The Distribution of Phytoplankton & Nutrients in the North East

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This report summarises the findings of collaborative research between the Environme Agency and Port Erin Marine Laboratory on nutrient and phytoplankton distributions in the northeast Irish Sea during 1998. The information within this document is for use by EA staff and others involved in the research and management of coastal waters w

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EXECUTIVE SUMMARY

Phytoplankton and Nutrient Distributions in the Eastern Irish Sea During

This report summarises the results of data collected as part of a collaborative research and monitoring program between the Environment Agency and Port Erin Marine Laboratory niversity of Liverpool). The objectives of the program have been to monitor the distribution of phytoplankton and nutrient salts in the eastern Irish Sea throughout the seasonal productivity cycle. This data has then been used to try and identify areas tha risk from the adverse effects of nutrient discharges from sewage, industrial and riverine sources. This is the fourth year of collaboration between the two organisations and previous findings are to be found in Allen

Winter concentrations of Dissolved Available Inorganic Nitrogen (DAIN) and Dissolved Available Inorganic Phosphorus (DAIP) exceeded the recommendations of the Comprehensive Studies Task Team (CSTT 1997) along stretches of the Cumbrian, Lancashire and Nort Wales coastlines during 1998. These waters are classified as hypernutrified under these guidelines and suggest the possibility of future eutrophication related problems. These findings are further supported by analysis of winter N:Si ratios. A winter N:S indicative of waters subject to future eutrophication. Results from the Cumbria coast survey show a region to the south of the Ravenglass estuary to have N:Si ratios greater than 2.

lts from riverine sources are readily apparent from the data. The influences of the Solway, Ravenglass, Duddon, Mersey and Dee freshwater systems on the distribution of nitrogenous and phosphorus compounds is evident on all pring and summer of 1998 elevated concentrations of soluble reactive phosphate were recorded from waters associated with the Ravenglass estuary. Industrial discharges of DAIN and DAIP are apparent from the data particularly from the

Under guidelines outlined by the CSTT summer chlorophyll concentrations must remain below μg/litre. Concentrations above this threshold were recorded along parts of the Cumbria coast during May 1998 but were within acceptable limits by J

Evidence of nuisance and potentially toxic algal groups were reported during 1998. The was reported from several localities during April and May. orted in dense blooms from various localities around the Irish Sea during July and August often leading to discoloration of the water column. The potentially toxic dinoflagellates also reported in concentrations above EA recommended levels during the spring and summer months in the north-eastern Irish Sea.

Nutrients, Irish Sea, Eutrophication, phytoplankton

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LIST OF FIGURES

Cumbria Coast

THE DISTRIBUTION OF PHYTOPLANKTON AND NUTRIENTS IN THE EASTERN IRISH SEA DURING 1998

This report summarises data collected during 1998 by the Environment Agency (North-West Region) and the University of Liverpool's Port Erin Marine Laboratory. This is the fourth year of a collaborative programme investigating the spatial and temporal distributions of nutrient salts (soluble reactive phosphorus, nitrate, nitrite, ammoniacal nitrogen and silicate) and associated changes on the phytoplankton community structure in the eastern Irish Sea. Reports on the three previous years' data have been produced to which the reader is referred (Allen

Measurements of nutrient salt concentrations have been undertaken

's (Slinn 1990). These measurements allow an insight into the trophic history of waters within the Irish Sea. It has been shown that concentrations of nitrate and soluble reactive phosphate (SRP) have approxima

during this time have seen a much more gradual rise and possible alteration of N:Si and P:Si

ent collaborative programme stems in part from the European Union's Urban Waste Water Treatment Directive (UWWTD). In 1994 Under the terms of this directive, the UK government identified 58 High Natural Dispersal Areas (HNDA's) around the English and Welsh coasts. Four such water-masses have been subject to regular monitoring via the current collaborative venture between the EA & PEML, namely Workington North, Workington South, Braystones and the Wirral. These areas were reviewed in 1997 and the

of the Wirral outfall was withdrawn. After further review of the HNDA classification scheme in 1998 the UK government effectively removed the remaining HNDA

'Raising the Quality' announcement of September 1998. The Government's objective is to now install secondary sewage treatment facilities at all significant coastal

Guidelines for the assessment of coastal waters with regard to the UWWTD are given in detail in the Comprehensive Studies Task Team report published in 1997.
in that report coastal waters are said to be adversely affected by nutrient inputs if;

a) Winter concentrations of Dissolved Available Inorganic Nitrogen (DAIN) exceed 12

µg/litre) in the presence of at least 0.2 mm µg/litre) Dissolved Available Inorganic Phosphate (DAIP) or;
b) Summer concentrations of chlorophyll µg/litre.

If levels of winter DAIN/DAIP or summer chlorophyll concentrations exceed those recommended by the CSTT then a water body is termed hypernutrified. It has also been suggested (NRA 1996) that a molar N:Si ratio of greater than 2 is indicative of waters prone to future eutrophication. A distinction between hypernutrification and eutrophication should be made as hypernutrified waters may not necessarily be eutrophic.

Eutrophication is the enrichment of a water mass with organic and inorganic plant nutrients. In freshwater bodies eutrophication can be a completely natural process. In such environments eutrophication is a slow process of enrichment and is generally asso
process of the water body in response to factors operating within its catchment. Such a definition is inadequate when discussing the cultural eutrophication of coastal waters. However, the semi-enclosed nature of the Irish Sea has ma
'catchment' will have dramatic effects upon its water quality and biota. For the purpose of this report eutrophication may be defined as nutrient enrichment from anthropogenic sources, leading to increased phytoplankton production and possible changes in the phytoplankton community structure. The cultural eutrophication of coastal waters has been associated with environmental problems in other European coastal areas (e.g. Hallegraeff 1995, Smayda 1990, Paerl 1988). These problems include excessive growth of algae, deoxygenation of bottom waters resulting in mortality of benthic organisms, increased abundances of nuisance and toxic algal blooms and the loss of

The effect that nutrient changes have upon phytoplankton population structure is very difficult to predict as the causal relationship between phytoplankton stocks and eutrophication is not wholly understood. Increasing loadings of N and P into coastal wate
potential effects upon the phytoplankton community. A general increase in productivity, especially of populations that may normally be limited by N and P, can be observed (Smayda 1990), which can subsequently lead to the classic problem
described above. Increases in the N:Si ratio can lead to a silica limitation of diatom dominated communities, which in turn can produce a shift from diatom dominated to smaller flagellate

changes in the relative ratios of one nutrient species to another is the increase in novel or nuisance algal blooms (Hallegraeff 1995). This shift from diatom dominated to the smaller
ed algal groups has potential effects upon the nutrient cycling and trophic energy flow in coastal marine systems. Diatoms being the larger planktonic autotrophs of the coastal environment are the major contributors to direct energy transfer to the higher
levels. The smaller flagellated algal groups are generally more involved in the 'microbial loop' (Doering *et al*. 1989) than the planktonic food chain. Any such changes in the phytoplankton community structure have potentially severe consequences, n
nutrient salt concentrations and ratios, but also for the transfer of energy from one trophic level

A generalised response of the phytoplankton community structure to changing nutrient salt
t be given. Different water bodies around Europe have been shown to respond in different ways to enhanced nutrient loadings. A common bloom-forming alga of

d with increased nutrient enrichment of coastal waters but it seems likely that

this species may be a result of elevated concentrations of phosphorus. Blooms of
species have occurred almost annually in Dutch coastal waters since 1978 (B
1986) and reports of blooms are also common in regions of the Irish Sea (Irish Sea Study Group 1991, Jones & Haq 1963, Jones & Folkard 1971, Kenningto

Increased reports of toxic algal species such as the dinoflagellates have also been linked to changing nutrient ratios of coastal waters, having severe implications for both public he has occurred in massive numbers in Norwegian coastal waters and has been responsible for the death of thousands of farmed fish since it was first reported in 1966 (Tangen 1977). Long term decreases in the Si:P ratio within the Black Sea have been associated with an increase in blooms of the dinoflagellate (Bodeanu & Usurelu 1979). Machetti's (1992) study of the semi-enclosed Adriatic Sea highlighted a connection between dense blooms of diatoms and dinoflagellates and eutrophication of the Po Delta, which led to deoxygenation of bottom waters and the production of surface scums.

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2. DESCRIPTION OF THE STUDY AREA

Comprehensive reviews of the biological, chemical, geological and physical characteristics of the Irish Sea are contained in several reports (Irish Sea Stud
1988). The Irish Sea encompasses the semi-enclosed sea area bounded by latitudes 52° and 55°N. Deepest waters are found to the west of the Isle of Man in the Beauforts Dyke (~275m). These deeper waters are found in a long open ended trench connected to the Celtic Sea via the
’s Channel in the south and the Malin Shelf via the North Channel in the north. Atlantic waters enter the Irish Sea via both entrances. To the east of the Isle of Man waters are
allower (<50m). The total volume of the Irish Sea has been calculated as
(Dickson & Boelens 1988), equivalent to only 6% of the total volume of the North Sea, 80% of this volume lying to the west of the Isle of Man. The north-eastern Irish Sea is defined as including the marine and coastal waters extending from the Solway Firth to the North Wales coast and from the English coast to the Isle of Man

In the eastern Irish Sea currents typically show a southward drift off S
irculation is found in Liverpool Bay. Differences in surface and bottom currents have also been identified to the north east of the Isle of Man with surface currents running westwards out of the Solway Firth and bottom currents running eastwards. Figure 1
summer hydrographic conditions in the Irish Sea (after Pingree & Griffiths 1978). The majority of the Irish Sea is shallow and well mixed. The main area of summer stratification can be found to the west of the Isle of Man due to increased water d
(thermal) stratification can also be found in Liverpool Bay. It can be seen from Figure 1 that large areas of the eastern Irish Sea are composed of transitional waters. These areas,
hire and Cumbrian coasts, can become stratified during winter and spring owing to haline effects. It has also been shown that summer thermal stratification can occur in these areas particularly when climate and current regimes are favourable (Allen
. 1997, 1998). Several frontal regions have been identified to the north and south of the stratified regions in the western Irish Sea and also an east-west frontal region
°N parallel. A fourth frontal region is located between the Isle of Man and the southern part of the Solway Firth which has received relatively less study than those mentioned previously. A further frontal region is located within Liverpool Bay.

The eastern Irish Sea receives land based nutrient inputs from major river, sewage and industrial sources. The most important individual inputs of nitrogen in the eastern Irish Sea are from the River Mersey (35%), the River Ribble (22%), the River Eden (10%), and BNFL
outfalls in the area are of minor importance by comparison, with the total of all major outfalls in the area, accounting only for approximately 3.5% of all inputs. Quantities of fuel reprocessed at BNFL Sellafield are increasing which may lead to some
rease in nitrogen inputs. The industrial outfall of Albright & Wilson at Whitehaven dominates phosphorus inputs into the eastern Irish Sea. This contribution currently represents approximately 29% of total inputs of phosphorus (EA 1997 data). The sum of al
outfalls is responsible for around 6% and all rivers for 49% (dominated by the Rivers Mersey and Ribble) of total phosphorus inputs from land.

Phytoplankton studies in the Irish and Celtic Seas have generally concentrated around frontal

(1995) and Gowen & Bloomfield (1996) on the regional differences in

stratification and its effect on phytoplankton production in the northwest Irish Sea. St
phytoplankton from the north-east Irish Sea are particularly scarce however, and the effect increasing nutrient concentrations in the Irish Sea have on phytoplankton communities is unclear. A comprehensive study of the eastern Irish Sea was condu
(1971) who played particular attention to the distribution of nutrient salts in the region. Allen
(1996) provided some evidence for elevated summer phytoplankton biomass in the area
nter nutrient concentrations. Previous research into the possible associations of winter nutrient salt concentrations on the spring phytoplankton community structure in the eastern Irish Sea suggested that concentrations of winter Total
TON) and silicate may best explain the spring phytoplankton community structure, suggesting a possible nitrate-N limiting environment (Kennington

3. Sampling Protocol and Methodology

3.1 Dates of Cruises and Location of Sampling Sites

Samples were collected from sites along the Cumbrian coast throughout the seasonal productivity cycle. Sampling trips were undertaken during January (winter nutri
May (spring phytoplankton maximum) and July (post peak summer sample). PEML sampled on an offshore grid (see Figure 81) and the EA sampled on an inshore transect (see Figure 82). The actual dates of sampling were as follows;

A total of 46 sampling stations were visited on each of the PEML surveys. Samples for surface phytoplankton, nutrients, salinity, temperature, and chlorophyll (and chlorophyll pigments) analyses were collected at all stations. A CTD cast and bottom water nutrient samples were taken at the ends and middle of each grid leg.

3.2 Sampling and Analytical Methods

Sampling and analytical methods remained the same as for the 1997 sampling program as
. (1998). The analytical methods outlined below are for the PEML samples only. EA analysed samples were determined using methods normally used on coastal
'Surface water' supply on board the R.V. Roagan is supplied by a direct intake pipe situated approximately 2m below water surface level. Surface temperature was recorded using a Meteorological Office mercury thermometer placed in the running water. Water samples for
measurements were collected and analysed
Salinometer (Ocean Scientific International Ltd).

Water for nutrient analysis was filtered through Watmans GF/C filter papers and placed directly into a freezer. Two samples were taken at each site and only one set of samples thawed for analysis. Nutrients were analysed by using an ALPKEM RF/A2 autoanalyser using standard colorimetric techniques as advised by the manufacturer. Artificial seawater was used
wash to overcome salinity effects (Grasshoff 1976). De-ionised UHQ water was used in artificial seawater for ammonia determination and washwater.

was determined via slow acetone extraction using the formulae given by HMSO
f water being filtered for each sample. It should be noted that the assessment of chlorophyll in the present study is labelled "chlorophyll *a*" although in reality this should be
"chlorophyll *a* and related pigments" (CSTT 1997). Additional samples for chlorophyll pigment analyses were collected. Between 1 and 1.5 litres of seawater were filtered through Watmans GF/F filter papers, the papers were then placed into cryogenic vials and frozen immediately in liquid nitrogen. HPLC analysis was under

Bottom water samples for nutrient and salinity analysis were collected using a Seabird Electronics Rosette Sampler deployed in conjunction with the CTD. Profiles for salinity, temperature, density and fluorescence were obtained using a SEACAT SBE 19 (Seabird
'SEASOFT' software was used to align data and to produce results averaged over 1m depth intervals. Simpson's stratification parameter was calculated from CTD data to give an indication of the degree of mixing in the water column (Simpson
1978). In previous years a template written by P.Edwards calculated the degree of stratification. In order to be in keeping with other studies in the Irish Sea using the Simpson
tratification parameters presented follow those of Dickey-Collas
where a value of greater than 20 is indicative of stratification and values in the range of 10-20

d included nutrients which were analysed at the EA facilitity in Nottingham, whilst physical parameters (temperature and salinity) and chlorophyll
'towed body' (Chelsea Instruments Ltd AQUASHUTTLE) which was equipped with a multi-parameter probe manufactured by Meerestechnic Electronic GmbH. Surface water supply on board the RV Coastal Guardian is pumped from approximately 1.5m

Phytoplankton samples were preserved immediately in acidified Lugol's iodine. All samples were analysed by PEML. Subsamples were settled in Uterm
using a Leitz DM 1L inverting microscope at magnifications of X200 and X400.

PEML currently subscribes to the Water Research Centre AQUACHECK analytical check sample scheme, providing a continuing audit on the accuracy of the analytical results obtained by the laboratory for nutrients in saline waters. During
Assurance of Information for Marine Environmental Monitoring in Europe) launched a laboratory-testing scheme for chemical measurement in marine sciences. PEML also

A stringent laboratory protocol for sample treatment and analysis is in place at the laboratory and essentially complies with recommendations given by Gillooly
modification to these disciplines is made as improvements become apparent. Blank
checks are performed throughout the analyses. Procedures include a laboratory reference standard. Accurate determinations of ammonia in seawater present notorious difficulties (Kirkwood & Aminot 1995). The laboratory remains aware of

4. RESULTS

4.1 Presentation of Results

All contour diagrams are produced by Surfer for Windows version 5.03 (Golden Software). Position of contours is determined using the kriging method and grids are blanked using a led land boundary. This process extrapolates data for areas where no samples were taken, so close attention to the location of sampling sites (Figures 80-82) should be made when making detailed study of any trends. In particular no samples were taken from
of the mapped area, due north of the Isle of Man. Separate diagrams are drawn for EA and PEML data. These maps are not corrected for the curvature of the earth and there is some distortion from north to south when compared to admiralty chart
for the area of 1-degree longitude to 1.7153 degrees latitude was used in plotting the maps. All SURFER plots are located at the end of the report. Where data is available for both inshore
ast and Liverpool Bay surveys, PEML (offshore grid)

Multivariate statistical analysis and associated plots were carried out using PRIMER version 4.0 (Plymouth Marine Laboratory). All other statistical analysis was undertaken using

Multivariate statistical analysis was undertaken on the data to try and further describe the complexities of phytoplankton community data and to identify any trends or discrete groups
ditionally an attempt was made to relate these phytoplankton groupings to environmental variables. All statistical analyses were carried out using PRIMER.

Cluster analysis (or classification) aims to identify similarities or "natural groupings" in the species composition between samples (sites). Such an exercise was undertaken using the CLUSTER procedure in PRIMER. A similarity matrix was calculated from Bray-Curtis similarity coefficients and hierarchical agglomerative clustering pe
average linking method to produce a dendrogram. Clustering is designed to delineate groups of samples that have a distinct community structure. Such an exercise may be misleading however if there are gradations in species assemblages. To overcome such potential problems clustering was used in conjunction with ordination techniques (non-metric multi-dimensional

4.1.2 Non-metric multi-dimensional scaling (MDS)

Ordination techniques may be defined as any method that arranges s
possible way in a continuum such that points that are close together correspond to sites that are similar in species composition, and points which are far apart correspond to sites that are
'similar'
means and what 'best' is. A measure of similarity (or dissimilarity) between sites is chosen and replaces the original species composition data with a matrix of dissimilarity values
n then be expressed via an ordination diagram. This final step is termed multi-dimensional scaling. MDS has many advantages over other ordination techniques (PCA, CCA, DCA etc.) as it is based on ranks and makes few model assumptions about the form of

the data. MDS uses these ranks of similarities to construct a two dimensional 'map' of the samples. Most data sets produce some distortion or 'stress' between the similarity ranking and the corresponding distance rankings on the plot. The stress level produce
procedure gives an indication of the adequacy of the MDS representation. Stress levels less than 0.1 indicate good representation of the data, stresses over 0.3 indicate that the points are close to being arbitrarily placed. Stress values of l
dimensional picture and it was therefore decided that further consideration of patterns highlighted by MDS would only be carried out for plots with stresses less than 0.2. MDS was
es-sample data based on fourth root transformations and

4.1.3 Linking Community Analyses to Environmental Variables

Patterns in community structure identified by the above techniques
environmental variables using the BIOENV procedure of PRIMER in which ranks of
ank correlation coefficients (weighted Spearman coefficient). Such an exercise was performed on groups of samples that proved to have low stress values in the species-samples MDS plots. Correlations were performed between species-sample
S) and environmental dis-similarity matrices (based on untransformed data and Euclidean distance). A coefficient close to zero implies no match between patterns of species-samples and environmental variables while values close to -1 or 1 imply complete
osition or agreement in the two sets of similarities. No assessment of the significance of the match in pattern can be made since the ranks are based on a large number of strongly interdependent similarity comparisons. BIOENV identifies the individual or c
'best match' the pattern in community structure. However, no conclusions can be made regarding the causality of any relationships, only suggested relationships may be assumed which may highlight any variable (or
for further investigation. BIOENV requires a full data set, so it was necessary to reduce species and environmental data to only those sites with no missing determinands.

4.1.4 The Determination of Discriminating Species

community structures or trends in floral assemblages identified by MDS were further worked to identify any characteristic species categories. This was achieved by carrying out MDS on the species similarities to determine which species varied in associatio
other. The species list was ordered according to the position on the sample similarity MDS plots and cluster diagrams carried out previously. Discriminating species were also identified by dissimilarity breakdown using the SIMPER procedure of P

Phytoplankton species abundance and environmental data for each sample date were converted to a standard format for use in PRIMER. Information from offshore grids alone was analysed. Similarity matrices and cluster dendrograms were produced for phytoplankton abundances. MDS plots were constructed from ranked matrices and the stress value noted. For sample sets having an MDS stress of less than 0.2 some distinct patterns in phytoplankton communities were assumed and further analysis was carried out to determine discriminating species (SIMPER) and to link patterns to environmental data (BIOENV).

4.2 Physical Patterns

Sea surface temperatures (SST) showed an east-west gradient on most sampling occasions. 2) coolest temperatures were located in waters associated with the °C) whilst warmest waters were found to the south and west of the region °C). This gradient continued during February, at this time however, the Solway Firth lightly warmer waters than the remainder of the region sampled with highest temperatures reaching approximately 8°C (Figure 3). Temperatures during April showed a more even distribution and waters across the whole of the study area were in the range of 7.8 °C. Coolest SST during April were located in a patch midway between Ravenglass and the Isle of Man (Figure 4). During May warmest SST were located to the south-east of the sampling region where temperatures reached a maximum of 12°C, coolest SST were located to the north and south-east of the region (Figure 5). Sea surface temperature during July once more showed an east-west gradient with highest temperatures being located along the Cumbrian coast between the Solway Firth and the Ravenglass estuary. during this time reached approximately 15.5°C (Figure 6).

Surface water salinities showed an increasing trend from the north-east to the south-west on all sampling occasions (Figures 7-12). Lowest surface salinities were recorded arou Firth and along the English coastline. Highest salinities (>34) were recorded from waters in the west of the region. The penetration of low surface salinities was greatest during the winter

The degree of mixing between surface and bottom waters can be restricted at certain times of the year by stratification of the water column. Stratification may be caused when the density of surface waters is altered by freshwater run-off or by insolation. ‘zig-zag’ transects showed there to be stratified regions within the eastern Irish Sea during May and July (Figures 13 & 14). A stratification value of greater than 20 is indicative of stratified conditions and values of between 10 and 20 are indicative of intermediate or transitional waters (Gowen

During January waters within the sampling region were generally well mixed. Waters to the marked stratification during May (Figure 13). The influence of the Duddon estuarine system on stratification during May is very marked but stratification during this time was caused by both temperature and haline anomalies. Waters to the north of on were generally well mixed during May. Some stratification did exist during July, at this time waters are suggested to be transitionally stratified in two regions, one to the north just off Workington and another to the middle of the sampling area (Figur southern stratified (or intermediate) region is coincidental with the approximate position of the summer frontal region noted by Pingree & Griffiths (1978) and is in good general agreement

4.3 Patterns Of Nutrient Distribution

4.3.1 Nitrogenous Compounds

During the January, February, April and May sampling dates the majority of the Dissolved available inorganic nitrogen was present as nitrate. The distribution of Total Oxidised Nitrogen (TON) during January showed maximum concentrations (>300µg/litre) to be found along the Cumbrian coastline between the Solway Firth and the Duddon estuary (Figure 15). Highest overall TON concentrations during January were found towards the Solway with µg/litre. Concentrations of TON during January decreased offshore but were rarely found at concentrations less than 200µg/litre.

Patterns of TON distributions during February remained relatively high (Figure 16) with concentrations still located towards the Solway Firth (>400µg/litre). The high relative concentrations recorded during January had however decreased along part of the Cumbrian coastline, noticeably at stations recorded south of the Ravenglass estuary. centrations of ammoniacal nitrogen during February were highest in waters towards the Solway Firth, at this location ammonia concentrations had reached ~20µg/litre (Figure 17).

Concentrations of TON during April had declined when compared to those recorde earlier months (Figure 18). Maximum concentrations during this time were found to the north µg/litre). Concentrations along the remainder of the coastline were µg/litre, whilst those offshore and to the north of the study area were generally below this concentration.

Concentrations of TON during May had declined drastically with highest concentrations (~200µg/litre) now being found to the south of the region (Figure 19). Concentrations north of ss estuary were generally less than 80µg/litre. Data from the inshore grid (EA data) for May show a very similar distribution with regard to nitrate as those from the offshore grid (Figure 20). Ammoniacal nitrogen concentrations for the inshore grid do ho elevated concentrations in a region between Sellafield and the Ravenglass estuary (Figure 21) µg/litre.

During July concentrations of TON had almost become exhausted over much of the study area µg/litre (Figure 22). Maximum concentrations during this time were recorded in waters adjacent to the Ravenglass estuary. At this time ammoniacal nitrogen had began to increase in concentration especially in waters associate Ravenglass estuary (Figure 23) where maximum concentration reached approximately µg/litre.

4.3.2 Soluble Reactive Phosphorus (SRP)

Concentrations of SRP during January was well correlated with the salinity distributions across the study area. Highest overall concentrations (40-60µg/litre) of SRP during this time were found in waters associated with the Solway Firth and along the Cumbrian coastline. Concentrations decreased westwards and were less than 20µg/litre in waters adjacent to the Isle of Man (Figure 24).

Phosphate concentrations remained relatively high into February and concentrations generally highest to the north of the study area and the highest overall concentrations μg/litre) were found adjacent to Whitehaven (Figure 25).

The pattern of SRP distributions had altered by April and highest concentrations (~45μg/litre) were now found in coastal waters between Sellafield and the Duddon Estuary. Concentrations to the north were lower and waters associated with the Solway Firth had SRP concentrations μg/litre (Figure 26).

Phosphate concentrations had decreased considerably by May. During this time highest concentrations (>40μg/litre) were recorded in waters to the north of the region centred around the Ravenglass estuary and in a smaller region in waters offshore from the Duddon Estuary concentrations of SRP during May were found in more open offshore waters and were generally less than 10μg/litre. Data presented from the inshore grid (EA data) for May are in good general agreement with those from the offshore grid although SRP tions are slightly higher (Figure 28).

Concentrations of SRP had decreased across the entire region by July with the exception of a small region associated with discharges from the Ravenglass estuary, concentrations in this μg/litre (Figure 29) whilst concentrations along the majority of the study area μg/litre.

4.3.3 Silicate

Winter concentrations of silicate showed concentrations (~800μg/litre) to be highest in waters associated with the Solway Firth and Duddon Estuary (Figures 30 & 31). Lowest concentrations (<400μg/litre) were found in waters to the south-west of the study area.

Silicate concentrations had begun to decline by April especially in waters to the north of the study area which now had concentr μg/litre. Highest concentrations were now found to the south of the area where they reached approximately 600μg/litre (Figure 32).

Concentrations of silicate had reduced considerably by May with waters to the north and east aving concentrations of less than 200μg/litre. Highest concentrations (~300μg/litre) were found to the south-east of the Isle of Man (Figure 33).

By July concentrations of silicate had decreased across the entire study (<200μg/litre) area. The highest concentrations were found in waters mid-way between the Cumbrian coast and the

4.4 The Distribution of Surface Chlorophyll

Concentrations of surface chlorophyll during January were low across the region (.25- μg/litre), highest concentrations being found in waters associated with Solway Firth and Ravenglass estuary (Figure 35). Chlorophyll concentrations remained low across the region until April when elevated concentrations (>1.5μg/litre) were recorded in coastal waters Bees Head (Figure 36).

By May concentrations had increased significantly with maximum concentrations of µg/litre being recorded in waters offshore and to the north-east of Isle of Man (Figure 37). A breakdown of the chlor
Chromatography) methods during May revealed several chlorophyll compounds to be in abundance. Fucoxanthin, a major pigment in the diatoms and prymnesiophytes was found at concentrations as high as 4000 ng/litre in waters offshore and to the north-east of the Isle of Man. A secondary peak in fucoxanthin was also found in waters associated with the Duddon ’-Hexanoloxyfucoxanthin was also found in relatively high concentration (~1200ng/litre) midway between the Isle of Man and the Ravenglass estuary. ’-Hexanoloxyfucoxanthin is a major pigment in certain prymnesiophytes (Figure 39). showed an identical distribution to 19’-Hexanoloxyfucoxanthin and had a concentration maximum of approximately 600ng/litre (Figure 40). The distribution of diadinoxanthin was identical to that of fucoxanthin and maximum concentrations of this compound reached 380ng/litre (Figure 41). Peridinin, a major pigment of photosynthetic aximum concentrations (~130ng/litre) in coastal waters between S
Bees Head and the Duddon estuary (Figure 42).

Surface chlorophyll concentrations had decreased by July. During this time, maximum µg/litre) were found in coastal waters associated with the Solway Firth and along the English coastline (~2.5µg/litre). Waters further west had chlorophyll concentrations µg/litre (Figure 43). A breakdown of the chlorophyll compounds during this time showed fucoxanthin and peridinin to be the two most abundant compounds. Fucoxanthin had its highest concentrations (~500 ng/litre) in waters associated with the Solway Firth (Figure 44). Peridinin was found to have highest concentrations (~400 ng/litre) towards Morecambe Bay (Figure 45). Diadinoxanthin a major pigment in diatoms and prymnesiophytes showed a similar distribution to that of fucoxanthin (max concentration = 120 ng/litre, Figure 46).

4.5 The Distribution of Phytoplankton

The distribution of total phytoplankton recorded during April is plotted in Figure 47. It can be seen that concentrations increase to the north of the region where con
over 100 000 cells/litre. The maximum concentration of phytoplankton was recorded in the west of the area sampled where concentrations reached 300 000 cells/litre. The phytoplankton

reached over 200 000 cells/litre. The diatom maximum was recorded in waters to the west of the area sampled. Waters along the coast between the Solway Firth and Ravenglass estuary diatoms (>50 000 cells/litre) during this time (Figure 48). Dinoflagellates were the second most abundant group amongst the phytoplankton during April with concentrations reaching over 20 000 cells/litre to the middle of the area sampled (Figure ntrations in the main however were much lower, being between 5-10 000 cells/litre.

Concentrations of total phytoplankton had increased by May with maximum concentrations of over 500 000 cells/litre being found in waters adjacent to the Duddon estuary. A
productivity region was also recorded to the middle of the sampling area where concentrations reached 400 000 cells/litre (Figure 50). Diatoms were the most abundant organisms found during May. Maximum concentrations of over 500 000 cells/litre
adjacent to the Duddon estuary. Diatom concentrations outside this area were generally less

than 200 000 cells/litre (Figure 51). The prymnesiophyte spp. was also present in the waters during May at concentrations in excess 80 000 cells/litre. The bloom of this species was generally restricted to waters in the north of the study area (Figure 52). Along the Cumbrian coastline the diatom community was dominated by

to the south were dominated by the diatoms
was also recorded offshore from S
of up to 25 000 cells/litre being recorded. A
recorded in waters associated with the Duddon estuary.

Dinoflagellates were also in abundance during May with maximum concentrations (~40 000
way between Ravenglass estuary and the Isle of Man. Another region of elevated dinoflagellate production was recorded in a plume running south-west of the Ravenglass estuary, concentration here being approximately 20-30 000 cells/litre (Figure 53).
h productivity area located to the middle of the study area was dominated by
sp. Concentrations of the potentially toxic dinoflagellates
reached over 500 cells/litre (Figure 54).

trations had decreased by July with concentrations now not exceeding 140 000 cells/litre (Figure 55) with highest concentrations generally being found adjacent to the Cumbrian coastline and decreasing offshore. Diatom concentrations during this time showed highest concentrations to be found in waters associated with the Solway Firth (Figure 56),
by Rhizosolenia setigera, R. styliformis
. Dinoflagellate abundances had increased since May with maximum con
(~60 000 cells/litre) being found to the south-east of the study area adjacent to Morecambe Bay (Figure 57). This region of elevated dinoflagellate abundances was dominated by a species

sp. The potentially toxic dinoflagellates
had combined concentrations of over 3000 cells/litre in waters to the south of the

4.6 Analysis of Spring Phytoplankton Community Structure and Environmental Variables - Results of Statistical Analysis

Variation in phytoplankton community structure during May was investigated via a multi-dimensional scaling exercise. An MDS stress of 0.07 was applied to the plot. Three groups were identified according to the similarity of species abundances. Group 1 reflects those sites to the extreme west of the study area, group 2 reflects sites to the north of the region and
h of the region (Figures 59a & 59b). A closer examination of the community structure of the three groups using a ranked Bray Curtis Similarity scale shows
accounts for 29.5% of the similarity between all three groups.
small flagellated algae account for 21% of the similarity and the larger diatom

The patterns in community structure outlined above were used in the BIOENV
identify which physical or chemical variables best explain the distribution of spring phytoplankton communities. Winter (January) nutrient and spring (May) salinity and

temperature variables were run against spring phytoplankton data. The BIO
conducted suggested some relationship between the spring phytoplankton and winter nitrate concentrations (r = 0.243, Harmonic Weighted Spearman). The best match between combined environmental variables was achieved with a combination of nitra

5. CUMBRIA COAST SURVEYS

5.1 Major Spatial and Temporal Trends

Sea surface temperatures, salinity and nutrient salts generally showed an east-west trend on all e winter and spring surveys (January, February, April and May) were positively correlated with salinity whilst July SST's were negatively correlated. The influence of riverine discharges on salinity, and nutrient salt concentrations was most ing the winter and spring sampling dates. The penetration of reduced salinity surface water was greatest during January. Concentrations and distributions of all nutrient salts were well correlated across the region during January and February (relationships had broken down by May after modification of the nutrient salts by the phytoplankton, although silicate and TON were still positively correlated during this time. Statistical relationships between the nutrient salts during July were n

All nutrient salts had maximum concentrations during the January and February sampling dates and had decreased significantly between February and April and again between May and July. ncrease at a few sites between April and May and again between May and July. These sites were located to the south-east of the study area and were associated with intermediate-stratified waters. Concentrations of silicate decreased first in orth of the region during April and May. SRP concentrations were highest in waters associated with the Ravenglass estuary and discharges from the Albright & Wilson

cated by surface chlorophyll concentrations) started in waters associated with the Solway Firth between February and April. This increase in chlorophyll is well correlated with the distribution of diatoms during April. Increased h the Solway Firth remained during May, during which time the

chlorophyll pigments during May showed peridinin to be correlated with the total number of = 0.004) whilst fucoxanthin showed a distribution similar to that of the total diatom community. High positive correlations also existed between the β-carotene and chlorophyll C_1C_2 and the distribution of *Phaeocysti*s sp.

The spring bloom was dominated by *Chaetoceros socialis* *Guinardia deliculata* sp. in waters to the north of the region whilst *Nitzschia seriata* dominated waters to the south. These results are in keeping with those previous years (Kennington et al. 1997, 1998). Dinoflagellate abundances were highest in waters adjacent to the Cumbrian coastline and to the centre of the study area. sp. accounted for most of the dinoflagellate sp

up to 600 cells/litre in waters to the south of the region and were strongly correlated with stratified conditions. Results from previous years have shown that waters to the south of the region tend to have increased abundances of dinoflagellates during the spring bloom, a phenomenon that is consistent with the results presented here (Allen

Productivity of the Cumbrian coastline, in particular the Solway Firth remained relatively high through to July and was dominated by diatom *species Rhizosolenia setigera, R. styliformis, R.*

algae (monads, prymnesiophytes etc.). Chlorophyll concentrations during July were well correlated with the total diatom concentrations and strong positive correlations existed between the photosynthetic pigments fucoxanthin, chlorop
violaxanthin and the concentrations of diatoms across the region. Dinoflagellate numbers had increased since May but were still concentrated in waters to the south-east of the region. Dominant species of dinoflagellates includ
sp. whilst the potentially toxic
of up to 3000 cells/litre in waters to the south of the study area. The photosynthetic pigment
ly correlated with the distribution of total photosynthetic dinoflagellates.
Multi-Dimensional Scaling of the spring phytoplankton data suggests three clusters distinguishing phytoplankton communities, one group representing waters to the west of the area, one representing northerly waters and one representing southerly waters. A further statistical comparison (BIOENV) between spring phytoplankton community dynamics and the distribution and concentrations of winter nutrient salts and spring physical h
suggest that winter concentrations of nitrate, soluble reactive phosphate and the spring salinity gradient may best account for differences in the spring phytoplankton community structure.

uts into the region via riverine runoff were evident throughout the whole sampling period though most were evident during the winter. Ammoniacal nitrogen, nitrate, nitrite and silicate were all found in greatest concentrations in waters associated with the
during January. Elevated concentrations of Soluble Reactive Phosphate (SRP) were also found in waters adjacent to Whitehaven on most sampling occasions reflecting the industrial discharges of SRP from the Albright and Wilson plant in Whitehav
of TON have been recorded from waters associated with the BNFL plant at Sellafield over the past four years, but during the 1998 sampling campaign no evidence could be found to directly

Guidelines set out by the Comprehensive Studies Task Team (CSTT 1997) of the Marine Pollution Monitoring Group suggest coastal waters to be adversely affected by nutrient input if winter concentrations of dissolved inorganic availabl
μg/litre) in the presence of at least 0.2 mmol/m μg/litre) DAIP, or if summer concentrations of surface chlorophyll are greater than 10μg/litre. Data collected during January, February and April showed that limits of both DAIN and DAIP were above the CSTT recommendations across most of the study area. DAIN concentrations during January
μg/litre whilst DAIP concentrations ranged from 10-60μg/litre.
Concentrations of surface chlorophyll during May exceeded the CSTT threshold of 10 μg/litre in waters north-east of the Isle of Man. The concentrations of surface chlorophyll had decreased by July and were within the limits recommended by the CSTT.

erm changes in nutrient salt concentrations and the alteration of nutrient salt ratios have been shown to alter the phytoplankton community structure of receiving waters (Lancelot
1997, Hellagraph 1995, Paerl 1988). It has been shown that eutrophic c
reduction in silica based organisms such as the diatoms in favour of non-siliceous flagellated

algae (Officer & Ryther 1980). Although there is scant evidence to support any such phenomenon from the eastern Irish Sea owing to the infrequency of sampling, the spring bloom has been dominated by either non-siliceous forms such as the nuisance algae or lightly silicified diatom forms such as species. over the past three years. sp. have been associated with elevated concentrations of nutrient salts (Veldhuis 1986), and with decreasing ratios of N:P

A winter molar ratio of N:Si greater than 2 (µg-at/litre) has been suggested to be indicativ hypernutrified waters or 'waters likely to become eutrophic' (NRA 1996). It can be seen from Figure 60 that waters adjacent to the Cumbrian coastline have an N:Si ratio >2. These results are consistent with results presented for the previous two years

Dense blooms of the nuisance algae sp. were reported throughout the eastern Irish Sea during May. Although thought to be non-toxic, this species can be r production of surface scums, which can be unpleasant to bathers and beach users. The potentially toxic dinoflagellates concentrations exceeding guideline levels during May and July. Con cells/litre were recorded in waters adjacent to Morecambe Bay during July.

Although the large dinoflagellate was not reported from the present study it was reported in very high concentrations off Morecambe B

During July of 1999 samples of queen scallops (western Scottish waters were sent for assay. Results from the assay showed the scallops to have high concentrations of azaspiracid (aka spiramino acid or Killary Bay Toxin 3) and as a cosequence 8000 square miles of scallop fishing grounds were closed. Azaspiracid is a compound very similar to algal toxins responsible for Paralytic and Amnesic shellfish also reported in high concentrations in waters associated with Strangford Lough during September 1999 resulting in closure of those fishing grounds also.

5.4 Cumbria Coast Survey: Conclusions

- Winter concentrations of dissolved available inorganic nitrogen (DAIN) and dissolved available inorganic phosphorus (DAIP) exceeded the recommended limits of the Comprehensive Studies Task Team (CSTT). Under these guidelines waters within the study area are classed

- genous compounds were highest in coastal waters located between the Duddon estuary and Solway Firth.

- Concentrations of soluble reactive phosphate (SRP) were highest in waters around Whitehaven/St Bees Head area on several occasions. These results being in agreement with those recorded in previous years (Allen et al 1996, Kennington et al. 1997, 1998), and may reflect operations of the Albright & Wilson Plant at Whitehaven. Elevated concentrations of SRP were also recorded in waters associated with the Ravenglass estuary during April, May

- Winter ratios of N:Si of greater than 2 were recorded in waters adjacent to the Cumbrian coast. Such high ratios are thought to be indicative of waters subject to future

- cation of the water column occurred during May and July. On both occasions water to the south of the region exhibited a marked thermal gradient. During May the region of thermally stratified waters was positively correlated to the distribution of the monad

- Concentrations of surface chlorophyll exceeded the 10 μg/litre threshold during May in waters to the north of the region but had decreased considerably by July and were well below the CSTT (1997) recommendations. A breakdown of the chlorophyll pigments vi analysis revealed peridinin to be positively correlated with the distribution of photosynthetic dinoflagellates and fucoxanthin to be positively correlated with the distribution of diatoms.

· The spring bloom was dominated by diatoms such as *deliculata, Nitzschia seriata* and *Phaeocystis* sp. Three distinct community groups were identified by multi-dimensional scaling and statistical analysis (using BIOENV) suggesting that the winter concentrations of nitrate and SRP and the spring salinity gradient best accounted for the spring phytoplankton community structures.

- Nuisance and potentially toxic organisms were reported from waters in the eastern Irish Sea during 1998. Several blooms of *Phaeocystis* were reported during April and May (MBCC 1999) one such bloom being identified in the present study in waters to the north-east of the Isle of Man during May. During late July several reports were also made of blooms of the ons around the eastern Irish Sea (MBCC .1999). The potentially toxic dinoflagellates were also reported in concentrations above EA recommendations during the

6. LIVERPOOL BAY SURVEYS

Three sampling trips were undertaken in Liverpool Bay during 1998 by the Environment
’s ‘R.V.Coastal Guardian’ (Figure 80). Sampling protocols and techniques remain the same as for the Cumbrian coast surveys. The actual sampling dates were as

Sea surface temperatures showed an east-west gradient on all sampling occasions. During April and May temperatures were warmest in waters adjacent to the coastline and decreased ffshore. Maximum temperatures during April (Figure 61) were <11°C but these had increased considerably by May (Figure 62) when maximum temperatures of 15°C were recorded. Sea surface temperatures during October were warmest in offshore waters and coolest i
adjacent to the coastline, maximum temperatures during October being 16°C (Figure 63).

Surface water salinities showed a similar distribution on all sampling occasions with lower salinities being recorded in waters adjacent to the coastline and i
penetration of lower salinity surface waters was greatest during April and May and lowest

6.2 Patterns of Nutrient Distribution

Data on nutrient salt distributions and concentrations are only availab
surveys. During April and May 1998 the majority of total inorganic nitrogen was present as nitrate. Concentrations of TON (Total Oxidised Nitrogen) during April were highest along the English coastline with maximum concentrations (µg/litre) being located in waters to the southwest of Southport (Figure 67). These high concentrations of TON decrease westwards
µg/litre were recorded. Concentrations of ammoniacal nitrogen during April were greatest in waters associated with the Mersey and Dee estuaries and decreased to the northwest of the region. Maximum concentrations of ammonia were between
µg/litre (Figure 68). Nitrite concentrations during April were highest in off-shore
µg/litre (Figure 69).

Nitrate concentrations had decreased considerably by May and concentrations then did not
µg/litre. Maximum concentrations during May were found in waters adjacent to the coast between Liverpool and Southport and another region to the north of Liverpool Bay (Figure 70). Concentrations of ammoniacal nitrogen had also decreased between April and May, highest concentrations still being found in waters associated with the Dee estuary (Figure
rite concentration was also observed between April and May and maximum concentrations were found along the coastline between Liverpool and Southport

Concentrations of soluble reactive phosphate (SRP) during April were highest along the coast between Southport and Liverpool and decreased offshore. Maximum concentrations were between 80-100µg/litre (Figure 73). SRP concentrations had decreased considera April and May after modification by the plankton flora. Maximum concentrations during this time were located in waters between Rhyl and Liverpool (Figure 74).

Silicate concentrations during April were highest in waters associated with the Dee where concentrations of up to 700µg/litre were recorded (Figure 75). Silicate concentrations had decreased across the entire region by May and were generally in concentrations less than µg/litre (Figure 76).

6.3 The Distribution of Surface Chlo

Surface chlorophyll concentrations within Liverpool Bay are only available for April, May and October. Concentrations of surface chlorophyll during April were highest in waters to the south east of the region, particularly around the Dee and Mers µg/litre were recorded (Figure 77). Productivity of the surface waters had increased significantly by May. During this time waters associated with the Dee and Mersey estuaries still had the highest concentrations whi µg/litre (Figure 78). Productivity of the surface waters during October was highest along the north Wales coast µg/litre were recorded, the rest of the waters in the region generally having concentrations o µg/litre (Figure 79).

6.4 Major Spatial and Temporal Trends

Physical variables (SST and surface salinities) showed a southeast-northwest trend within Liverpool Bay on all sampling occasions. Warmest SST's were found inshore during April and May and offshore during October. Surface water salinities were greatest offshore on all sampling occasions. The influence of freshwater runoff from estuaries within Liverpool Bay on salinity, nutrients and temperature was evident on all sampling occasions.

Levels of all the major nutrient salts were highest in waters associated with the major estuarine systems during April. During this time the distribution of surface chlorophyll was well correlated with the distribution of silicate, TON and SRP. The spri was very evident during May when chlorophyll concentrations of up to 40µg/litre were recorded, productivity during May being highest in waters associated with the north Wales coastline. The peak concentrations of nitrate and silicate during May were located away from areas of high chlorophyll concentrations suggesting modification of these nutrients by the diatom flora. Although no phytoplankton samples were enumerated on this sampling date, p. were reported along the Lancashire and Welsh coastlines between the 19th of April and the 14th of June (MBCC 1999). During the summer of 1998 an extensive bloom of the chain forming diatom nd Lancashire coasts during a period commencing 15th July, finally disappearing 3rd November (MBCC 1999).

6.5 Evidence Of Impact Of Nutrient Inputs

Nutrients entering Liverpool Bay arrive from several sources - agricultural practices operating e Liverpool Bay catchment are responsible for phosphorus and nitrogenous leachates which enter the Bay via the rivers and estuaries. Atmospheric rainout of nitrogenous products will also contribute to the nutrient pool of the Bay although to date this has quantified. Point source discharges of silicate are known from one source in the Liverpool Bay catchment. The contribution of nutrients from sewage related operations are of minor significance when compared to those from agricultural origin. The c December 1998 should help reduce the contribution of sewage related nutrient salts to the overall nutrient pool.

Guidelines set out by the CSTT (1997) suggest an area to be adversely aff

1) Observations of winter dissolve available inorganic nitrogen (DAIN) are greater than μg/litre) in the presence of at least 0.2mmol/m μg/litre) dissolved available inorganic phosphate (DAIP) or;

2) Summer chlorophyll concentrations are greater than 10μg/litre.

Although no data exist for the winter nutrient concentrations during 1998, it can be assumed that those recorded during April 1998 would represent a near maximum nutrient concentration after some modification of the nutrient pool by the phytoplankton since maximum concentrations of nitrate and phosphate would have peaked only 4-8 weeks earlier (see . 1998, Figure 66). Given this assumption, it is clear that the levels of DAIN bove those recommended by the CSTT and could have only been higher during the winter months. The surface chlorophyll concentrations during May exceeded the CSTT recommendations where concentrations along the north Wales coast μg/litre. No data exist for summer chlorophyll concentrations, however concentrations of surface chlorophyll during October remained relatively high along the north

6.6 Liverpool Bay Surveys: Conclusions

- Data collection by the Environment Agency in 1998 wa reorganisation of their Coastal Survey vessel operations, therefore shortage of data at critical times of the productivity cycle makes it difficult to draw any firm conclusions for

- ns nutrient concentrations were highest along the Lancashire and Welsh coastlines, particularly around the Mersey, Dee and Ribble estuaries.

- Winter concentrations of dissolved available inorganic nitrogen and phosphorus exceeded the guidelines of the Comprehensive Studies Task Team (CSTT 1997) along the Lancashire and Welsh coastline. Under these guidelines such waters are said to be adversely affected

- Surface chlorophyll concentrations exceeded the CSTT (1997) recommendations during M 1998. However no data exist for the summer months and as such no conclusions can be

THE DISTRIBUTION OF NUTRIENTS AND HYTOPLANKTON IN THE EASTERN IRISH SEA DURING 1998: SUMMARY AND MAJOR CONCLUSIONS

- Winter concentrations of DAIN and DAIP along the Cumbria, Lancashire and North Wales coastlines exceeded the recommendations of the Comprehensive Studies Task Team (1997). Under these guidelines these waters are classed as hypernutrified and possibly subject to future eutrophication. Winter ratios of N:Si of greater than 2 were also reported for waters south of the Ravenglass estuary, such high ratios further indicating the possibility of future eutrophication.

- The influence of riverine discharges upon the concentrations and distribution of nitrogeno compounds is readily apparent from the data. Between January and May highest concentrations were recorded in waters associated with the Solway Firth, Mersey and Dee estuaries, whilst between May and July highest concentrations were associated with the

- During January and February highest concentrations of phosphorus were found in waters to the north of the Duddon estuary. During April, May and July highest concentrations of SRP were found in waters associated with the Ravenglass estua of nutrient salts within Liverpool Bay were located to the southeast of the study area particularly in waters associated with the Dee and Mersey estuaries. These results indicate that the phosphorus load into the eastern Irish Sea is primarily riverine in origin. The industrial discharges of SRP from Albright & Wilson at Whitehaven is also evident in the data, particularly during the winter months.

- Concentrations of surface chlorophyll recorded during the spring and summer sampli exceeded the CSTT recommendations during May but had reduced to acceptable levels by July. A breakdown of the chlorophyll pigments showed good correlations between diatom abundances and fucoxanthin concentrations and between dinoflagellate abund peridinin concentrations. The results from the HPLC analysis are encouraging and could potentially lead to a more rapid assessment of phytoplankton differentiation than does microscopy, however further work is required to validate such techniques

- Results from the Cumbrian coast surveys show stratification of the water column during May and July. During May stratification was caused by a combination of thermal and salinity anomalies. During July the waters were intermediately stratified in two reg north and one to the south of the study area.

- The spring phytoplankton bloom was dominated by diatoms and the prymnesiophyte *Phaeocystis* sp. A bloom of *Guinardia deliculata* was also recorded around St Bees Head during May. The diatoms were still the most dominant representatives of the phytoplankton during July, although monads and small flagellated algae had become much more abundant

- Comparisons between winter nutrient salt concentrations and spring phytoplankton community structure suggested that winter TON and SRP concentrations and the spring salinity gradient best explain the spring phytoplankton community.

- Evidence of nuisance and potentially toxic algal groups were reported during 1998. The prymnesiophyte *Phaeocystis* sp. was reported from several localities during April and May (MBCC 1999). The large dinoflagellate *Noctiluca scintillans* was also reported in dense ious localities around the Irish Sea during July and August often leading to a discoloration of the water column (MBCC 1999, Shammon

bove EA recommendations during the Spring and Summer months in the

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