech North West, Mersey Barrage Study Group, The University, Manchester, 1, 25 pp., 2, 115 pp.

MAXWELL, T. H. (1978). The plankton of Belfast Lough. pp. 103-136. In: Downey W. K. and Ni Uid, (Eds.) Coastal Pollution Assessment: Proc. Seminar, Cork, 20-21 April 1978. National Board for Science and Technology, Dublin, 216 pp.

MELLERGAARD, S. and NIELSEN, E. (1984). Preliminary investigations on the eastern North Sea and the Skaggerak dab (Limanda limanda) populations and their diseases. ICES CM 1984/E:28, 14 pp. (mimeo).

MÖLLER, H. (1981). Fish diseases in German and Danish coastal waters in summer 1980. ICES CM 1981/E:26, 20 pp. (mimeo).

NORRIS, Sue (1985). Current meter observations near the Sellafield pipeline, May 1981 - December 1983. Data Rep., MAFF Direct. Fish. Res., Lowestoft, (4), 1-14.

NORTON, M. G., FRANKLIN, A., ROWLATT, S. M. NUNNY, R. S. and ROLFE, M. S. (1984a). The field assessment of effects of dumping wastes at sea: 12. The disposal of sewage sludge, industrial wastes and dredged spoils in Liverpool Bay. Fish. Res. Tech. Rep., MAFF Direct. Fish. Res., Lowestoft, (76), 1-50.

NORTON, M. G., ROWLATT, S. M. and NUNNY, R. S. (1984b). Sewage sludge dumping and contamination of Liverpool Bay Sediments. Estuar. Cstl Shelf Sci., 19, 69-87.

OWEN, A. (1979). Effect on the M2 tide of permeable tidal barrages in the Bristol Channel. Part 2. Design and theory. Proc. Instn. Civ. Eng., 67, 907-928.

OWEN, M. ATKINSON-WILLES, G. L. and SALMON, D. G. (1986). Wildfowl in Great Britain. The University Press, Cambridge, 613 pp.

PARKER, M. (1981). Red tides. Fish. Seminar Ser., Dept. Fish. For., Dublin, (1), 1-42 (mimeo).

PEARSON, T. H. (1986). Disposal of sewage in dispersive and non-dispersive areas: contrasting case histories in British coastal waters. pp. 577-595. In: Kullenberg, G. (Ed.), The Role of the Oceans as a Waste Disposal Option. D. Reidel, Dordrecht, Boston, Lancaster and Tokyo, 725 pp.

PEARSON, T. H., JOSEFSON, A. B. and ROSENBERG, R. (1985). Peterson's benthic stations revisited. 1. Is the Kattegat becoming eutrophic? J. exp. mar. Biol. Ecol., 92, 157-206.

PERKINS, E. J. (1977). The quality and biology of the environment adjacent to the Workington Works of the British Steel Corporation. Sci. Rep., Cumbria Sea Fish. Comm., (77-1), 1-61 + Appendices (mimeo).

PERKINS, E. J., GILCHRIST, J. R. S. and ABBOT, O. J. (1972). Incidence of epidermal lesions in fish of the north-east Irish Sea area, 1971. Nature, Lond., 238, 101-103.

PETERSEN, C. G. J. (1918). The sea bottom and its production of fish-food. Rep. Dan. biol. Sta., 25, 62 pp.

PINGREE R. D. and GRIFFITHS, D. K. (1978). Tidal fronts on the shelf seas around the British Isles. J. geophys. Res., 83, (C9), 4615-4622.

PINGREE, R. D. and GRIFFITHS, D. K. (1979). Sand transport paths around the British Isles resulting from M_2 and M_4 tidal interactions. J. mar. biol. Ass. U.K. 59 (2), 497-513.

PRATER, A. J. (1981). Estuary Birds of Britain and Ireland. T. and A. D. Poyser, Carlton, 456 pp.

PRESTON, A. (1973). Heavy metals in British waters. Nature, Lond., 242, 95-97.

PROCTOR, R. (1981). Tides and residual circulation in the Irish Sea: a numerical modelling approach. Ph.D Thesis, University of Liverpool, Liverpool, UK, 254 pp.

RAMSTER, J. W. and HILL, H. W. (1969). Current systems in the northern Irish Sea. Nature, Lond., 224, 59-61.

RATCLIFFE, D. A. (Ed.) (1977). A Nature Conservation Review. 2 Vols. The University Press, Cambridge, 1, 401 pp., 2, 320 pp.

READING, C. J. and McGRORTY, S. (1978). Seasonal variation in the burying depth of Macoma balthica (L.) and its accessibility to wading birds. Estuar. Cstl Mar. Sci., 6, 135-144.

REES, E. I. S. and HOPE JONES, P. (1985). Late summer moult/nursery concentration areas of auks in the Irish Sea. p. 28. In: Tasker, M. L. (Ed.), Population and Monitoring Studies of Seabirds, Proc 2nd int. Conf. of the Seabird Group. The Seabird Group, Aberdeen, 36 pp.

REES, E. I. S., EAGLE, R. A. and WALKER, A. J. M. (1976). Trophic and other influences on macrobenthos population fluctuations in Liverpool Bay. 10th Eur. mar. Biol. Symp., 2, 589-599.

RICHARDSON, K., LAVIN-PEREGRINA, M. F., MITCHELSON, E. G. and SIMPSON, J. H. (1985). Seasonal distribution of chlorophyll a in relation to physical structure in the western Irish Sea. Oceanol. acta, 8, 77-86.

RILEY, J. D., SYMONDS, D. J. and WOOLNER, L. (1986). Determination of the distribution of the planktonic and small demersal stages of fish in the coastal waters of England, Wales and adjacent areas between 1970 and 1984. Fish. Res. Tech. Rep., MAFF Direct. Fish. Res., Lowestoft, (84), 23 pp.

ROBINSON, I. S. (1979). The tidal dynamics of the Irish and Celtic Seas. Geophys. J. R. astr. Soc., 56, 159-197.

RODEN, K. (1986). Personal communication. Shellfish Research Laboratory, Carna, Co. Galway, Ireland.

ROWLATT, S. M., LAW, R. J., HARPER, D. J. and LIMPENNY, D. S. (1984). Sewage sludge dumping and the composition of sediments and suspended particulate matter in the eastern Irish Sea. ICES CM 1984/E:9,
4 pp. (mimeo).

ROWLATT, S. M., REES, H. L. and REES, E. I. S. (1986). Changes in sediments following the dumping of dredged materials in Liverpool Bay. ICES CM 1986/E:17, 7 pp. (mimeo).

SAGER, G. (1963). Atlas der Elemente des Tidenhubs und der Gezeitenstrome fur die Nordsee, den Kanal und die Irische See. Deutsche Akadamie der Wissenschaften zu Berlin. Institut fur Meereskunde, Rostock, 45 pp.

SAGER, G. and SAMMLER, R. (1975). Atlas der Gezeitenstrome fur die Nordsee, den Kanal und die Irische See. Seehydrographischer Dienst der DDR, Rostock, 48 pp.

SAVIDGE, G. (1976). A preliminary study of the distribution of chlorophyll in the vicinity of fronts in the Celtic and western Irish Sea. Estuar. Cstl Mar. Sci., 4, 617-625.

SEYMOUR, A. G. (1976). Benthic biology of the River Liffey estuary. PhD Thesis, University of Wales, 199 pp.

SHELTON, R. G. J. and WILSON, K. W. (1973). On the occurrence of lymphocystis with notes on other pathological conditions in the flat fish stocks of the north-east Irish Sea. Aquaculture, 2, 395-410.

SHERWIN, T. J. (1983). Internal wave regime of the western Irish Sea. Unit of Coastal and Estuarine Studies, Paper (U83-3), Univ. Coll. N. Wales, Marine Science Lab., Menai Bridge, Gwynedd, 120 pp. (mimeo).

SIMPSON, J. H. and HUNTER, J. R. (1974). Fronts in the Irish Sea. Nature Lond., 250, 404-406.

SPENCER, C. P. (1972). Plant nutrient and productivity study. pp. 357-401. In: Out of Sight, Out of Mind, Vol. 2, Appendix 16. Report of the DOE Working Party on Sludge Disposal in Liverpool Bay. HMSO, London, 483 pp.

STEELE, J. H., McINTYRE, A. D., JOHNSON, R., BAXTER, I. G., TOPPING, G. and DOOLEY, H. D. (1973). Pollution studies in the Clyde Sea Area. Mar. Pollut. Bull., 4, 153-157.

STRIDE, A. H. (1973). Sediment transport by the North Sea. pp. 101-130. In: Goldberg, E. D. (Ed.), North Sea Science. MIT Press, Cambridge MA, 500 pp.

SUTCLIFFE, S. J. (1986). Changes in the gull populations of SW Wales. Bird Study, 33, 87-97.

TANGEN, K. (1977). Blooms of *Gyrodinium aureolum* (Dinophyceae) in north European waters, accompanied by mortality in marine organisms. Sarsia, 63, 123-133.

TURLEY, C. M. and LOCHTE, K. (1985). Direct measurement of bacterial productivity in stratified waters close to a front in the Irish Sea. Mar. Ecol., Progr. Ser., 23, 209-219.

WATER RESEARCH COUNCIL (1983). Estimates of the mass of the six List I and six List II substances discharged to tidal waters in the United Kingdom. Internal Rep., Wat. Res Coun., (611-M), 1-33.

WATER RESOURCES BOARD (1966a). Morecambe Bay Barrage: Report of Consultants. HMSO, London, 23 pp.

WATER RESOURCES BOARD (1966b). Solway Barrage: Report of Consultants. HMSO, London, 30 pp.

WATER RESOURCES BOARD (1966c). Morecambe Bay and Solway Barrages: Report on Desk Studies. HMSO, London, 14 pp.

WILLIAMSON, D. I. (1952). Distribution of plankton in the Irish Sea in 1949 and 1950. Proc. and Trans. L'Pool. Biol. Soc., 58, 1-46.

WOODCOCK, H. M. (1904). Note on a remarkable parasite of plaice and flounders. Rep. Lancs. Sea Fish. Labs., 1903, 12, 63-72.

WOOTTEN, R., McVICAR, A. H. and SMITH, J. W. (1982). Some disease conditions of fish in Scottish waters. ICES CM 1982/E:46, 4 pp. (mimeo).

SECTION E TABLES

Table 1 Mean values of physical and chemical characteristics along the path of six seasonal cruises in Liverpool Bay during 1975. (From Foster et al., 1978)

	Salinity $^{o}/oo$	Temp °C	Si µg at l^{-1}	NO_3^- -N µg at l^{-1}	NO_2^- -N µg at l^{-1}	NH_3^- -N µg at l^{-1}	PO_4^- -P µg at l^{-1}
January	32.90	7.81	12.1	10.4	0.5	0.4	1.16
April	32.59	7.14	7.9	17.2	0.5	2.6	1.87
May	32.66	11.54	3.8	5.6	0.4	0.3	0.68
June	32.83	13.03	0.7	0.9	0.2	1.3	0.35
September	33.21	16.82	3.2	0.7	0.2	0.7	-
December	32.54	7.96	10.7	12.0	0.9	5.5	1.71

Table 2 Salinity to nutrient correlation coefficients for the seasonal cycle of cruises. (From Foster et al., 1978)

	Nitrate	Silicate	Phosphate
January	-0.972	-0.916	-0.794
April	-0.915	-0.157	-0.005
May	-0.712	+0.280	-0.413
June	+0.560	+0.021	-0.311
September	-0.553	-0.277	-
December	-0.851	-0.896	-0.846

Table 3 Dissolved metals in surface waters from the Irish Sea area

Area	Hg	Cd	Cu	Pb	Ni	Zn	Fe	Mn	References
Liverpool Bay		(140-740)270	(0.90-3.0)1.45	(0.66-4.17)1.74		(2.3-48)12			Abdullah *et al.* (1972)
Cardigan Bay		(480-2410)1110	(0.98-4.02)1.72	(1.12-3.53)2.24		(3.6-20)7.5			" " " "
North Channel		(<10-180)	(0.30-1.50)	(0.02-0.36)					Steele *et al.* (1973)
Western Irish Sea		(<10-520)110	(0.18-3.75)0.59	(<0.05-1.20)0.19	(0.22-0.55)0.38	(0.8-9.0)3.0	(0.03-0.6)0.09	(0.15-2.6)0.53	Preston (1973)
Eastern Irish Sea		(<10-620)40	(0.28-0.98)0.66	(<0.05-1.00)0.11	(0.32-23)0.71	(2.3-7.5)4.2	(0.06-1.9)0.18	(0.22-15)1.95	" "
Irish Sea	(6-22)13								Baker (1977)
Irish Sea		(<10-230)76	(0.08-1.32)0.44		(0.03-0.34)0.12	(1.0-13)2.6			Jones and Jefferies (1983)
South East Irish Sea		(11-220)	(1.01-2.48)1.73	(0.21-1.4)					Van den Berg (1984)
Offshore of sewage sludge dump site		(77-78)77	(0.72-0.95)0.83		(0.27-0.34)0.30	(4.20-6.20)5.2			Norton *et al.* (1984(a)(b))
At dump site		(64-100)82	(0.87-1.25)1.1		(0.37-0.45)0.41	(6.46-8.93)7.7			" " " "
Inshore of dump site		(87-160)120	(0.98-1.43)1.2		(0.51-0.57)0.54	(7.66-13.3)10.5			" " " "
North East Irish Sea		(22-85)37	(0.32-1.28)0.49	(0.016-0.053)0.023					Balls (1986, in press)

(Range) Mean units are μg l^{-1} except for Cd and Hg which are in ng l^{-1}

Note: The decline in certain metal levels over time may not be real. See text page 19.

Table 4 Elemental composition (mg kg^{-1}) of suspended particulate material from the Irish Sea area

Area	Cd	Cu	Pb	Zn	Ni	Mn	Fe	References
Irish Sea	(0.04-0.56)0.22	(1.34)16		(75-445)210	(4-117)40			Jones and Jefferies (1983)
Offshore of Liverpool sewage dump site	(0.21-0.5)0.35	(32-48)40		355	(39-690)365			Norton *et al.* (1984(a)(b))
At dump site	(0.18-0.8)0.13	(30-103)66		(336-529)442	(31-974)500			" " " "
Inshore of dump site	(0.27-0.3)0.28	(28-54)41		(327-349)338	(27-83)55			" " " "
Irish Sea/North Channel	(0.04-1.5)0.41	(9-49)28	(28-87)58	(190-510)300		(1100-6400) 2,600	(32,000-110,000) 70,000	Balls (1986, in press)

(Range) mean

Note: Average composition of 115 surface sediments from the central north eastern Irish Sea, Cronan (1970), (Co, Cu, Ni, Mo, Sn, V, Zn, 12 samples) B 32 ppm, Ba 252 ppm, Cr 17 ppm, Fe 1.59%, K 0.99%, Mn 637 ppm, P 439 ppm, Sr 302 ppm, Ti 1021 ppm, Zr 168 ppm, Co 3 ppm, Cu 7 ppm, Ni 18 ppm, Mo n.d.

Table 5 Mean values and ranges of selected metals ($\mu g\ g^{-1}$) in Belfast Lough sediments, 1978

No. of sites	Docks 5	Inner Lough 15	Outer Lough 21
Cr	248 (200-290)	212 (150-355)	169 (116-235)
Mn	523 (424-578)	432 (188-728)	449 (379-582)
Ni	115 (97-138)	87 (36-148)	76 (57-102)
Cu	90 (59-205)	28 (11-54)	19 (10-32)
Zn	529 (245-669)	309 (83-798)	135 (46-414)
Pb	290 (176-460)	139 (52-207)	166 (128-250)

Table 6 The range, mean and standard deviation of metal concentrations in the <90 μm fraction of surface sediment samples ($\mu g\ g^{-1}$ dry weight)

	Cr	Ni	Cu	Zn	Cd	Hg	Pb
Range	28-230	13-100	11-130	81-490	<0.2-1.7	0.08-2.6	29-570
Mean	76	30	31	230	-	0.59	87
SD	25	8.8	15	76	-	0.46	59

Table 7 Contaminants in fish and mussels from the Irish Sea

Contaminant		Range in concentration (mg kg^{-1} wet weight)			
		Western Channel	Liverpool Bay	Morecambe Bay	St Bees' Head/ NE Isle of Man
Hg	Fish (M)	0.05-0.11	0.21-0.35	0.17-0.60	0.10-0.22
	Mussels	0.04-0.07	0.06-0.12	0.06-0.10	0.05-0.06
Cu	Fish (M)	<0.2-0.2	0.2-0.3	0.2-0.3	<0.2-0.3
	Mussels	1.2-3.8	1.7-2.2	1.1-1.8	1.4-1.5
Zn	Fish (M)	3.0-5.8	3.3-5.3	2.4-6.2	3.3-6.1
	Mussels	15-50	17-62	25-28	20-24
Cd	Fish (L)	<0.2 (M)	<0.2-0.4	<0.2	<0.2
	Mussels	0.3-0.5	0.4-0.5	0.3-0.6	0.5-2.0
Pb	Fish (L)	<0.2 (M)	<0.4	<0.2	<0.2
	Mussels	1.0-1.8	1.2-4.3	1.6-2.6	1.0-2.0
Dieldrin	Fish (L)	0.02-0.35	0.01-0.20	<0.01-0.23	0.08-0.09
	Mussels	<0.01	0.03	0.01	0.02
ΣDDT	Fish (L)	0.06-1.0	0.27-2.8	0.03-3.4	0.21-0.42
	Mussels	0.01-0.08	0.08	<0.01-0.02	0.01
PCBs	Fish (L)	0.2-4.0	0.9-8.4	0.4-6.4	0.18-2.0
	Mussels	<0.05-0.1	0.15	<0.05	<0.05

Fish species included - cod, whiting, plaice, dab, flounder and sole (where available)

(M) = muscle tissue analysed

(L) = liver tissue analysed

Mussels (*Mytilus edulis*), total homogenate analysed

Table 8 Concentrations of metals and selected organochlorine residues in mussels from English and Welsh coasts of the Irish Sea ($\mu g\ g^{-1}$ dry wt)

Location	Mercury	Cadmium	Lead	Zinc	Copper	HCH α and γ	Dieldrin	ΣDDT	PCB
Angle Bay	0.19	-	6.4	150	6.4	-	-	-	-
Nolton Haven	0.09	0.9	2.8	66	5.7	-	-	-	-
Cardigan	0.09	0.9	4.2	71	7.5	-	-	-	-
Aberporth	0.17	1.7	7.6	100	7.9	-	-	-	-
Aberaeron		2.6	5.1	76	6.4	-	-	-	-
Aberdovy	0.19	-	61	110	4.6	-	-	-	-
Porthmadog	0.62	1.4	16	100	4.9	-	-	-	-
Tal-y-Foel	0.42	2.1	7.6	93	8.1	-	-	-	-
Bangor	0.61	3.5	13	120	8.2	-	-	-	-
Conwy	0.27	1.8	5.3	75	7.5	-	-	-	-
Liverpool	0.87	3.6	31	450	16	<0.03	0.22	0.60	1.1
Lytham St Annes	0.19	-	8.0	170	11	<0.02	0.08	0.19	0.24
Blackpool	0.22	-	7.1	130	8.5	-	-	-	-
Fleetwood	0.49	2.1	14	190	10	<0.03	0.08	0.08	<0.3
Heysham	0.47	2.7	11	190	12	<0.03	0.03	0.04	<0.3
Morecambe	0.34	1.7	11	140	10	<0.02	0.06	0.10	<0.2
Barrow in Furness	0.51	3.1	13	130	5.7	-	-	-	-
Ravenglass	0.42	3.5	6.9	170	9.7	-	-	-	-
Whitehaven	0.38	15	15	150	12	-	-	-	-
Maryport	0.42	4.2	11	120	7.1	-	-	-	-
Silloth	0.17	2.2	5.3	66	7.5	-	-	-	-
Bowness	0.13	1.3	4.3	55	7.7	-	-	-	-

Table 9 Concentrations of metals and selected organochlorine residues in mussels from Northern Ireland coasts of the Irish Sea ($\mu g\ g^{-1}$ dry wt)

Location	Mercury	Cadmium	Lead	Zinc	Copper	HCH α and γ	Dieldrin	ΣDDT	PCB
Cultra	0.30	2.4	9.9	190	7.6	<0.06	0.03	0.08	0.21
Bangor	0.30	2.0	8.5	210	7.3	<0.05	<0.03	<0.02	<0.47
Newtownards	0.58	3.7	12	140	8.7	<0.03	<0.03	<0.02	<0.01
Kircubbin	0.37	1.6	6.0	92	6.0	<0.03	<0.03	<0.02	<0.01
Killyleagh	0.41	2.2	13	130	7.3	<0.02	<0.03	<0.02	<0.01
Whiterock	2.2	1.7	8.3	91	5.3	0.02	<0.03	<0.02	<0.01
Warrenpoint	0.22	1.5	5.9	80	6.6	<0.02	<0.03	<0.02	<0.01
Tyrella	0.14	1.4	5.7	86	6.1	<0.01	<0.03	<0.02	<0.01
Belfast	0.29	9.4	15	180	9.4	-	-	-	-
Macedon Pt	0.06	1.8	6.1	105	6.5	-	-	-	-
Whiteabbey	0.03	1.5	5.8	99	5.8	<0.01	<0.03	<0.02	<0.03
Lough Larne	0.02	2.2	5.3	46	5.7	<0.05	<0.03	<0.02	0.49

Table 10 Chlorinated hydrocarbon concentrations in sea water from coastal sites in Wales

Site location	Salinity ($^0/oo$)	Suspended load (mg l^{-1})	Concentrations in sea water (ng l^{-1})			
			ΣDDT	Dieldrin	γ-HCH	PCB Aroclor 1260
Angle Bay	33.52	348	ND	0.9	3.1	ND
Pembroke	29.49	167	ND	0.8	3.1	ND
Mussel Wick	31.71	872	ND	0.6	3.2	ND
Nolton Haven	32.23	24	ND	0.6	2.8	ND
Strumble Head	34.62	49	ND	0.4	4.6	ND
Cardigan	6.10	32	ND	0.9	6.2	ND
Aberaeron	19.47	55	ND	0.4	3.9	ND
Aberystwyth	31.32	77	ND	0.3	2.9	ND
Barmouth	10.37	17	ND	0.6	18.0	ND
Porthmadog	10.92	12	ND	1.0	7.8	ND
Pwllheli	4.82	22	ND	0.7	7.0	ND
Caenarvon	13.97	33	ND	1.0	7.0	ND
Menai Bridge	32.45	44	ND	0.8	8.2	ND
Beaumaris	30.94	172	ND	0.8	6.2	ND
Conwy	6.95	70	ND	1.0	9.2	ND
Rhyl	30.55	100	ND	1.1	11.4	ND
Mostyn	29.20	124	ND	0.8	15.2	ND
Flint	7.09	30	ND	0.8	17.6	ND
Connah's Quay	2.85	15	ND	1.4	26.4	ND

Note: ND = not detectable

Table 11 Estimates of contaminant inputs via Atlantic inflow to Irish Sea. Assumes a mean inward water transport of 5 km^3 d^{-1} (i.e. 5.8 x 10^4 m^3 s^{-1})

	Assumed concentration (ng l^{-1})	Mean input (kg d^{-1})
Cd	5	25
Hg	1	5
Pb	10	50
Cu	70	350
Zn	10	50
DDT	0.1	0.5
PCB	0.1	0.5
Total hydrocarbons	1000	5000

Table 12 Estimated inputs to coastal and estuarine waters of the Irish Sea from English and Welsh coasts

Sector	Route	Flow (10^3 m^3 d^{-1})	Tonnes per day				Grams per day				Kilograms per day							
			BOD	NH_4-N	No_x-N	PO_4-P	γHCH	Drins	DDT	PCBs	Mercury	Cadmium	Arsenic	Chromium	Copper	Lead	Nickel	Zinc
E26	River	6853	9.6	0.4	8.2	0.3	83	30	56	56	0.6-1.3	2.7-4.6	11-14	24-74	37-61	30-87	61-88	720
	Sewage	26	9.0	1.0	NS	0.2	1.0-3.6	0.3-1.1	0.4-2.1	0.2-1.5	-	0.1	0.1	0.8	2.4	1.6-1.8	0.4-0.5	8.2
	Trade	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	TOTAL	6879	18.6	1.4	8.2	0.5	84-86.6	30.3-31.1	56.4-58.1	56.2-57.5	0.6-1.3	2.8-4.7	11.1-14.1	24.8-74.8	39.4-63.4	31.6-88.8	61.4-88.5	728
E27	River	5440	9.0	0.7	7.6	0.8	29	14	27	27	0.2-0.5	1.0-2.6	5.3	20-28	14-24	33-50	22-26	167
	Sewage	76	7.1	1.3	0.7	0.5	3.4-7.7	2.6-3.3	3.8-7.6	2.6-7.6	-	0.7-0.9	0.6	4.6-4.7	7.9	5.8	2.3-2.7	210
	Trade	16	5.8	0.1	NS	NS	-	-	-	-	-	0.9	-	5.8	6.0	9.1	3.5	966
	TOTAL	5532	21.9	2.1	8.3	1.3	32.4-36.7	16.6-17.3	30.8-34.6	29.6-34.6	0.2-0.5	2.6-4.4	5.9	30.4-38.5	27.9-37.9	47.9-64.9	27.8-32.2	1343
E28	River	5918	31	31	24.2	6.7	41-76	max. 18	max. 34	max. 34	3.5	1.9	7-21	48-75	58	223	56	205
	Sewage	515	176	11	0.6	1.6	14-52	12-19	9-14	1-20	0.2	1.7	1	51-63	131	192	27-99	639
	Trade	113	48	2.3	0.2	NS	NS	NS	NS	NS	NS	0.5	NS	2	80	10	1-8	14-50
	TOTAL	6546	255	44.3	25.0	8.3	55-128	12-37	9-48	1-54	3.7	4.1	8-22	101-140	269	425	84-163	858-894
E29	River	9271	26	2.5	21.6	2.7	14-68	max. 30	max. 58	max. 58	0.4-1.2	2.5	11-13	36-83	45	21-51	25	146
	Sewage	226	48	7.1	NS	0.5	7-24	6-9	6-11	2-11	0.1	0.5	1	12-23	41-68	21	5-25	149
	Trade	48	6	0.5	2.4	NS	NS	NS	NS	NS	0.5	NS	NS	4	3	2	4	5
	TOTAL	9545	80	10.1	24.0	3.2	21-92	6-39	6-69	2-69	1.0-1.8	3.0	12-14	52-110	89-116	44-74	34-54	300
E30	River	8813	18	0.5	11.6	0.8	9-53	max. 26	max. 49	max. 49	0.2-1.0	0.3-0.8	10	20-100	17	20-44	11	66
	Sewage	34	5	0.7	NS	NS	1	0.3-0.6	0.2-0.4	max. 0.6	NS	NS	NS	1-2	6	9	1-5	25
	Trade	92	36	0.2	NS	31.7	NS	0.3	NS	NS	0.5	44.1	NS	225	81	30	67	170
	TOTAL	8939	59	1.4	11.6	32.5	10-54	0.6-26.9	0.2-49.4	max. 49.6	0.7-1.5	44.4-44.9	10	246-327	104	59-83	79-83	261

Notes: NS indicates input thought to be not significant.
Range of values given where alternative estimates are significantly different or where alternative methods of interpreting results less than limit of detection have been used.
In the absence of reliable WA data, values reported in WRC report (WRC, 1983) have been used for all inputs of drins, DDT, PCBs and arsenic.
The comparable discharge data in Figure 2 (Anon, 1978) are in units of 10^6 m^3 y^{-1}.
The major industrial zinc input to the Dee, included in this table (Area E27), has now ceased (from end of 1985).
Sector boundaries are illustrated in Figure 2.

Table 13 Known inputs of metals in tonnes per year from Northern Ireland

	Cd	Cr	Cu	Pb	Hg	Ni	Zn
Sludge dumping	0.08	1.40	2.69	2.21	0.04	0.87	8.90
Trade and sewage effluents	1.32	1.59	ND	ND	ND	ND	ND
Rivers	0.25-0.38	5.52	8.88	17.4	0.06-0.11	8.08 10.45	20.2-25.2

ND = No data

Table 14 Comparison of estimated inputs of metals to the Mersey Estuary with net inputs to Liverpool Bay calculated from the flux investigations and inputs from other sources

Metal	Load discharged to Mersey Estuary (kg/tide)				Load discharged to Liverpool Bay (kg/tide)				
	Rivers	Sewage	Industry	Total	Sewage sludge	Dredge spoil	Other	Mersey Estuary[1]	Ebb tide transport[1]
Zn	107	328	21	456	209	926	2281	1522	9 913
								1606	17 604
								1036 (NS)[2]	30 315
								-1144 (NS)[3]	34 787
Ni	29	51	0.6	81	7	123	30	129	1 192
								142 (NS)	1 862
								-100 (NS)	2 371
								-80 (NS)	2 788
Cu	30	67	41	138	80	188	55	280 (NS)	3 231
								-227 (NS)	5 584
								-335 (NS)	7 151
Cd	1	0.9	0.3	2.2	1.6	2.7	3.7	12	61
								20	73
								21	101
								-7 (NS)	116
Hg	1.8	0.1	0.005	1.9	0.7	2.5	0.85	19	170
Pb	116	98	5	219	96	329	58	471	2 347
								265	2 773
								346 (NS)	8 373
								-677 (NS)	9 358

Notes: 1. Data from Mersey flux surveys.
2. (NS) not significant.
3. Negative sign indicates landward transport.

Table 15 Inputs of sewage sludge, industrial wastes, dredge spoil via dumping, tonnes in 1984

Location	Total weight	Organics	Solids	Cd	Cr	Cu	Ni	Pb	Zn	Hg	Ocs	N	P
Liverpool Bay													
Sites 114-120 incl.													
Industrial	28 924	1 894	4 527	0	0	0.1	0.1	0	0.5	0	0	77	-
Sewage sludge	1 279 050	49 303	49 303	0.6	41.1	26.4	3.1	47.4	143.1	0.3	3.6	2.232	838
Dredge spoil	3 545 000	-	1 371 947	1.1	113.3	103.3	60.9	191	560.7	3.1	0.1	-	-
Holyhead Site 111													
Dredge spoil	10 400	-	10 088	0	0.2	1.2	0.8	1.7	2.2	0			
Outer Morecambe Bay													
Sites 122/124													
Dredge spoil	688 500	-	513 400	0	6.9	12.3	0	20.7	34.4	0.5			
Cumbria Coast													
Site 127 Dredge spoil	119 600	-	59 800	0	1.2	1.2	0	4.8	7.2	0			
128 " "	353 600	-	176 800	0.2	7.1	7.1	17.7	31.8	0.1	0			
132 " "	85 600	-	42 800	0	1.7	4.3	0	3.4	8.6	0			

Table 16 Total international catch in kilograms per hectare averaged for the period 1973-78

	North Sea				Irish Sea (VIIa)	English Channel (VIId+e)	Bristol Channel (VIIg)
	IVa North	IVb Central	IVc South	IV Total			
Demersal	20.2	15.3	13.7	17.3	8.0	6.5	6.3
Pelagic	15.9	18.9	1.9	15.8	9.1	19.9	28.3
Industrial	24.8	16.6	3.6	18.7	+	0.1	0.8
Total fish	60.9	50.8	19.3	51.7	17.1	26.4	35.4
Shellfish	0.3	3.0	21.3	3.9	4.3	10.1	1.0
Area ($km^2 \times 10^3$)	253.6	270.4	64.5	588.5	48.2	86.5	18.3

Table 17 Total biomass of the main commercial demersal species in the Irish Sea and North Sea

Rank	Irish Sea			North Sea		
	Species	Biomass (t)	Cumulative percentage	Species	Biomass ($t \times 10^3$)	Cumulative percentage
1	Cod	18 056	29	Saithe	725	26
2	Whiting	15 482	55	Whiting	625	49
3	Sole	7 324	67	Cod	483	66
4	Plaice	6 241	77	Haddock	400	80
				Plaice	385	94
5	Rays	6 198	87	Sole	50	96
6	Saithe	3 108	92			
7	Hake	1 360	94	Ling	34	97
8	Monk	1 026	96	L. sole	17	98
9	Pollack	786	97	Turbot	13	98
10	Ling	412	98	Monk	13	99
11	Haddock	376	99	Rays	13	99
12	Brill	303	99	Hake	8	99
13	Turbot	285	100	Pollack	7	100
14	Megrim	205	100	Brill	4	100
15	L. sole	198	100	Megrim	2	100
	Total	61 360		Total	2 779	
	Dab	7 166		Dab	670	
	Dogfish	6 380		Dogfish	589	
	Gurnard	3 120		Gurnard	39	

Table 18 Nominal catch (t) in Division VIIa, 1976-85 as reported to ICES

Species	Year									
	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985[1]
Cod	10 178	8 054	6 328	8 358	10 739	14 894	13 281	9 880	8 529	9 758
Whiting	12 193	10 721	11 069	10 111	12 665	17 029	16 989	10 829	12 542	15 603
Plaice	3 484	2 904	3 313	3 489	3 903	3 906	3 228	3 653	4 207	6 066
Sole	1 463	1 147	1 098	1 617	1 938	1 669	1 339	1 265	1 085	1 683

1 Preliminary

Table 19 Corrected effort and cpue: UK (E + W) otter trawl - Division VIIa

Year	Effort	No. of voyages	Species cpue								Total demersal (t)
			Cod	Hake	Angler	Plaice	Saithe	Rays	Sole	Whiting	
1972	128 401	2 443	18.08	0.71	1.39	6.96	3.32	15.59	1.06	4.78	7 053
1973	147 642	2 703	15.01	0.97	1.16	6.33	2.04	11.08	1.06	7.78	7 666
1974	115 161	2 460	16.41	1.02	1.20	7.45	2.53	12.67	1.09	5.81	6 278
1975	130 733	4 086	11.50	1.17	0.99	7.71	1.59	11.06	1.39	3.90	6 107
1976	122 337	4 302	12.01	0.98	1.03	5.03	1.39	11.04	0.94	4.30	5 390
1977	101 881	3 380	9.95	0.80	0.82	4.82	1.35	11.83	0.80	5.94	4 765
1978	89 070	3 151	8.61	0.97	1.11	6.77	1.02	14.48	1.04	7.35	4 583
1979	89 864	3 497	8.66	0.90	1.17	7.18	0.92	15.20	1.43	7.00	4 642
1980	107 026	4 386	16.34	0.85	1.25	8.24	2.73	15.42	1.01	7.88	5 922
1981	107 063	4 451	20.46	0.88	1.24	6.87	1.29	13.37	0.75	6.58	6 524
1982	127 194	4 415	15.74	0.93	1.29	4.92	1.47	14.46	0.53	6.12	7 912
1983	88 088	3 070	11.51	1.10	1.37	5.32	0.99	14.84	0.57	6.03	4 647
1984	103 109	3 482	11.73	0.95	1.40	7.77	0.90	15.05	0.71	5.89	5 730
1985	102 763	3 655	9.37	0.79	1.40	9.87	2.19	12.79	0.56	7.71	6 063

Effort = Hours fishing, corrected for fishing power.
cpue = kg (whole weight per corrected hour, weighted by area of each rectangle group).

Table 20 Corrected effort and cpue: UK (E + W) beam trawl - Division VIIa

Year	Effort	No. of voyages	Species cpue Cod	Hake	Angler	Plaice	Saithe	Rays	Sole	Whiting	Total demersal (t)
1978	880	34	1.24	0	0.04	4.46	0	0.69	30.64	1.73	36
1979	1 702	45	5.22	0.03	1.25	15.23	0	2.12	32.01	1.31	93
1980	4 283	109	7.11	0.10	1.61	8.93	0.10	1.53	31.70	1.00	260
1981	6 433	113	2.97	0.68	3.30	4.91	0	11.72	21.32	0.84	342
1982	5 503	65	5.81	0.11	3.04	1.77	0	2.54	29.94	0.56	234
1983	2 770	30	3.40	0.34	3.01	3.08	0.03	1.99	37.31	0.96	130
1984	4 136	66	4.48	0.36	4.46	6.98	0.03	11.84	16.24	2.02	233
1985	6 972	110	1.38	0.24	3.64	37.54	0.01	14.33	19.14	3.06	418

Effort = Hours fishing, corrected for fishing power.
cpue = kg (whole weight per corrected hour, weighted by area of each rectangle group).

Table 21 Percentage prevalence of epidermal anomalies found in the seven fish species examined from the Irish Sea (RV CLIONE 5/82 - 8-17 April 1982)

	Total examined	Epidermal hyperplasia or papilloma	Fin rot	Lymphocystis	Ulcers	Healed ulcers (reparation)	Pigment anomalies	Skeletal deformities	Eye defects	Other tumours
Dab	3 769	1.1	2.1	1.5	1.4	0.4	0.7	0.2	0	0.05
Plaice	5 579	0	1.1	1.4	0.1	0.6	1.3	0.1	0	0
Flounder	841	0	2.8	6.4	0.4	2.0	2.8	0.2	0	0.1
Lemon sole	190	0	0	0	0.0	0	0	0.5	0	0
Dover sole	398	0	0.8	0	0.3	0.8	2.3	0.3	0	0
Cod	444	0	0.7	0	0.2	0	0.7	2.5	0	0.2
Whiting	1 997	1.2	0.3	0	0.1	<0.1	0	0.2	0.25	0

Table 22 A summary of morphological characteristics and abnormalities seen in dab livers from the Irish Sea (RV CLIONE 5b/82, 8-17 April 1982). The figures are shown as percentages

Morphological characteristics		Abnormalities	
33	Eosinophilic	16	Focal necrosis
3	Intermediate	21	Lipoid degeneration
64	Basophilic	1.4	Granuloma
		1.0	Nodules
		1.4	Melanomacrophage centre

A total of 208 livers was examined.

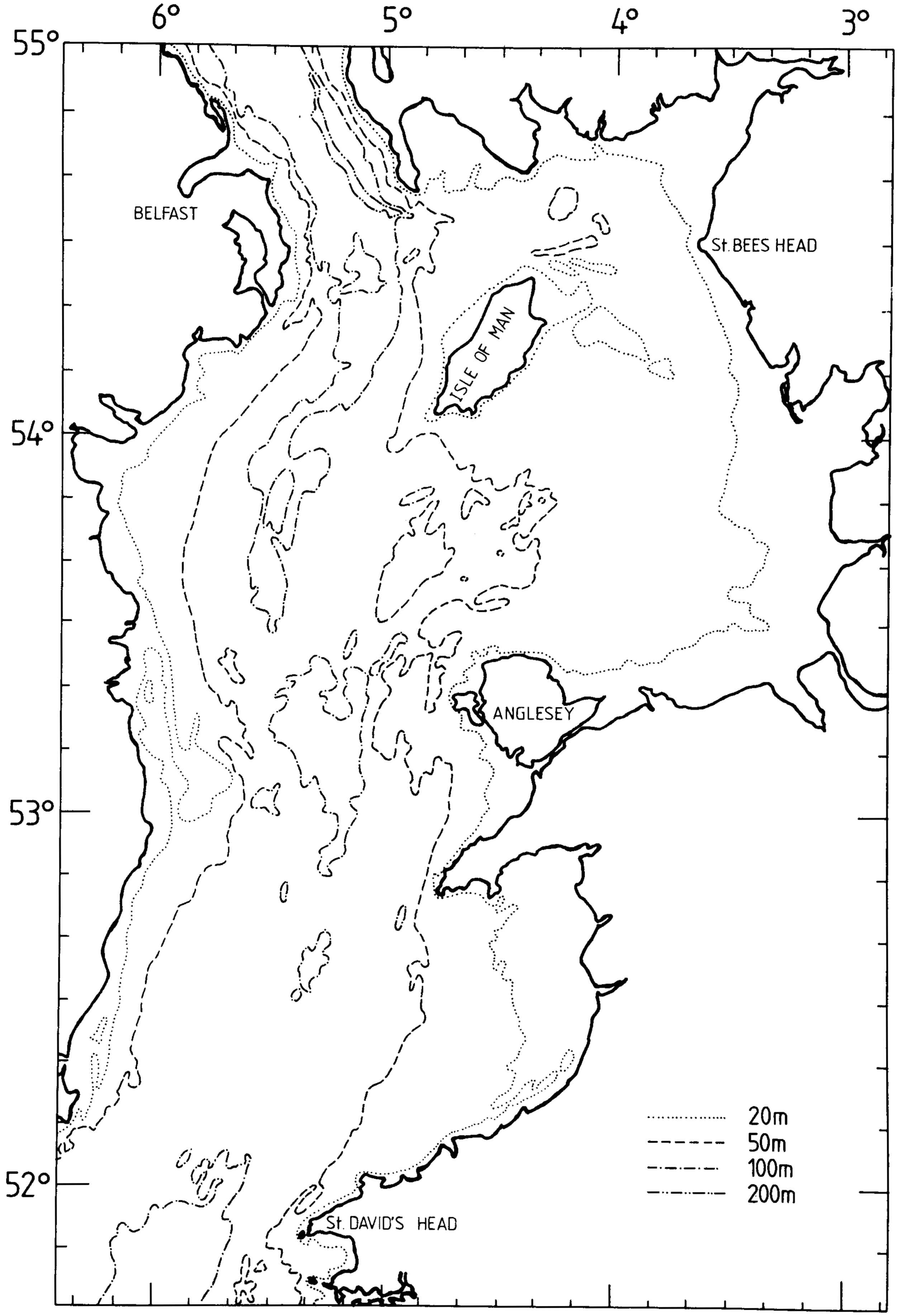


Figure 1 Bathymetry of the Irish Sea.

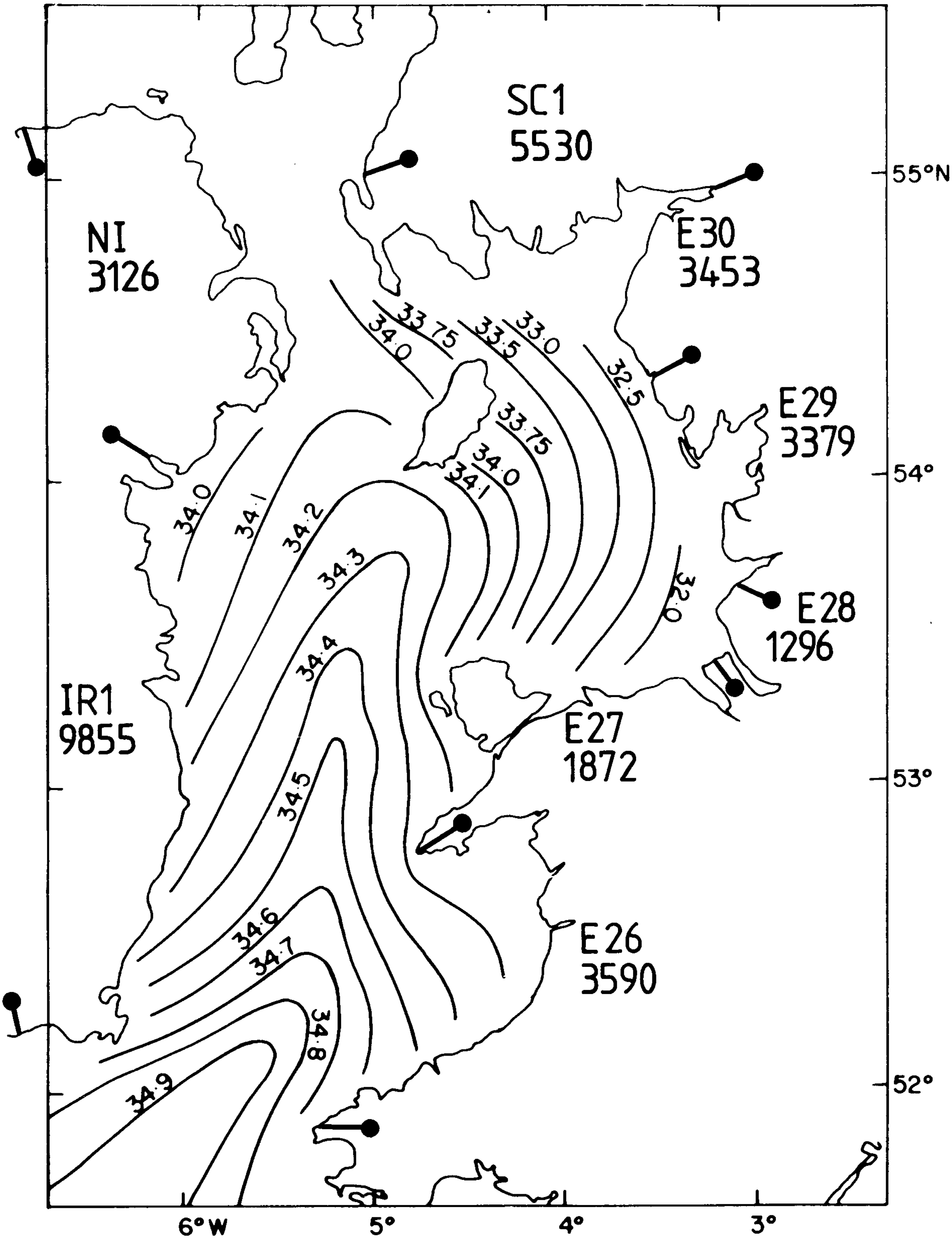


Figure 2 Mean annual surface salinity of the Irish Sea from Bowden (1980), together with river discharge estimates for each coastal sector ($\times 10^6$ m^3 yr^{-1}). (From ICES Cooperative Research Report, (77), (Anon., 1978). Code letters and numbers (e.g. E27) are the identifiers for area divisions used in the ICES report and Table 12.)

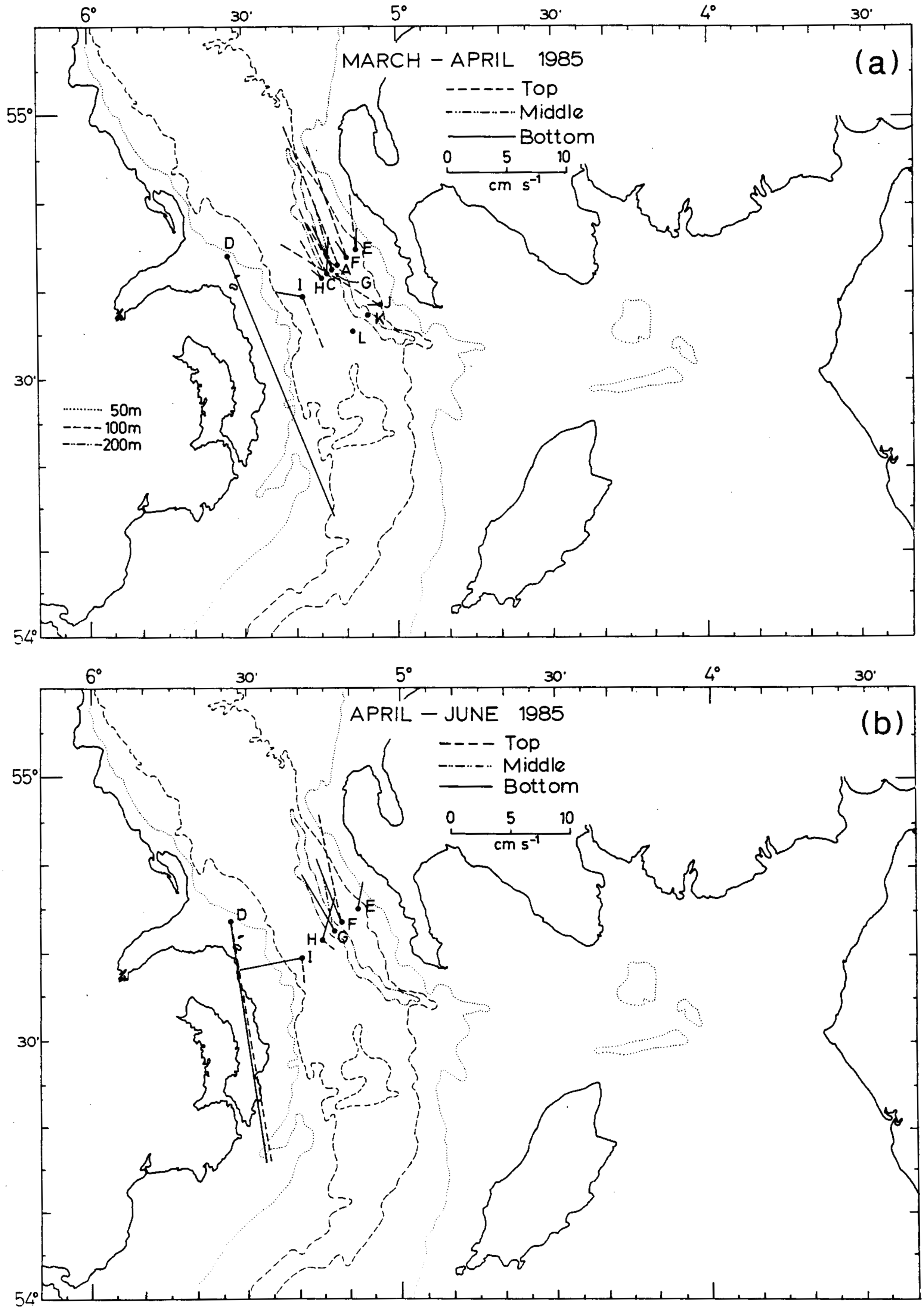


Figure 3 Exercise-mean residual flow vectors for MAFF North Channel current meter arrays in: (a) March-April; and (b) April-June 1985.

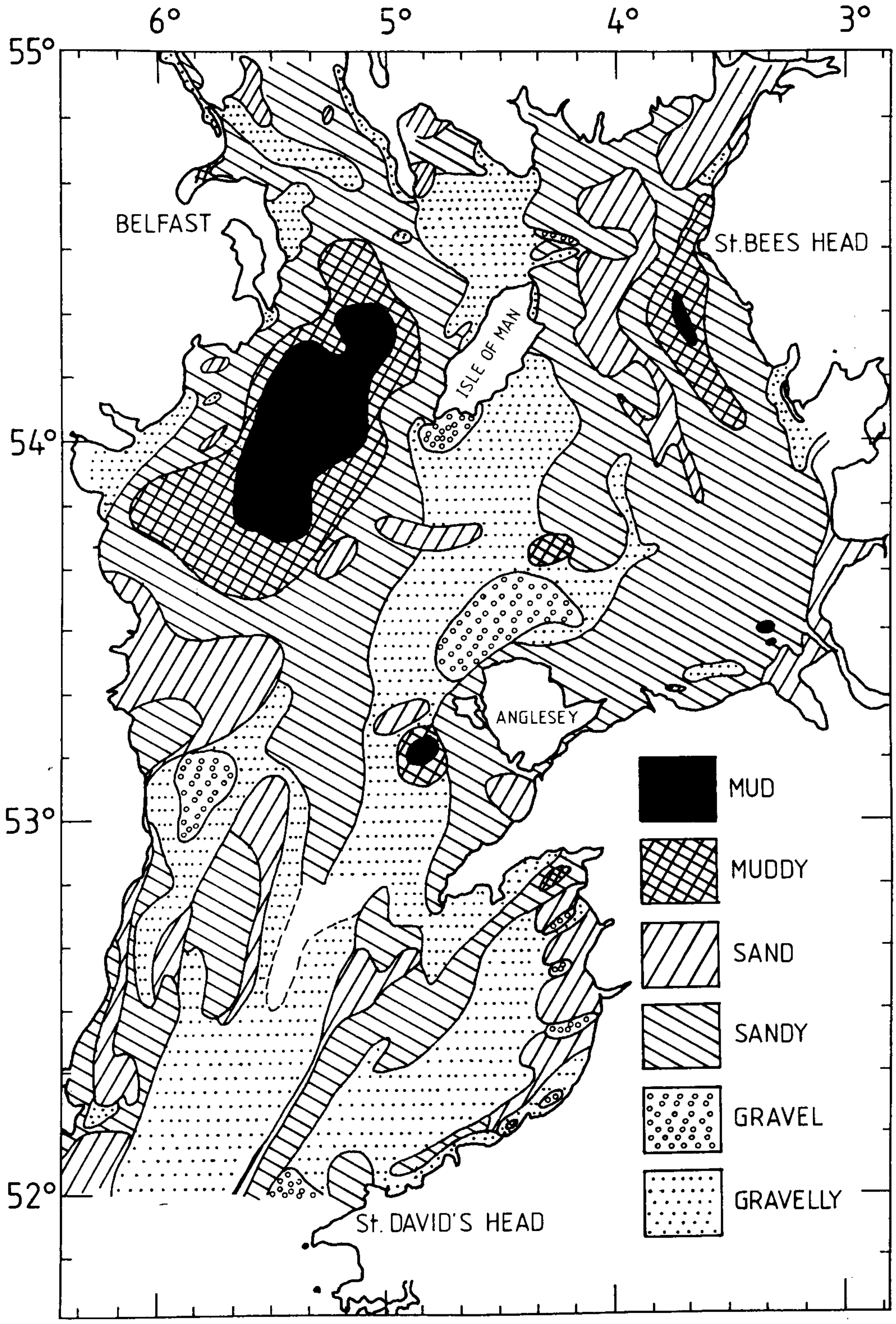


Figure 4 Simplified distribution of surficial sediment types in the Irish Sea. Based on British Geological Survey 1:250000 Series: Sheets 53°N-04°W, 54°N-04°W, 54°N-06°W, the unpublished draft of sheet 52°N-06°W and survey data for sheet 53°N-06°W. 'Muddy' covers categories sM, (g)M, (g)sM, gM. 'Sandy' covers categories mS, (g)S, (g)mS, gmS, gS. 'Gravelly' covers categories mG, msG, sG.

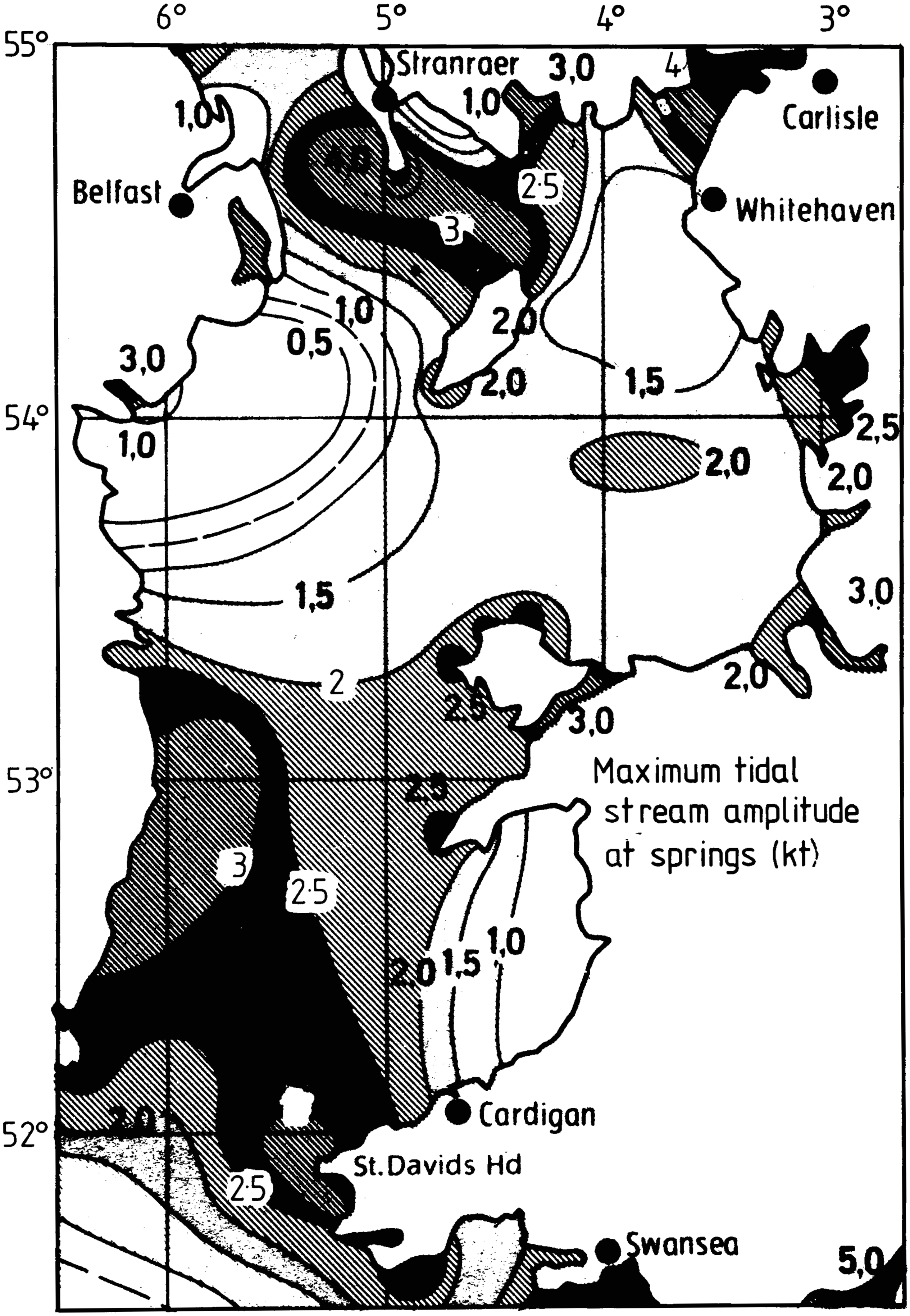


Figure 5 Maximum tidal stream amplitude at Springs (kt). From Sager and Sammler (1975).

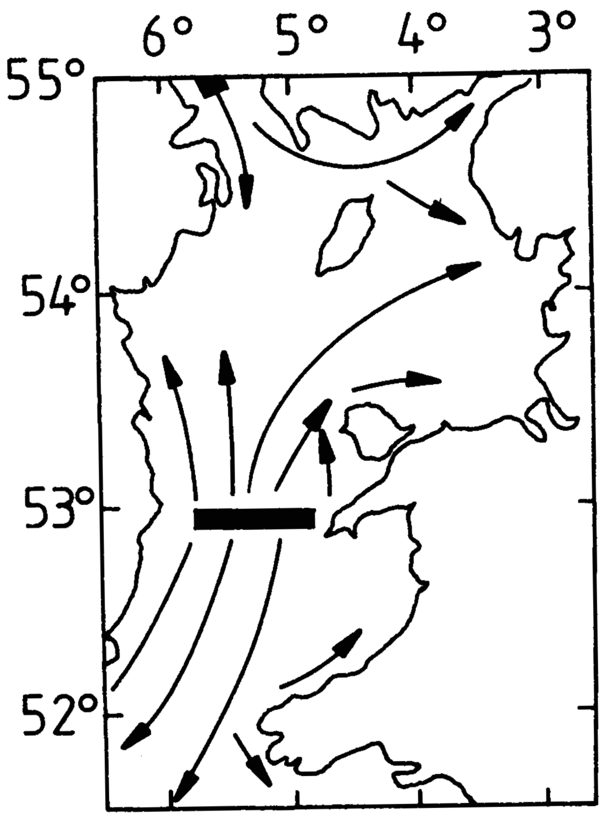
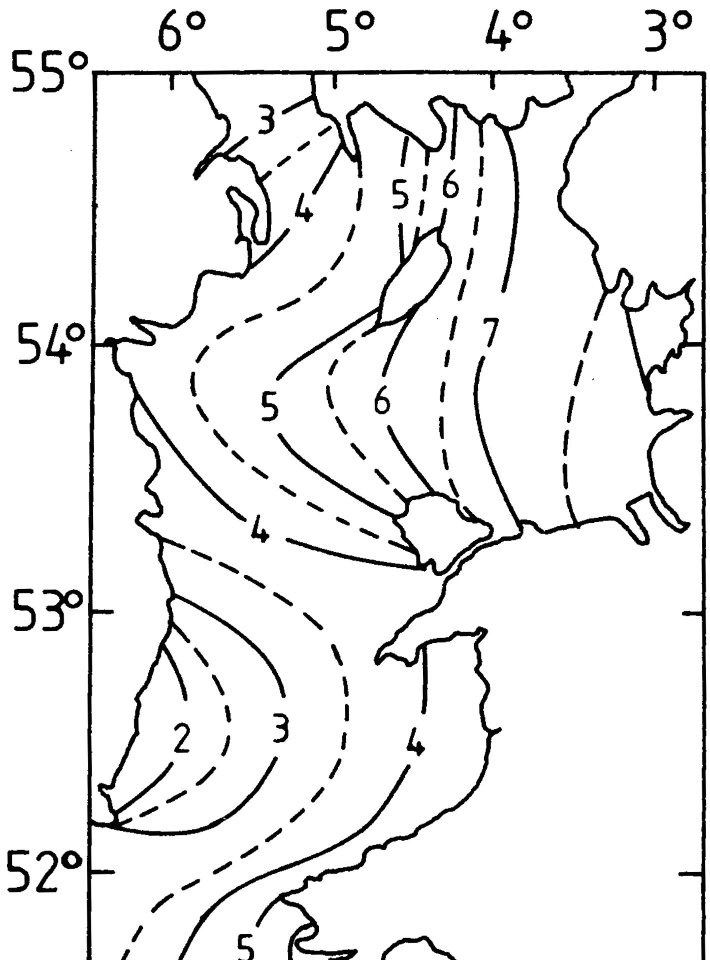


Figure 6 Principal sand transport paths for the Irish Sea. From Stride (1973). (Bars represent bed load partings.)

Figure 7 Tidal range at springs. (From Sager, 1963.)



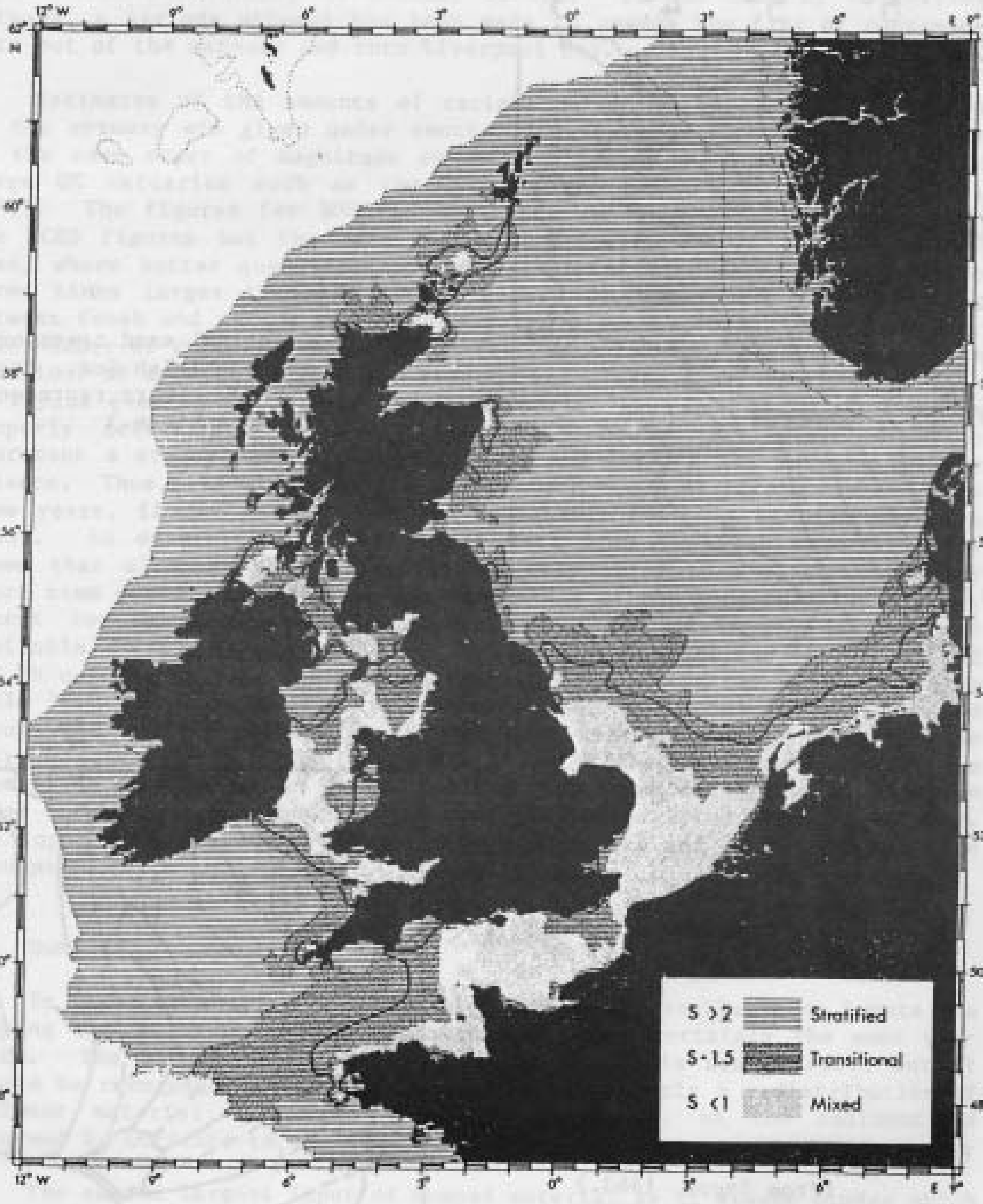


Figure 8 Distribution of the stratification parameter $S = \log_{10} \frac{h}{c_D u^3}$ on the European Shelf. (From Pingree and Griffiths, 1978.)

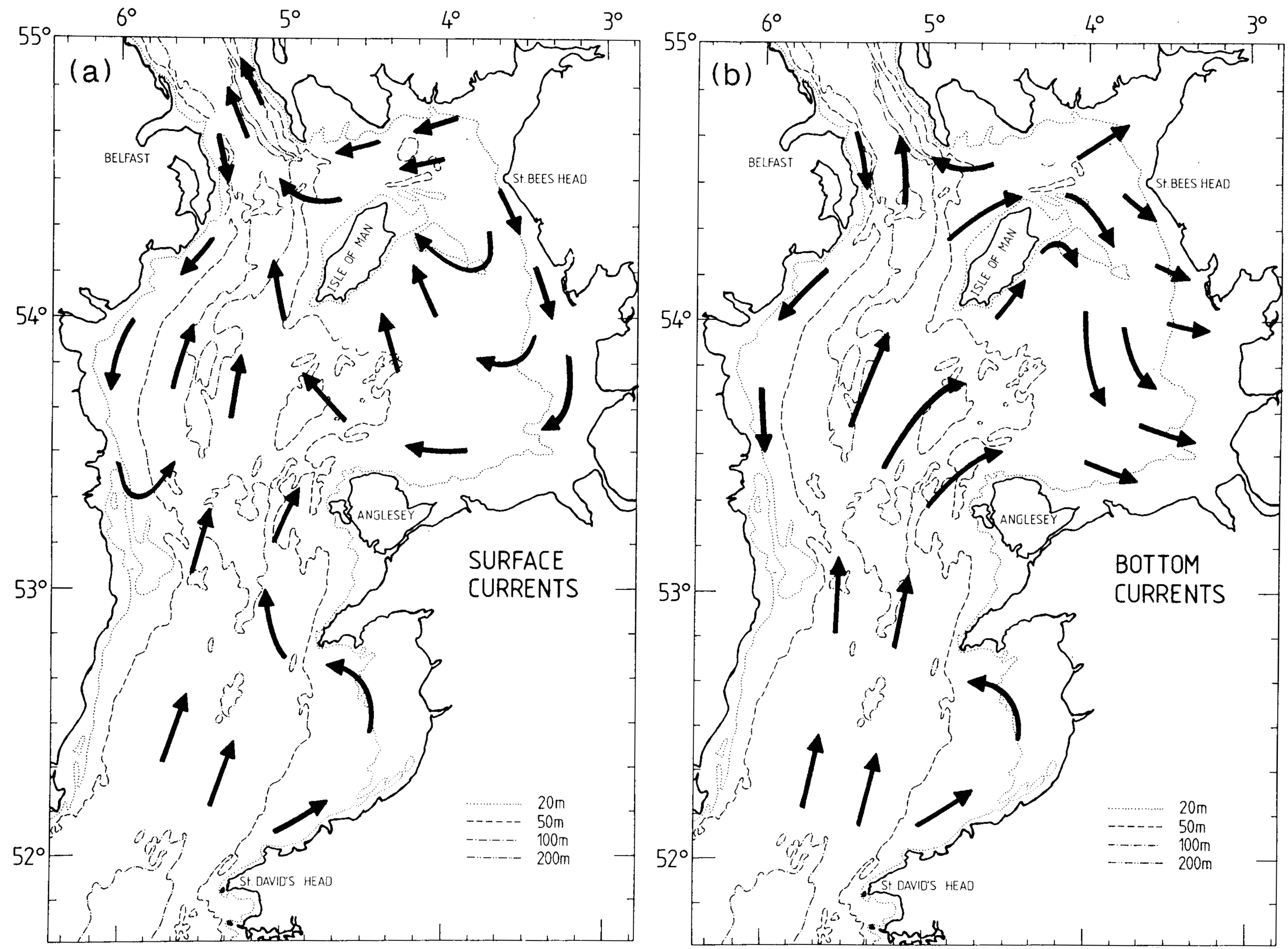


Figure 9 Schematic distribution of: (a) surface; and (b) near-bottom residual currents.

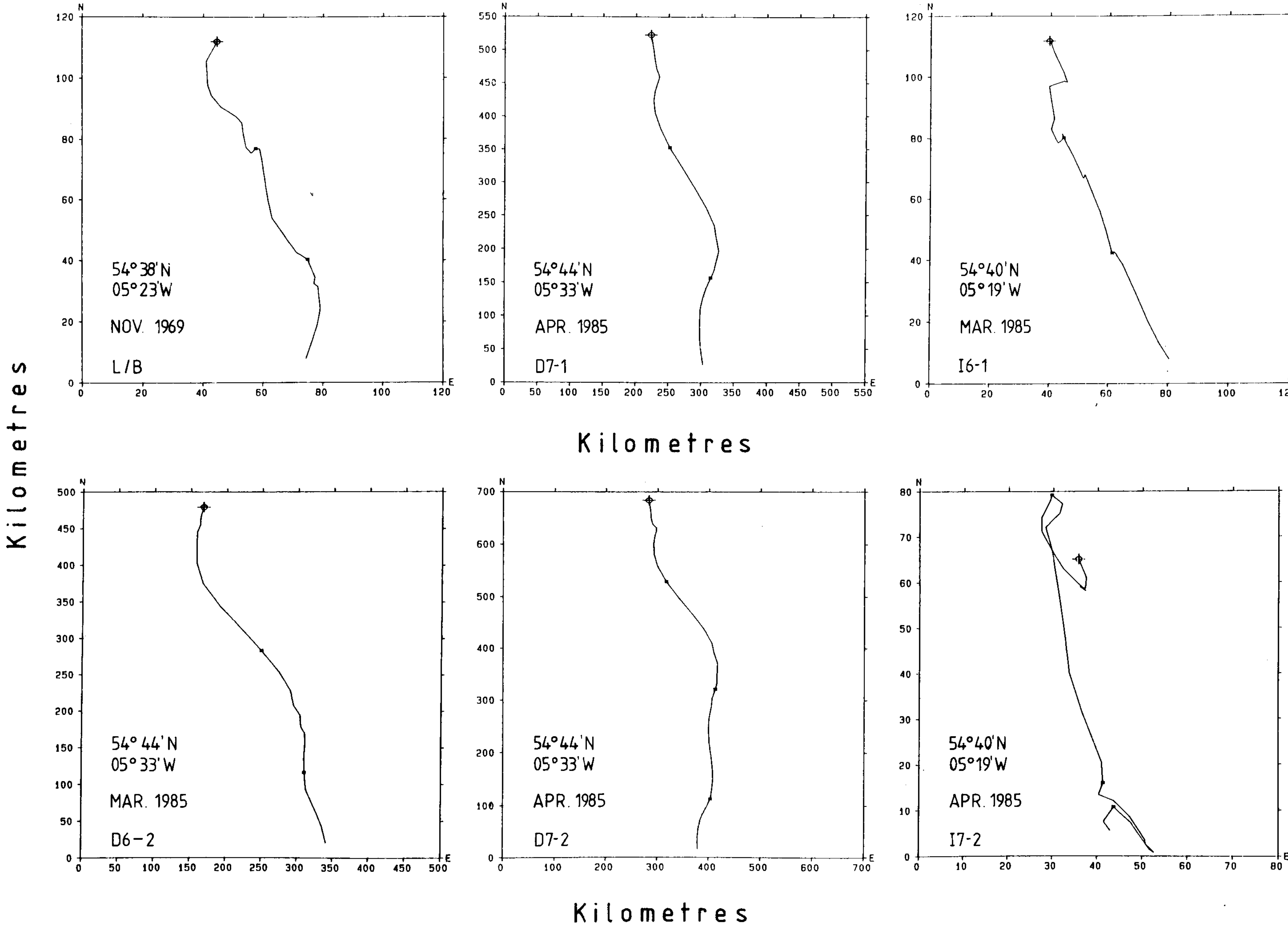


Figure 10 Progressive vector diagrams for all available current meter records obtained from the Irish coastal current in the North Channel of the Irish Sea in 1969 and 1985.

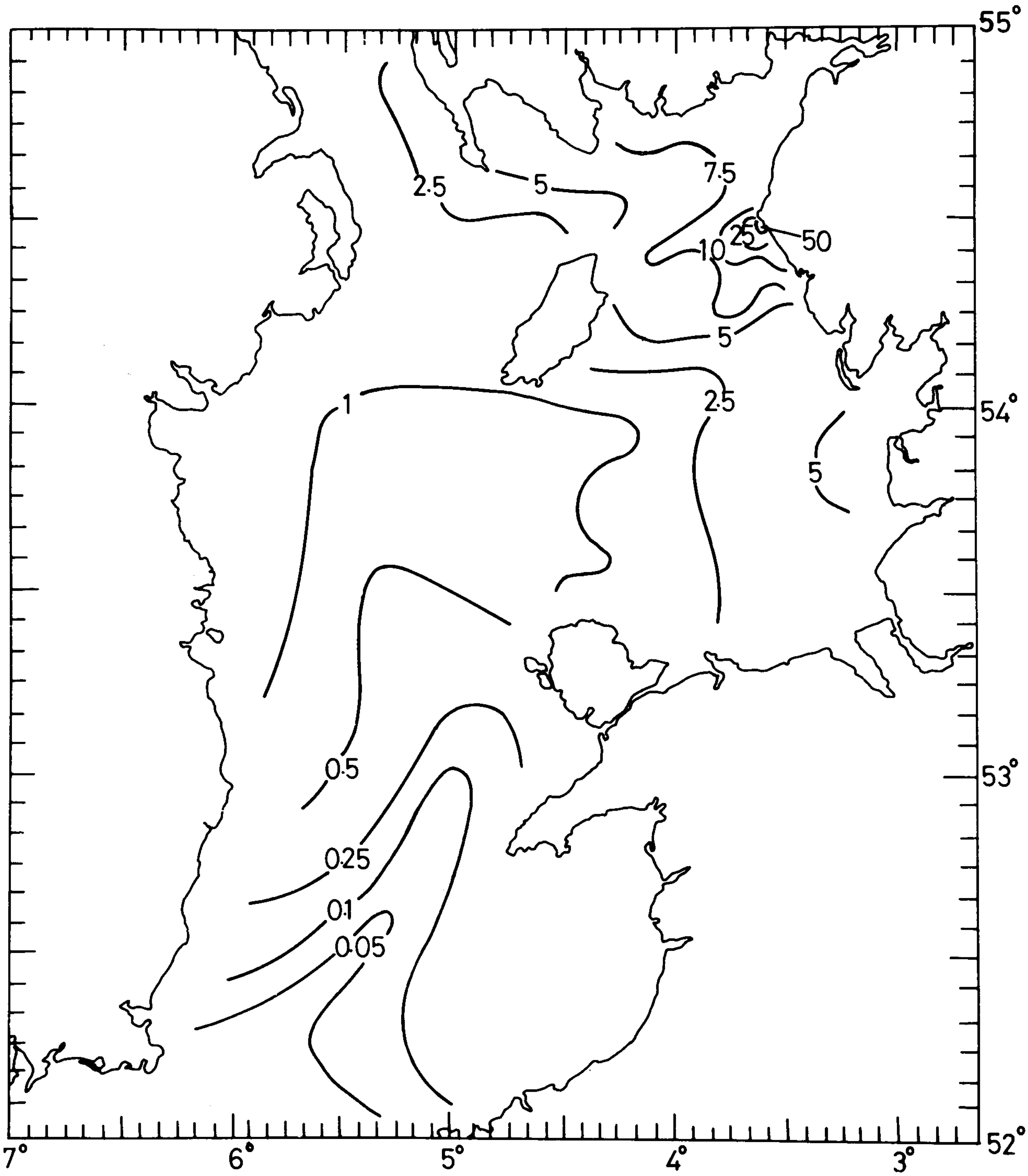


Figure 11 Concentration (Bq kg^{-1}) of caesium-137 in filtered water from the Irish Sea, May 1978 (1 Bq ≈ 27 pCi). (From Hunt, 1980.)

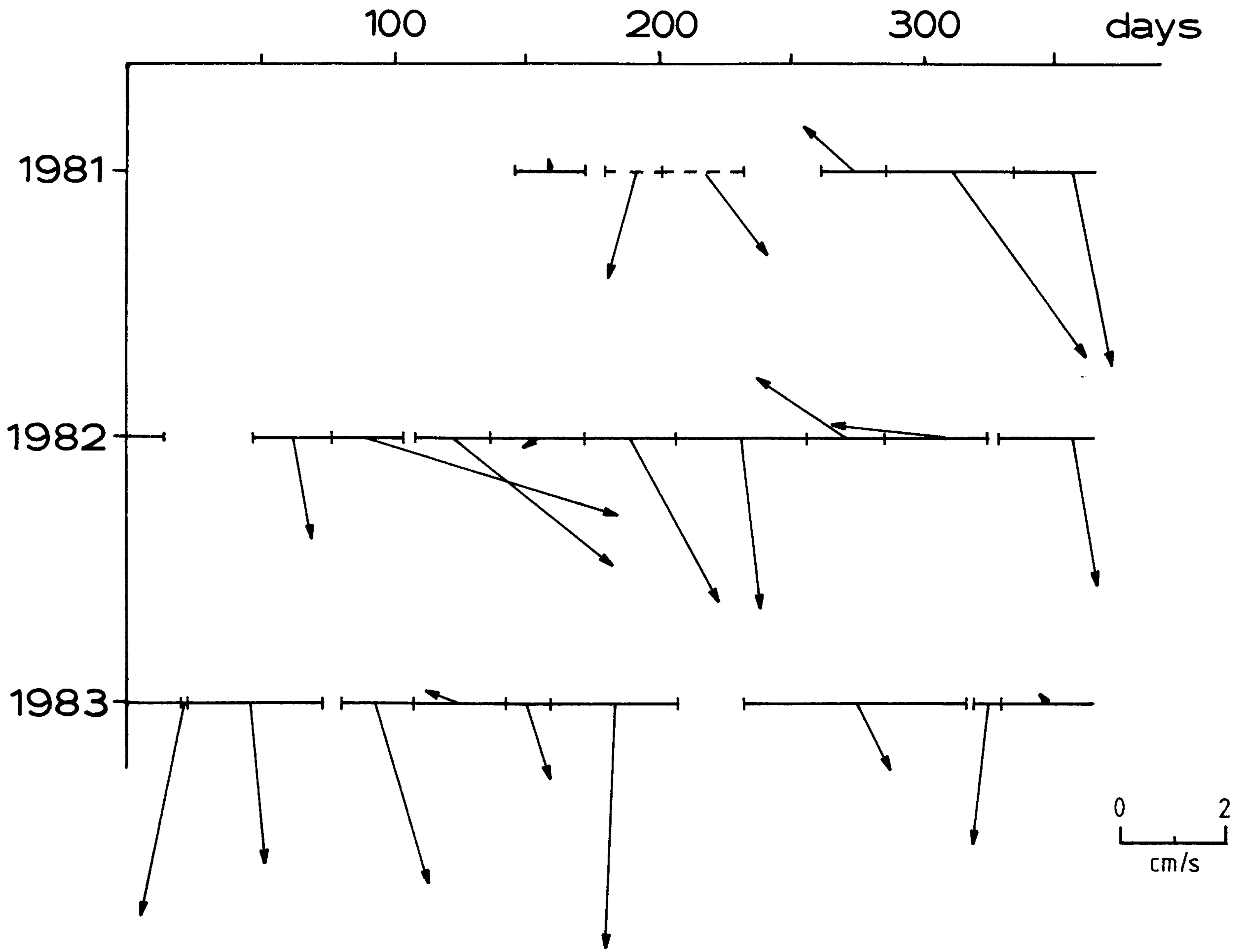


Figure 12 Exercise mean residual current vectors from successive current meter deployments off Sellafield. (From Norris, 1985.)

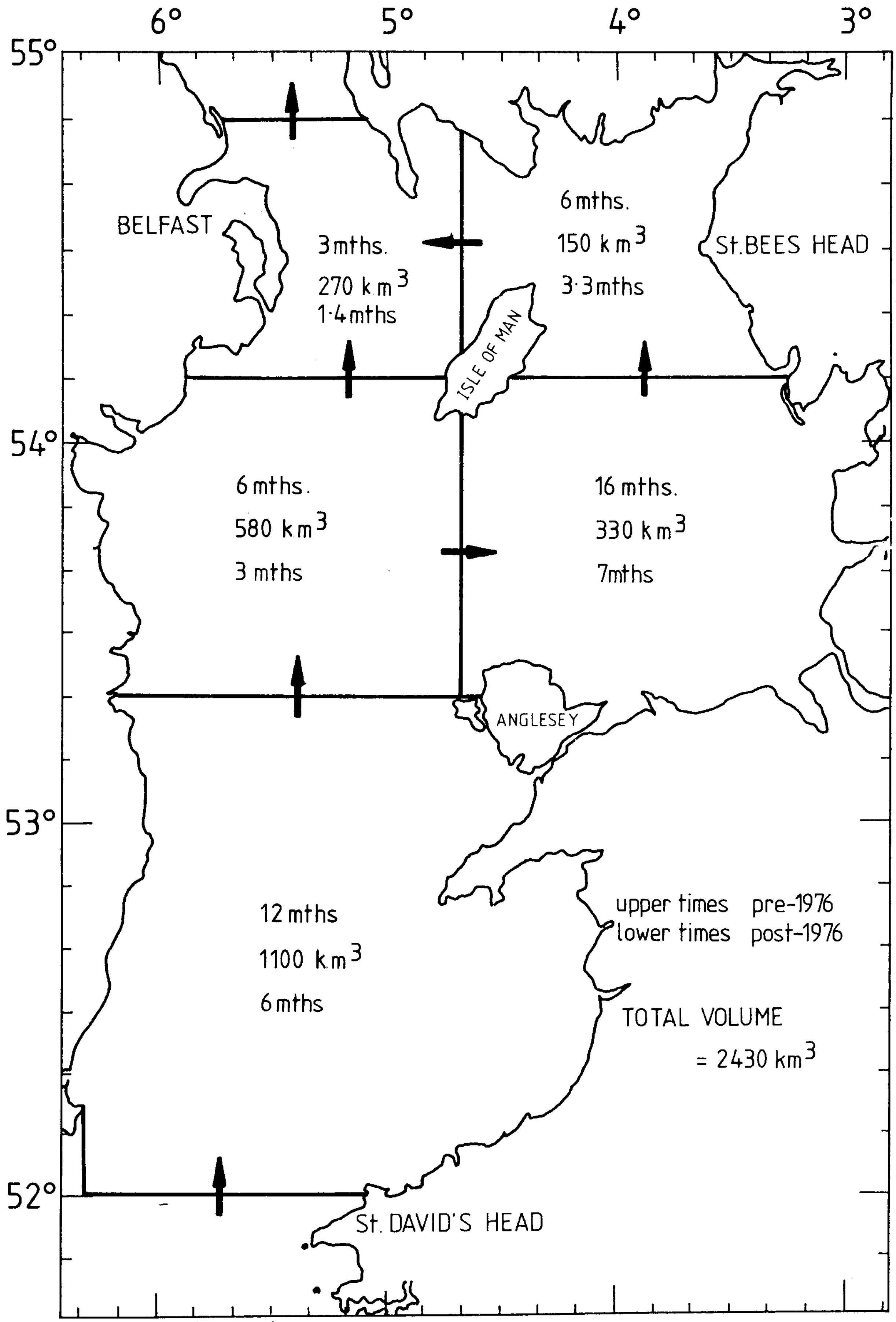


Figure 13 Residence times and volumes for sub-areas of the Irish Sea used in the MAFF model.

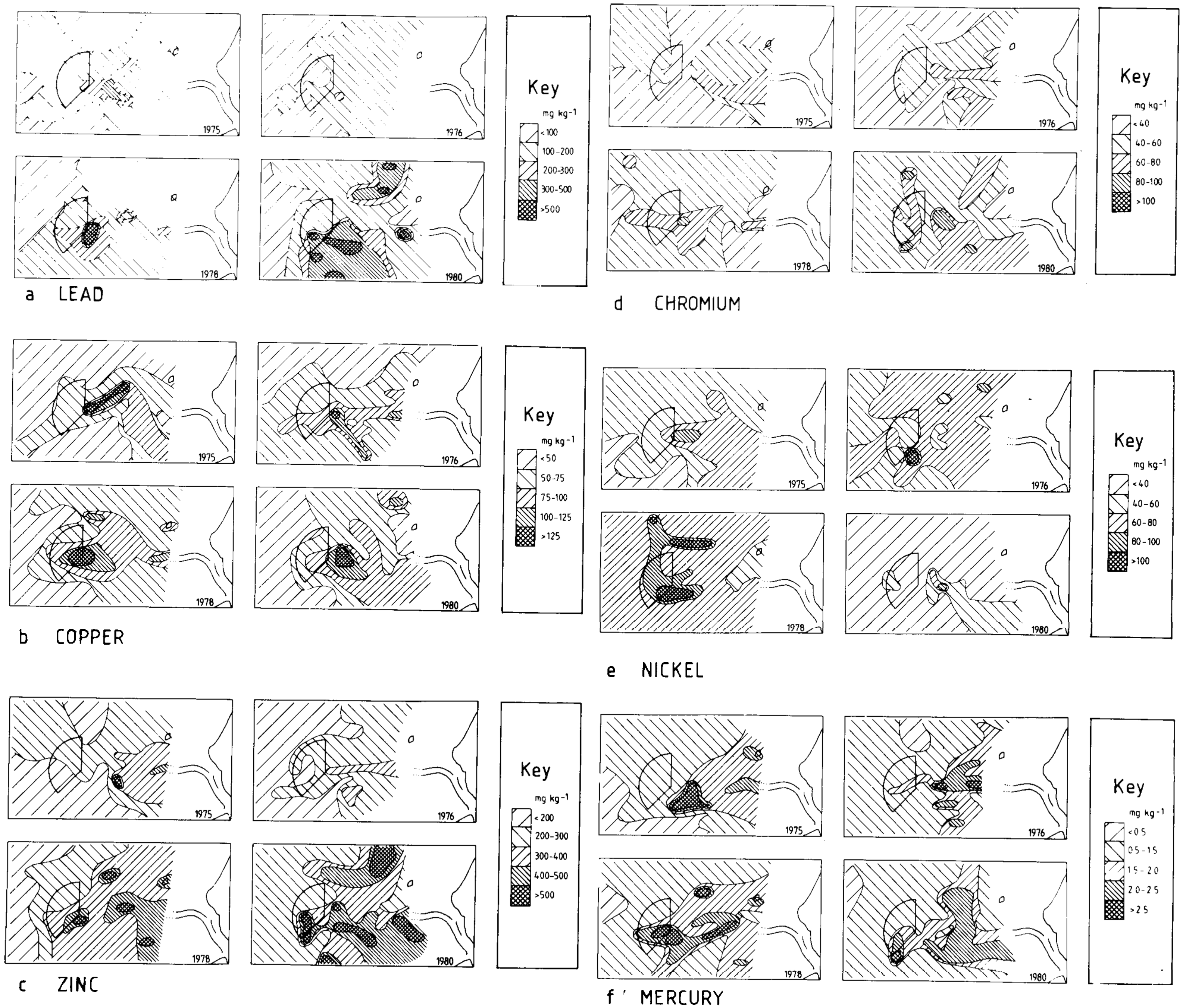


Figure 14 Concentration of metals (mg kg^{-1}) in the fine (< 90 μm) fraction of the sediments in the south-eastern Irish Sea 1975-80. (From Norton et al., 1984.)

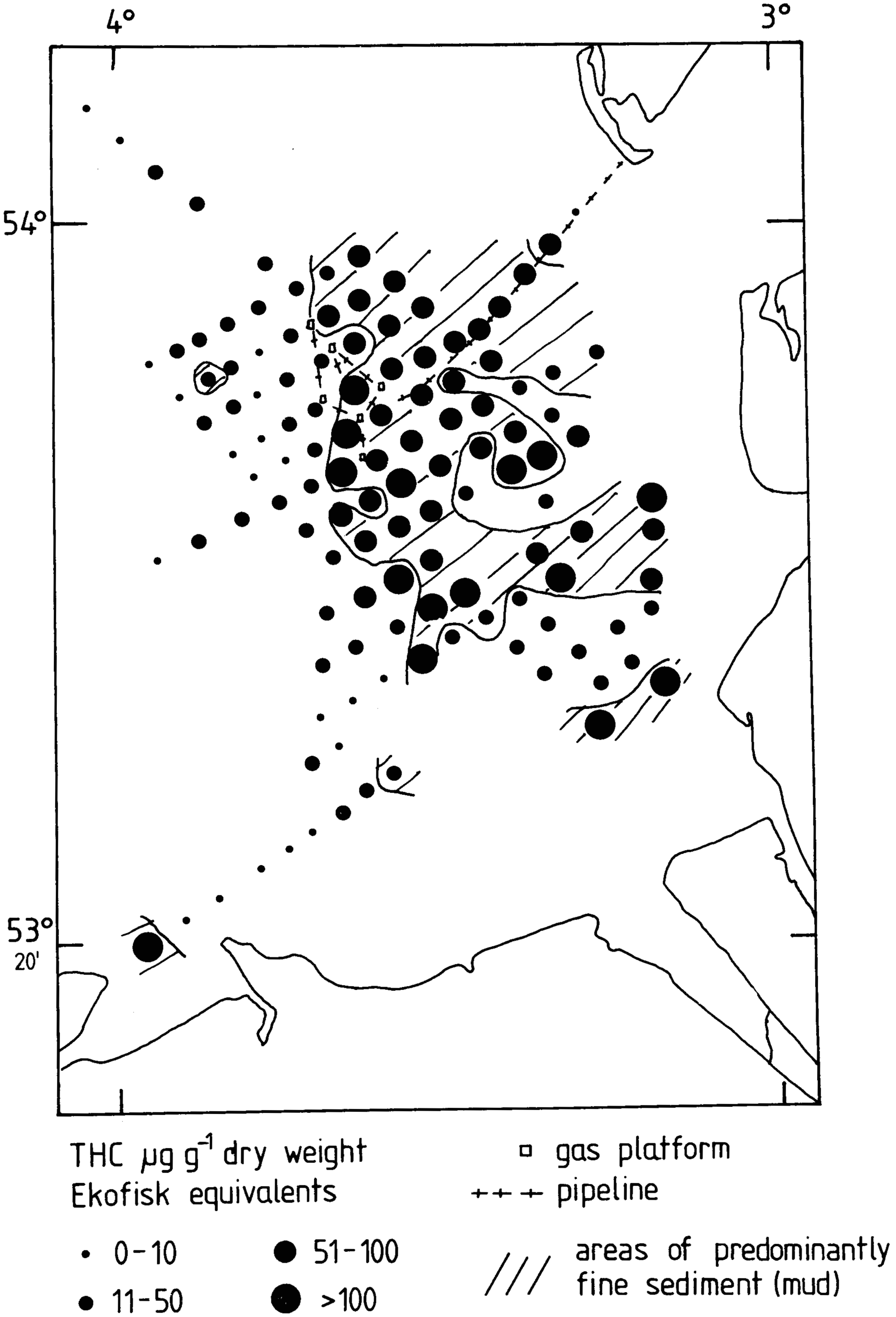


Figure 15 Total hydrocarbon concentrations (µg g^{-1} dry weight Ekofisk equivalents) in sediments of the south-eastern Irish Sea. (From Bedborough, Blackman and Law, in press.)

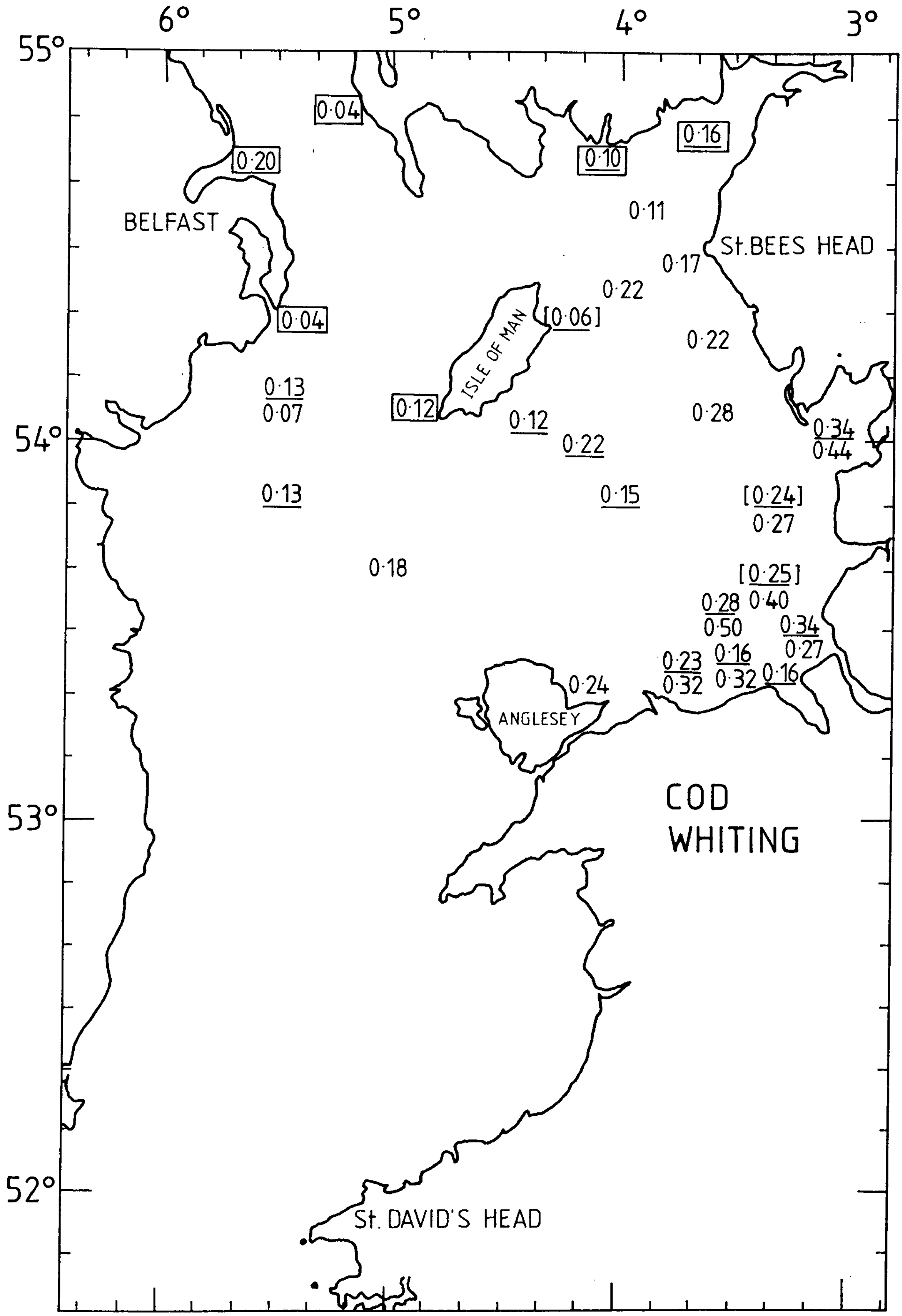


Figure 16 Mean Hg concentrations (mg kg^{-1}, wet) in cod and whiting from the Irish Sea. Samples are predominantly from 1982 to 1984. Values for cod are underlined, and boxed values derived from NWWA sampling.

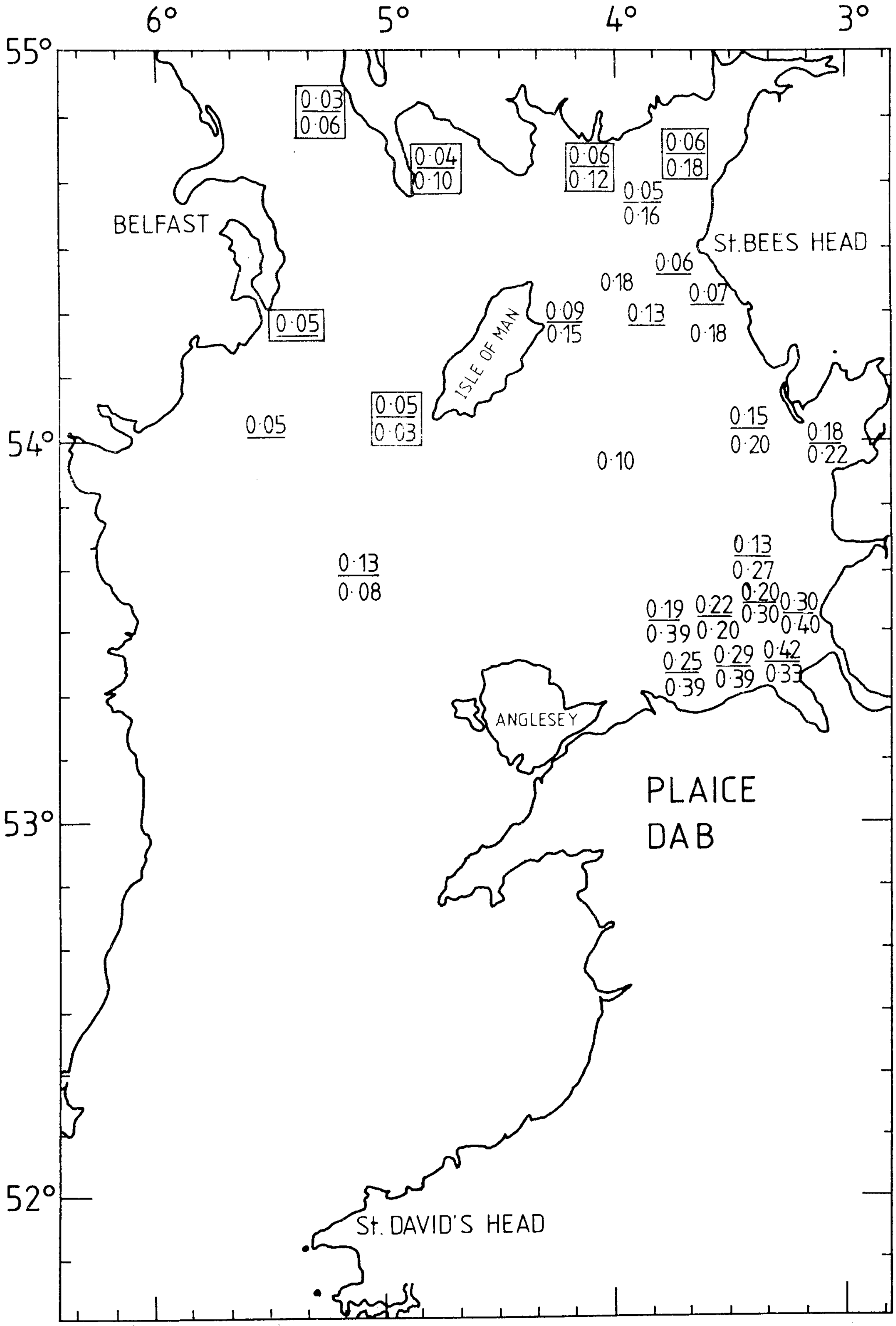


Figure 17 Mean Hg Concentrations (mg kg^{-1} wet) in plaice and dab from the Irish Sea. Samples are predominantly from 1982 to 1984. Values for cod are underlined, and boxed values derived from NWWA sampling.

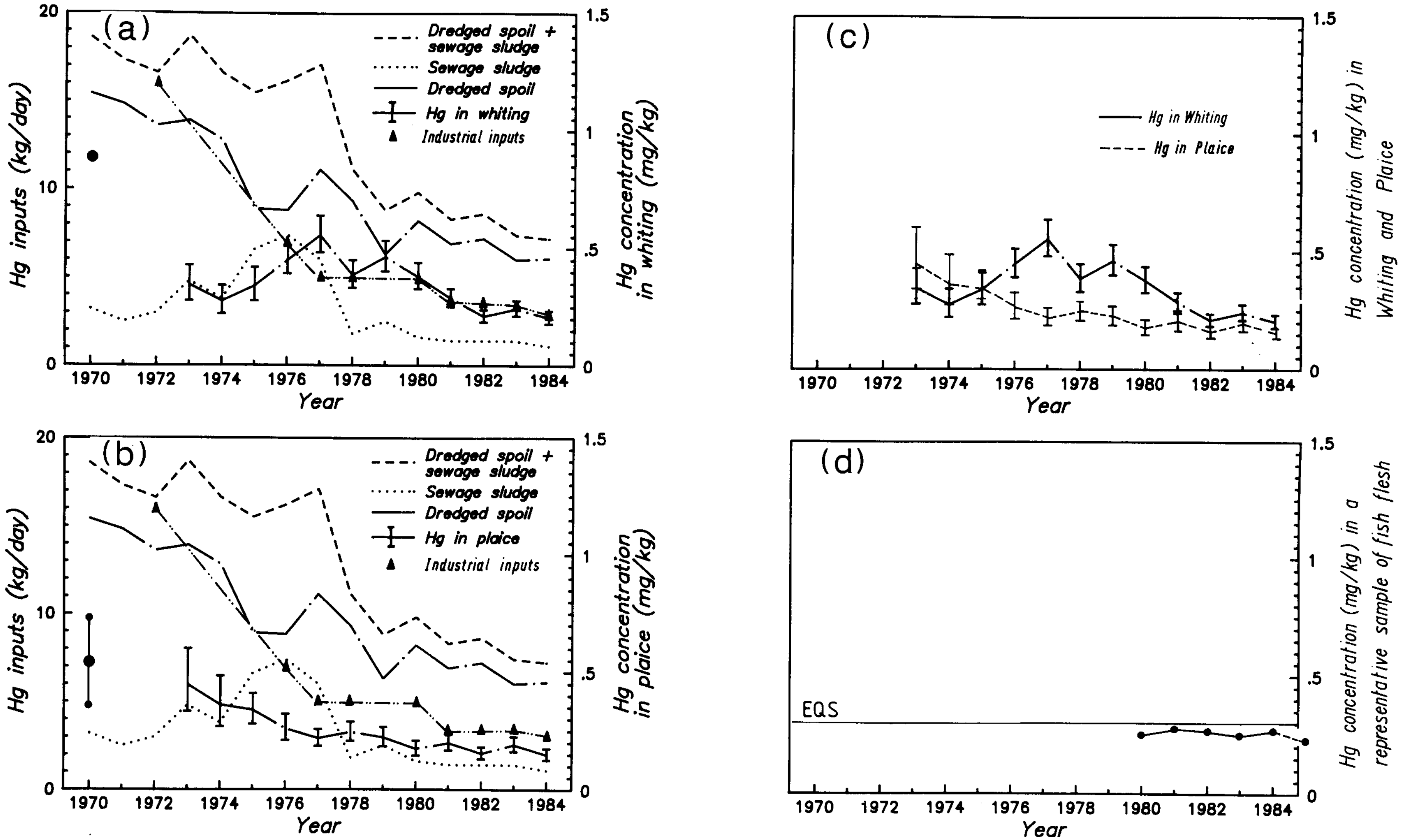


Figure 18 Time variation of Hg concentration in: (a) whiting and (b) plaice, compared with estimates of Hg input to Liverpool Bay from a variety of sources (1970-84). Curves of Hg in fish apply to mean length of fish in samples from the vicinity of Liverpool Bay dump sites (28 cm); (c) Curves of Hg in whiting and plaice recalculated to reflect the mean length of Irish Sea fish available to the consumer (33.2 cm for whiting; 31.2 cm for plaice); (d) 'Shopping basket' estimates of Hg in fish compared with the EQS of 0.3 mg kg^{-1} (wet). The 1985 value is provisional.

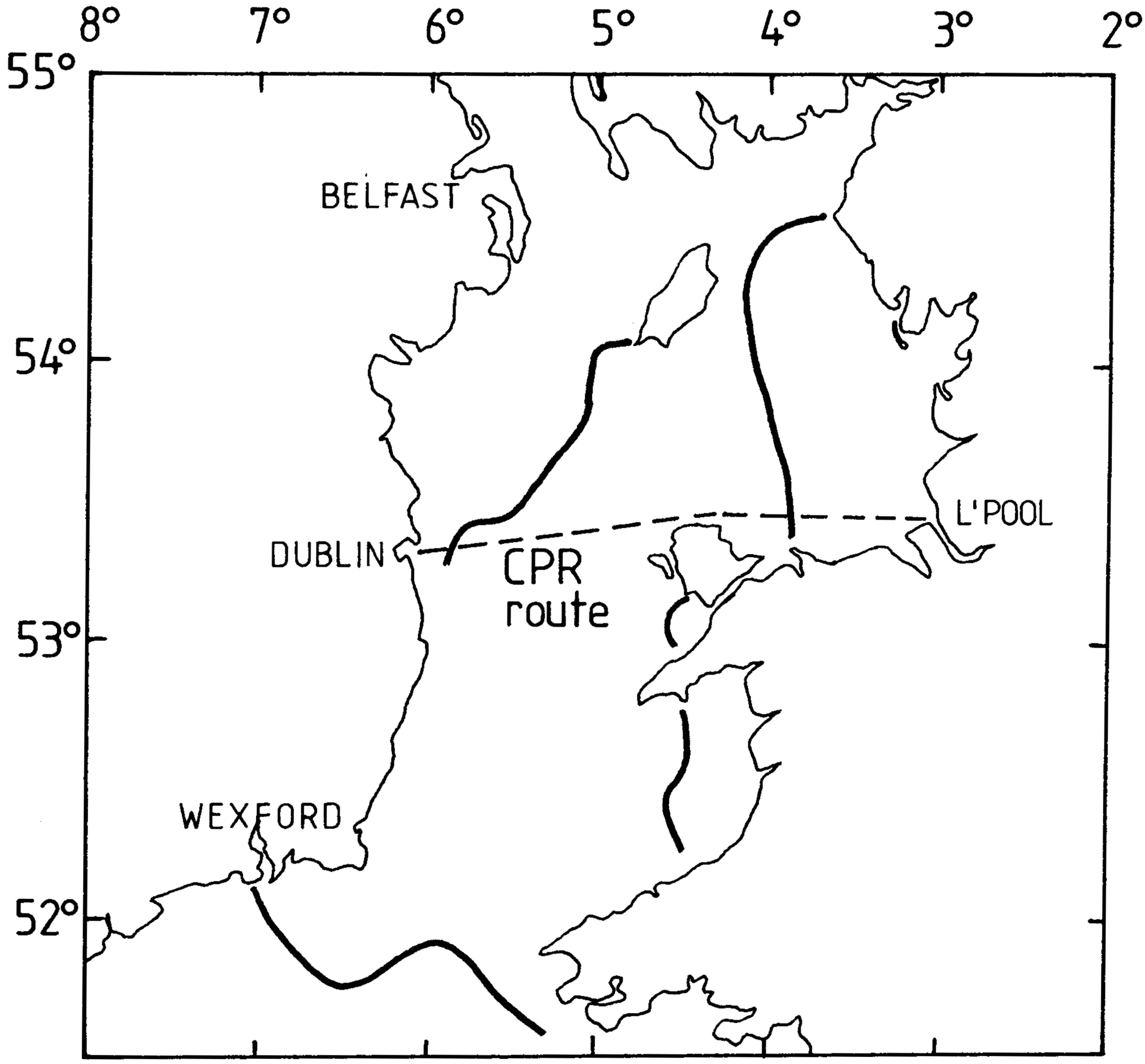


Figure 19 CPR Liverpool-Dublin route (IN) in relation to Irish Sea fronts.

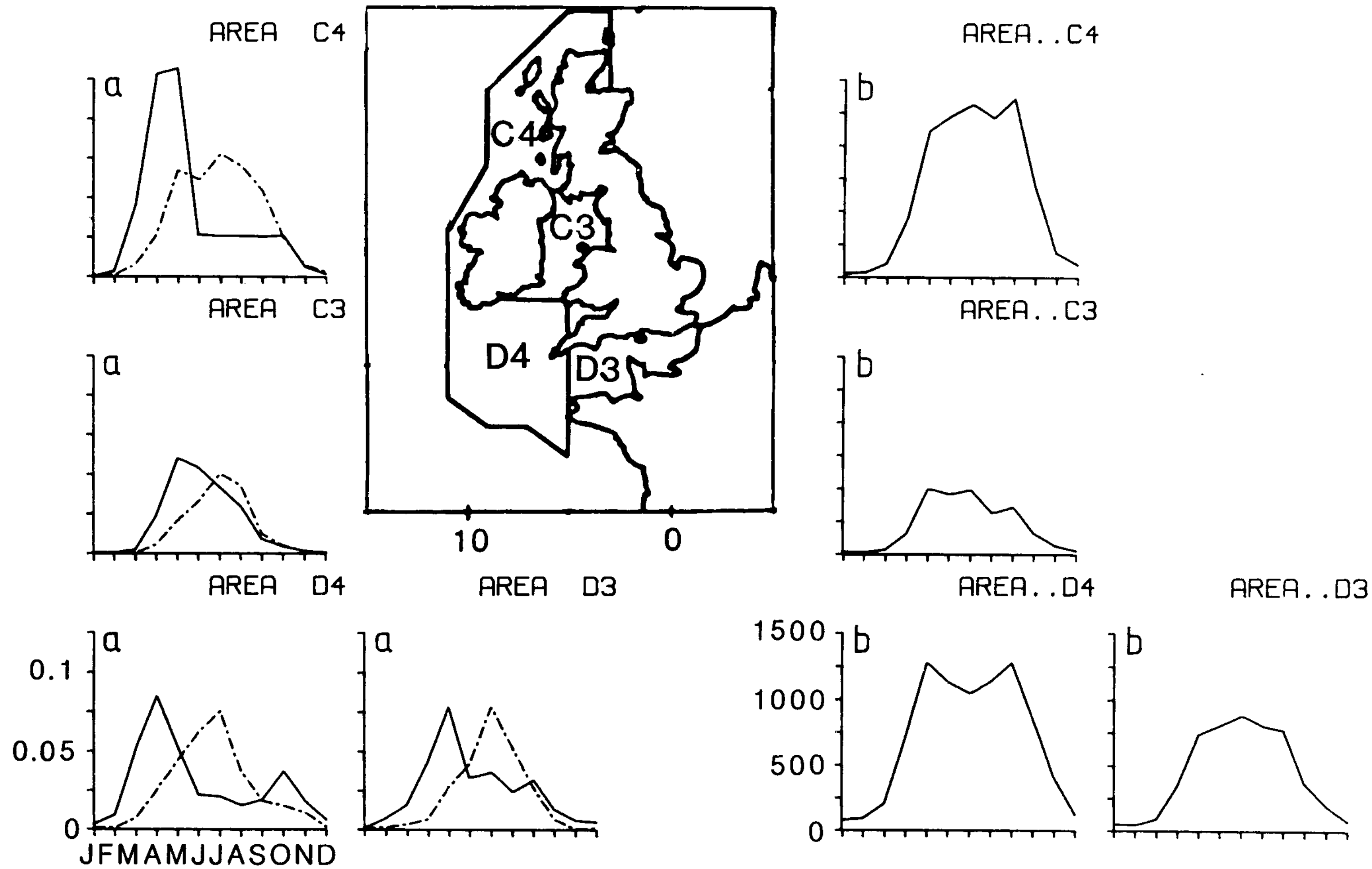


Figure 20 The graphs (a) show the seasonal variations in the abundance of spring (continuous lines) and summer (broken lines) species of phytoplankton for each of the areas shown in the key chart. The y-axis scales are log mean numbers per sub-sample averaged for the period 1971 to 1984. The graphs (b) show the seasonal variations in the abundance of total copepods in each of the four areas. The y-axis is mean numbers per sample of 3 m^3.

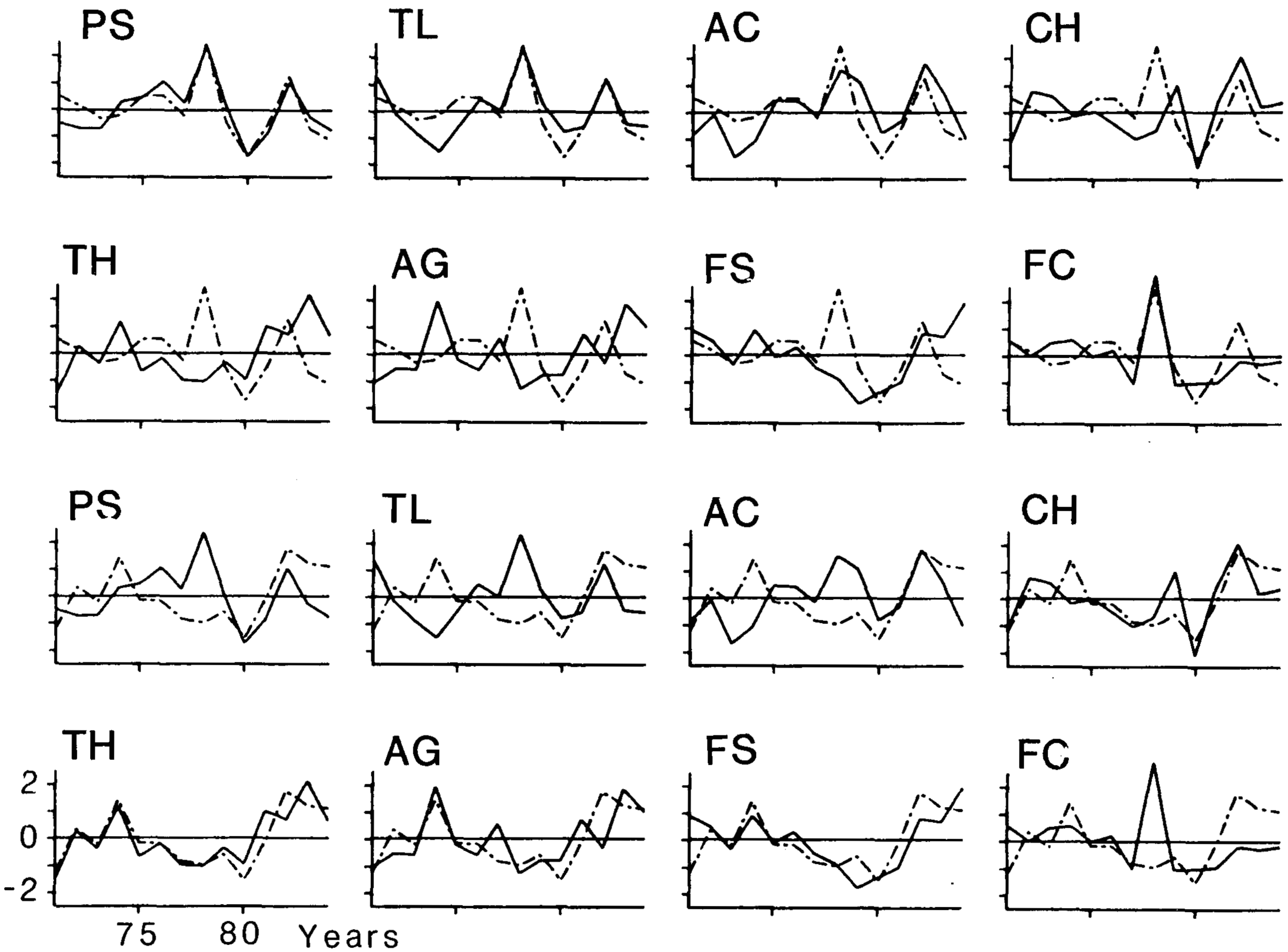


Figure 21 Graphs of the year-to-year changes in the abundance of four zooplankton and four phytoplankton species for the years 1971 to 1984. These are superimposed on plots of the first (top two rows) and second (bottom two rows) principal components (broken lines) derived from the data for 25 species (broken lines). All the plots are standardised to zero mean and unit variance. Key to species: PS - *Pseudocalanus elongatus*; TL - *Temora longicornis*; AC - *Acartia clausi*; CH - *Calanus helgolandicus*; TH - *Thalassiosira* spp.; AG - *Asterionella glacialis*; FS - *Ceratium fusus*; FC - *Ceratium furca*.

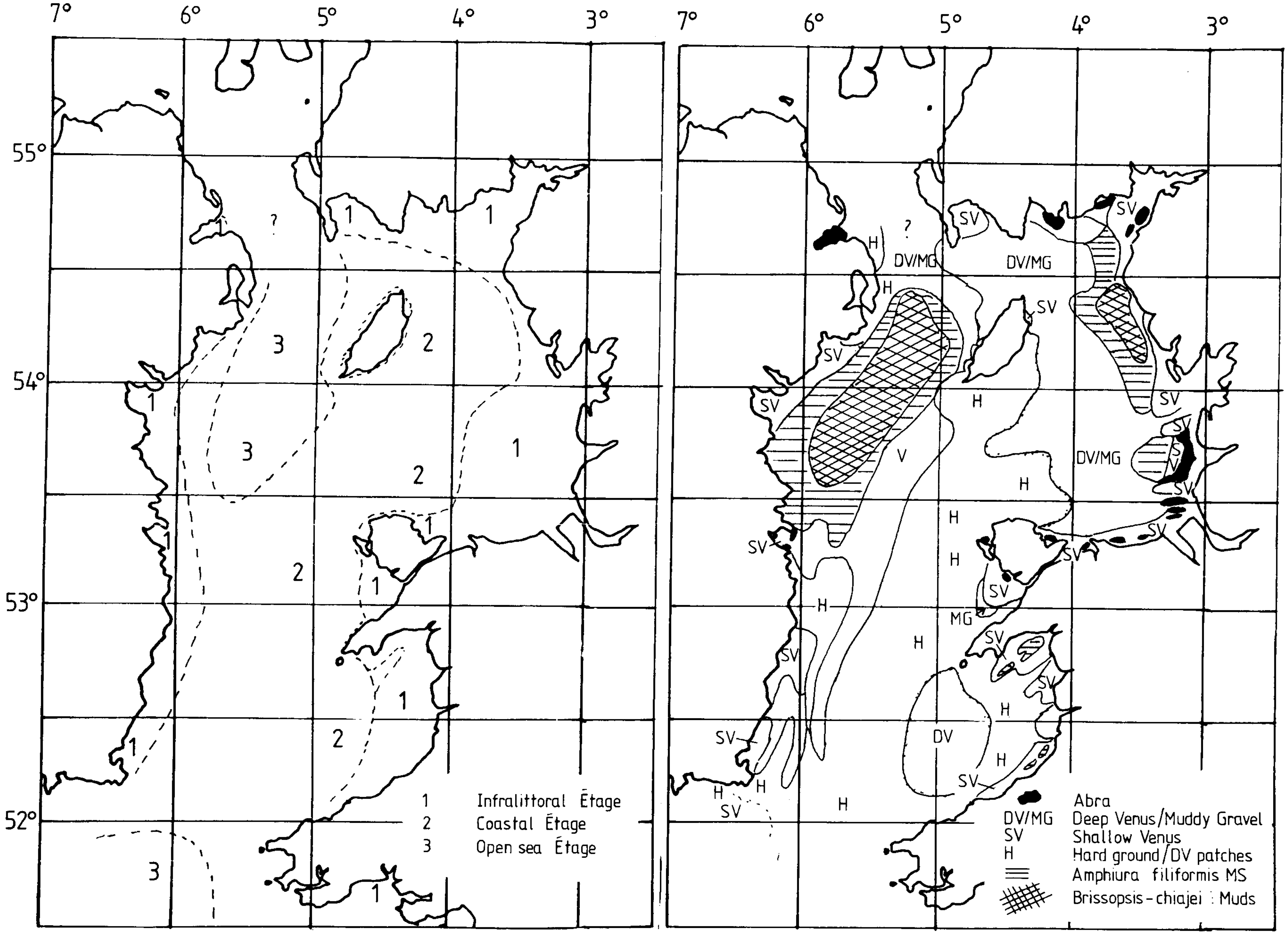


Figure 22 Distribution of benthic étage. (From E. I. S., Rees, unpublished; after Glemarec, 1973.)

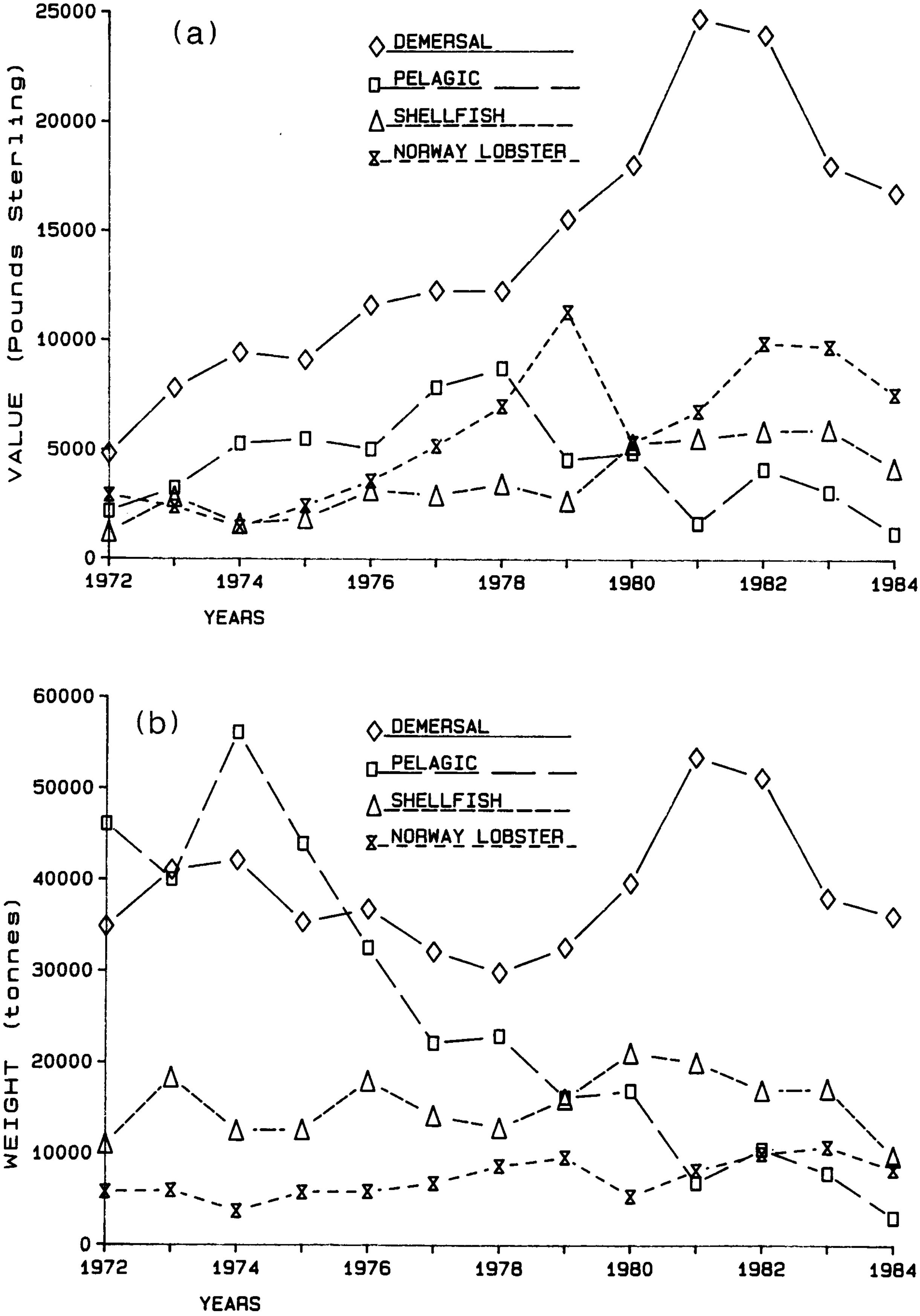


Figure 23 Irish Sea landings 1972-84 by: (a) value; and (b) weight.

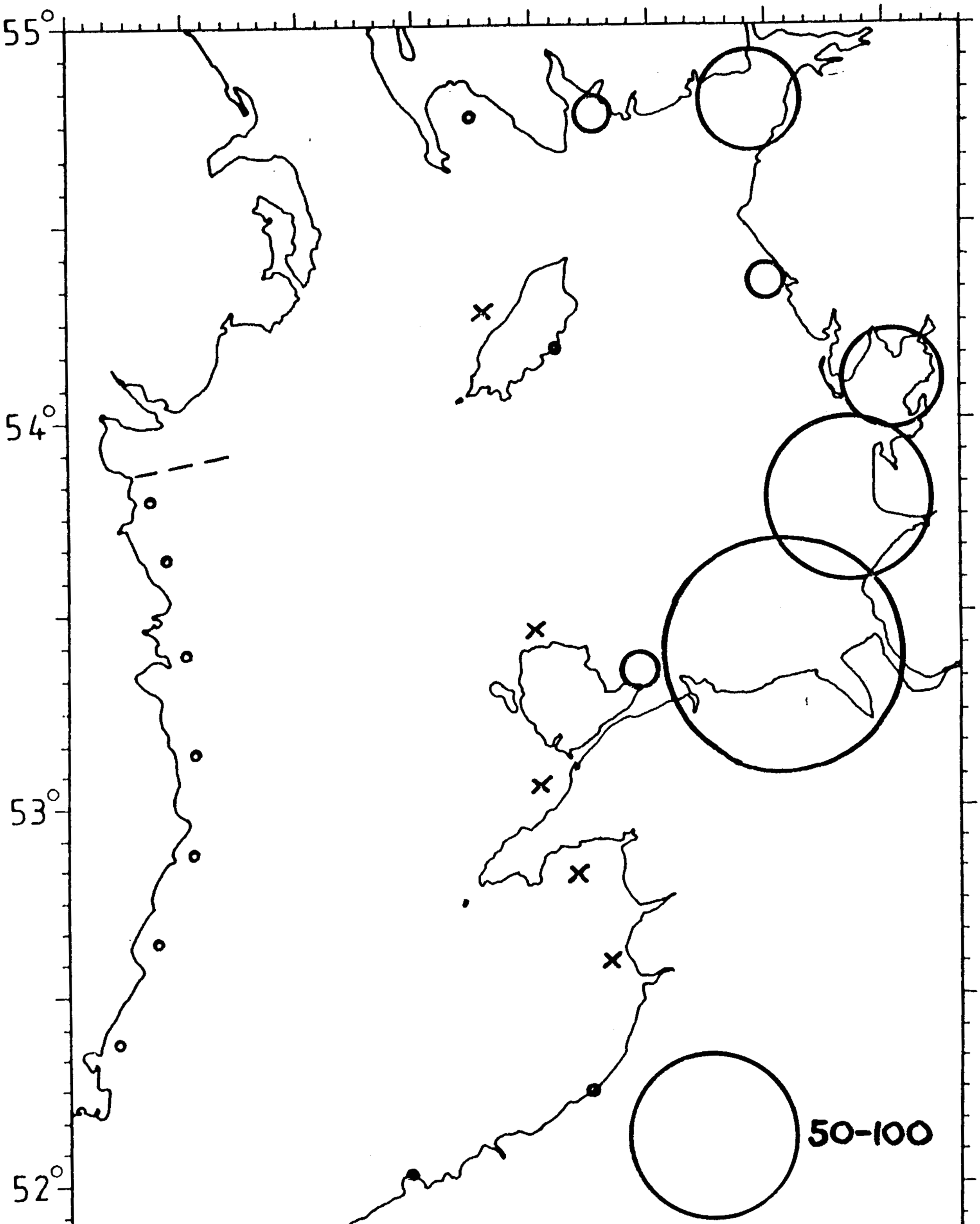


Figure 24 Relative abundance of 0-group sole on beaches of the Irish Sea.

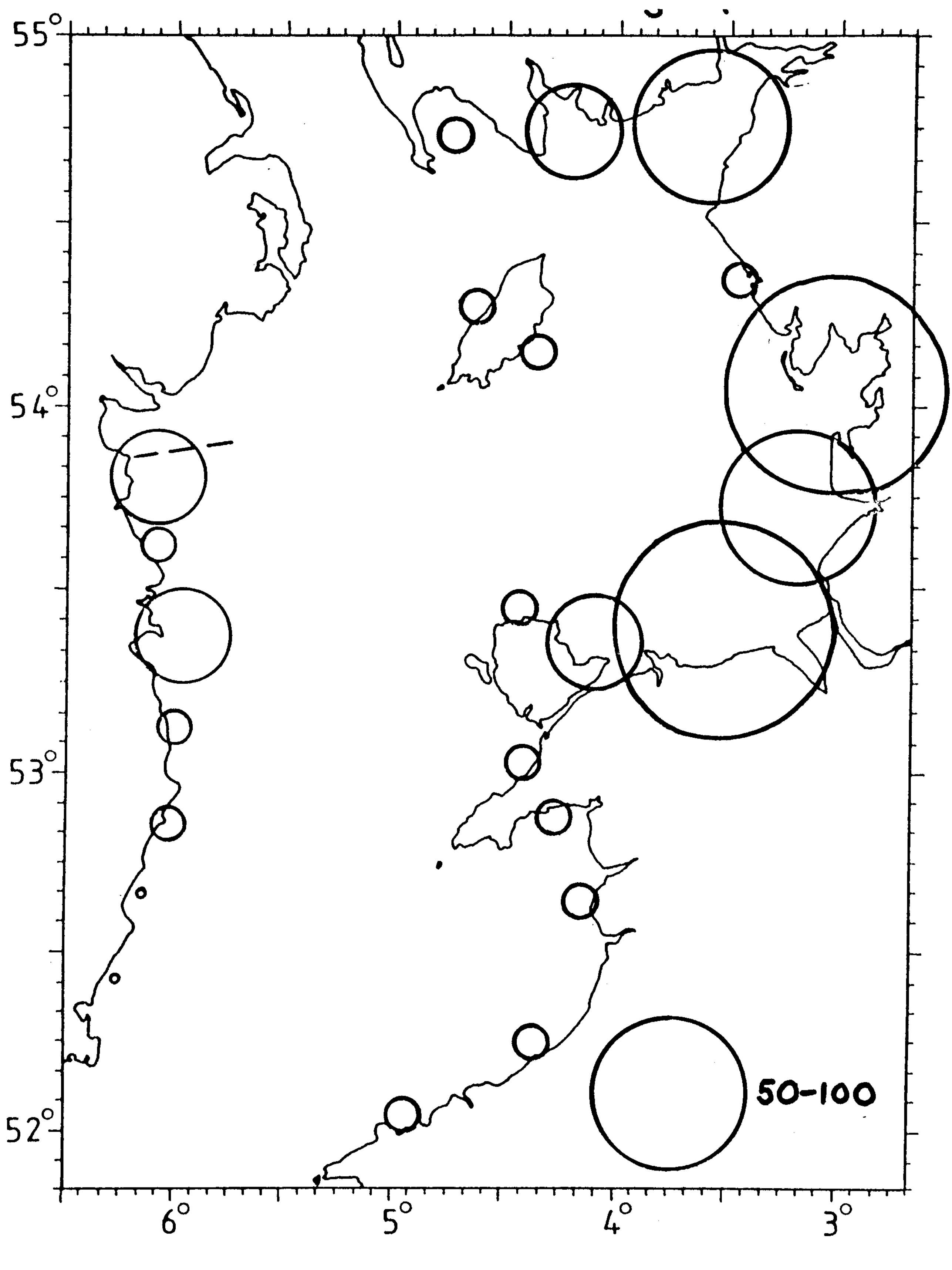


Figure 25 Relative abundance of 0-group plaice on beaches of the Irish Sea.

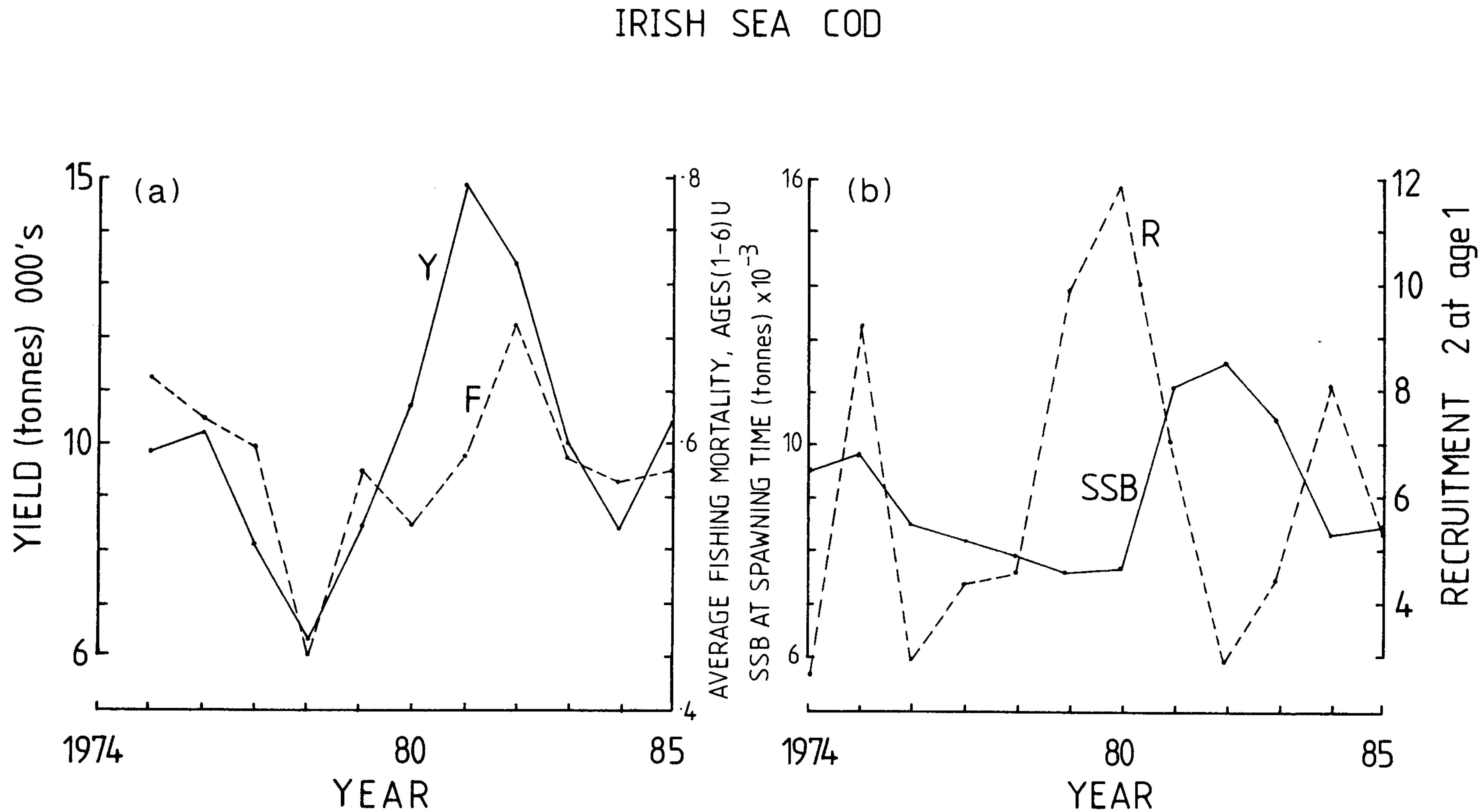


Figure 26 Trends in: (a) yield and fishing mortality; and (b) spawning stock biomass and recruitment for Irish Sea cod.

IRISH SEA WHITING

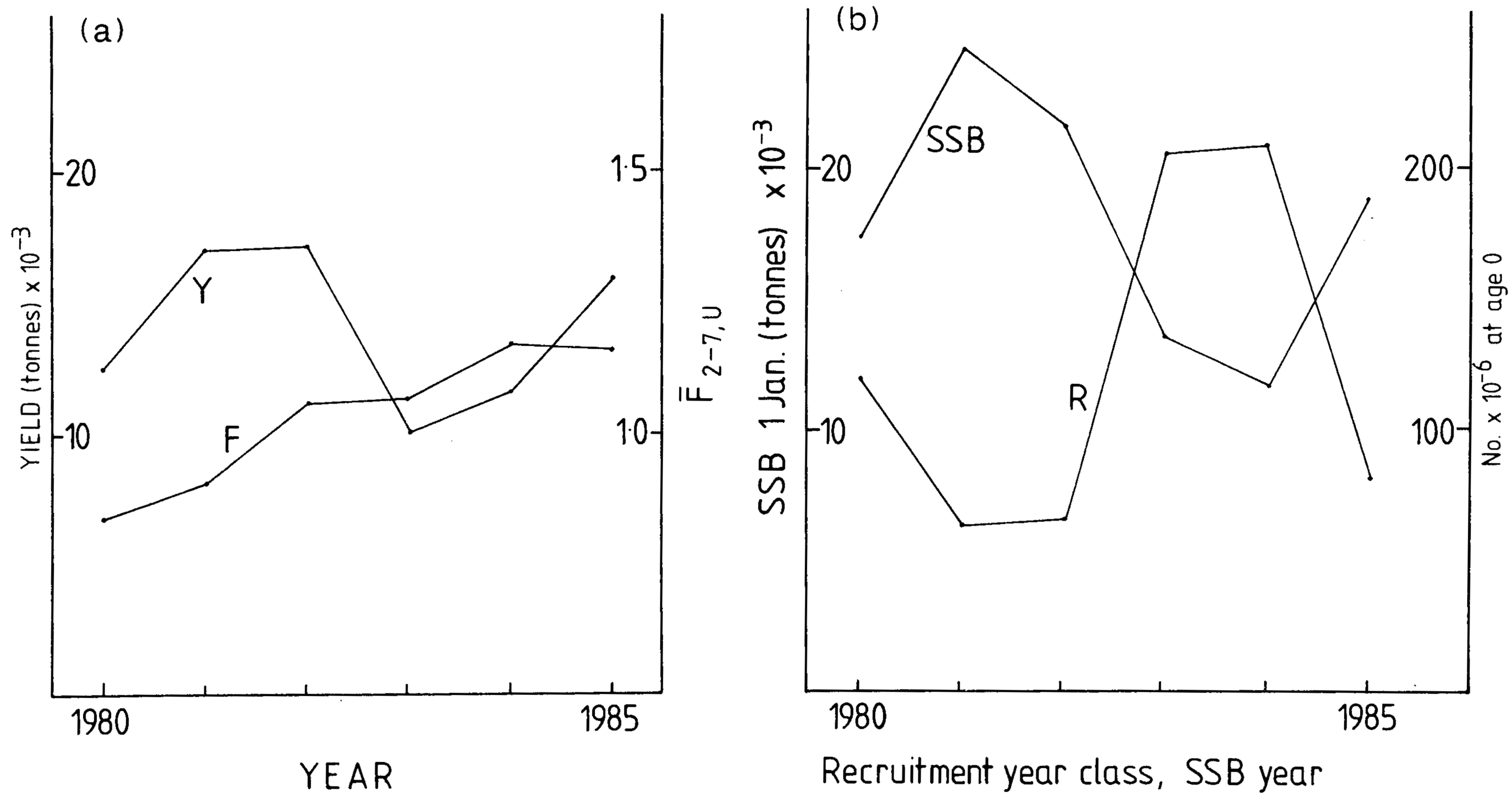


Figure 27 Trends in: (a) yield and fishing mortality; and (b) spawning stock biomass and recruitment for Irish Sea whiting.

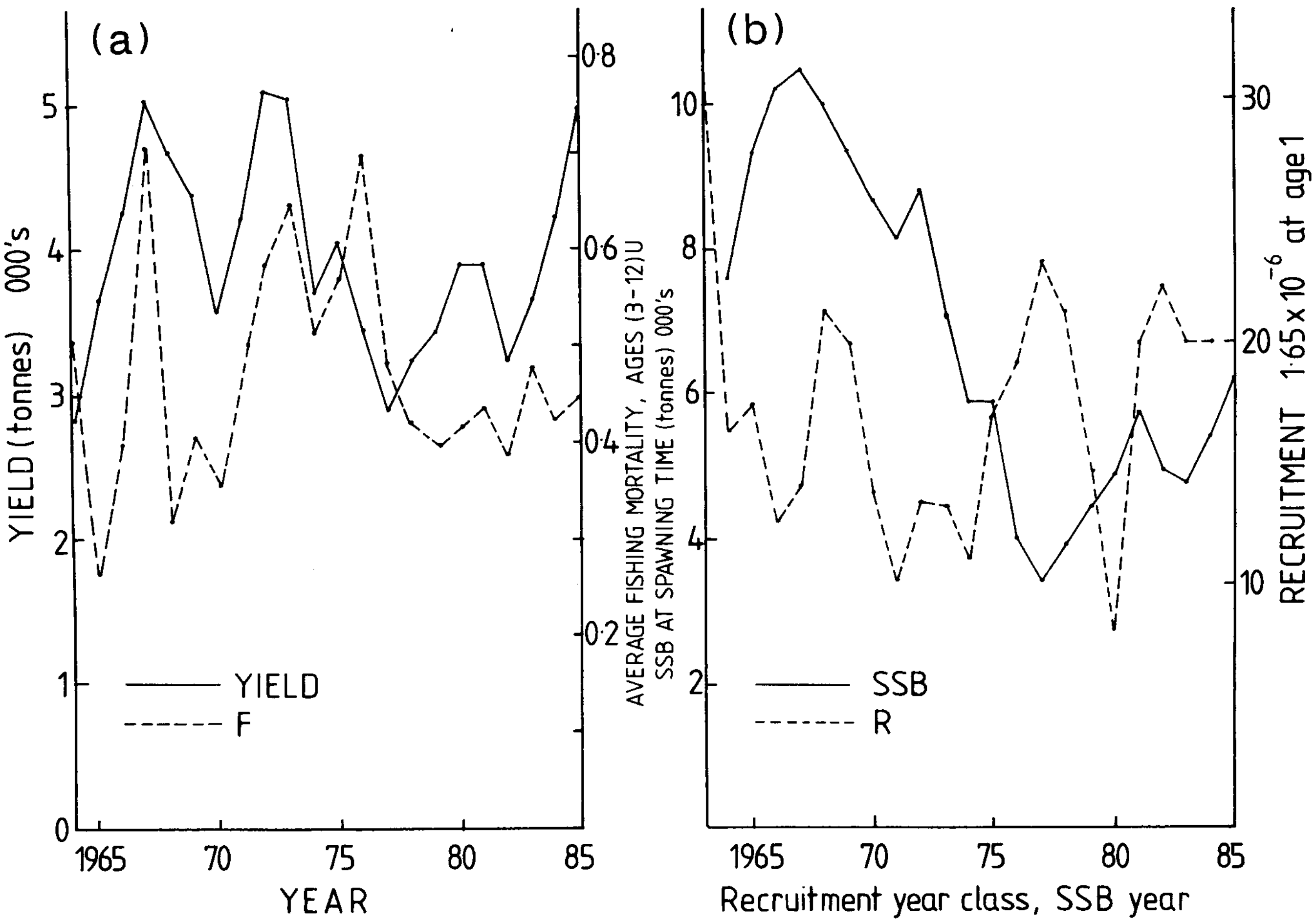


Figure 28 Trends in: (a) yield and fishing mortality; and (b) spawning stock biomass and recruitment for Irish Sea plaice.

IRISH SEA SOLE

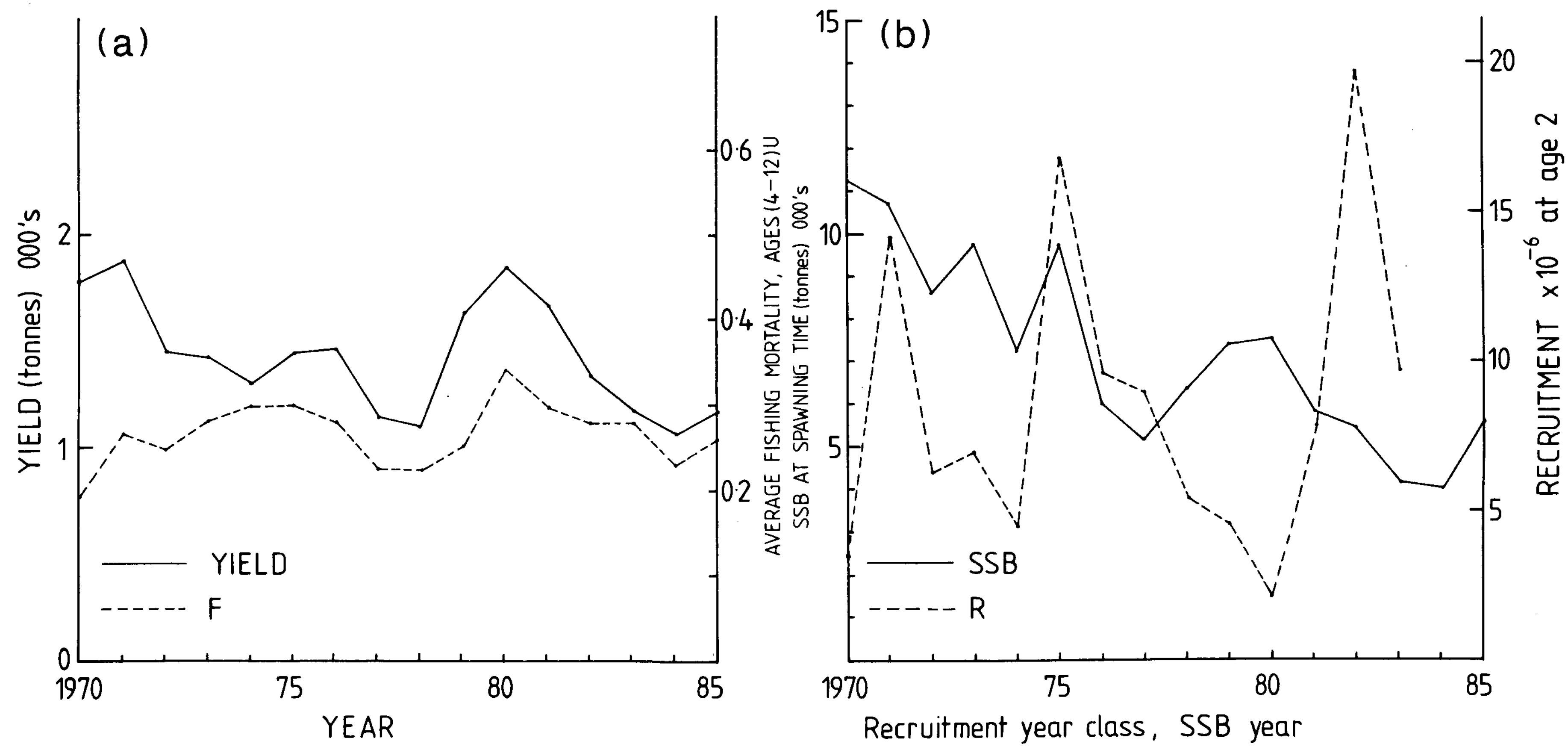


Figure 29 Trends in: (a) yield and fishing mortality; and (b) spawning stock biomass and recruitment for Irish Sea sole.