EA-NCEDS BOX 3

National Marine Baseline Survey 1995

Littoral Cell 3
The Wash to the Thames

ENVIRONMENT AGENCY

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Foreword

In recent years we have carried out National Baseline Surveys of the coastal zone which have involved analysis of samples taken at specific locations in coastal waters around England and Wales for a wide range of determinants. These data have been supplemented by further continuous analysis from the Coastal Survey Vessels and by spatial data from airborne remote sensing operations.

The dissemination of information from these data in an easily digestible form has proved to be a difficult task. To try to overcome this problem the data for the 1995 surveys have been distilled into a summary for each littoral cell.

The information in these summaries is meant to reflect the main features of the littoral cell. More extensive data as well as data collected in previous surveys are held at the National Centre and can be made available on request.

David Palmer

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Introduction

The object of this report is to present an overview of the results of the four 1995 surveys in a compact form. The report is accompanied by the full laboratory analysis results and a catalogue of image data stored on CD-ROM and video. In total there are seventeen parts to the report, and those parts included in this pack are listed at the end of this section.

The coastline has been divided into coastal cells, known as littoral cells using the procedure developed by HR Wallingford (Motyka and Brampton, Report SR 328, January 1993). A map of the divisions between these cells is shown in Figure (i). The rationale of these cells means that any changes within a cell should not affect adjacent cells. In addition each cell has a significantly different character to adjacent cells, in terms of geology or biology. The divisions were defined principally for coastal defence construction, but the position of boundaries have implications on water quality variations. For example, effects from effluent outfalls should not be transferred across boundaries.

The water chemistry results for each cell have been reviewed for each season. In particular the nutrient results have been investigated for high concentrations in Summer which may be linked to anthropogenic sources, and which may result in eutrophic waters. In parallel with this the chlorophyll-*a* concentrations have been studied for any increases which are linked to high nutrient values, by two techniques. Firstly, the individual samples have been investigated, and secondly, maps of the entire coastal zone have been produced to allow spatial estimates of eutrophic waters to be made.

The absolute concentration of chlorophyll-*a* is compared with a concentration of 10 µg/l. This is the level suggested as representative of a bloom event by the Department of the Environment in their document "Criteria and Procedures for Identifying Sensitive Areas and Less Sensitive Areas" which was produced as a response to the EC Urban Waste Water Treatment Directive. Although this level signifies the presence of a phytoplankton bloom, it must be associated with other indicators to show that waters are effected by eutrophication.

Dissolved metals concentrations have been investigated in terms of their relation to the Environmental Quality Standard (EQS) levels. These levels are established in response to the EC Dangerous Substances Directive. The definition of the EQS level is as an annual mean. This has been calculated for any sites in which an individual sample exceeds the EQS. Organic contaminants have also been compared with EQS levels where they exist.

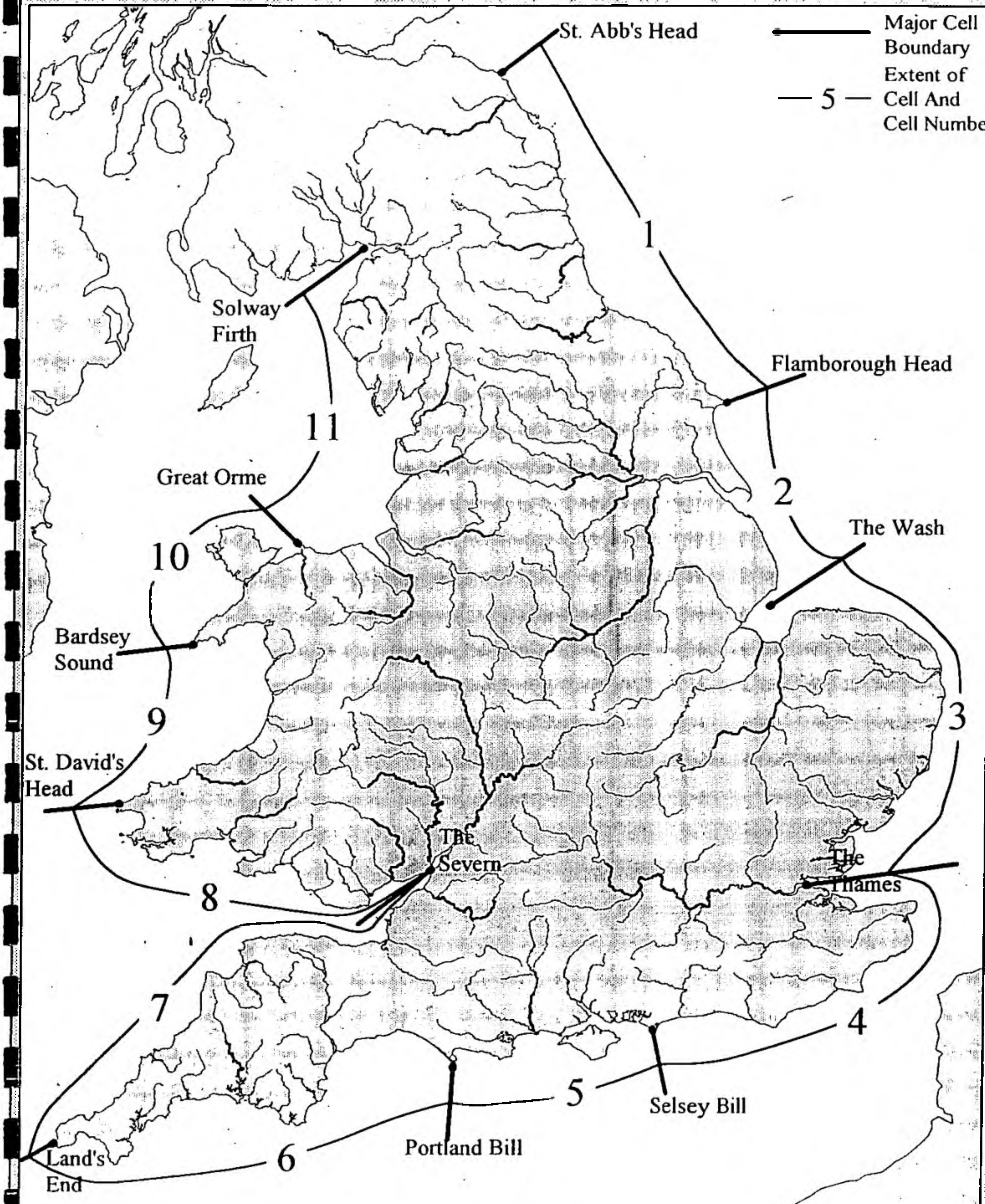
Consideration has been given to the position of the baseline sampling sites in relation to estuaries or major oceanographic features.

The image data and underway data have been investigated for major oceanographic features and changes in water quality. These may be manifested in the image data in two ways. Features are seen in the CASI imagery if they result in an alteration in the ocean colour signal. This usually requires a change in the amount of light scattered or absorbed by particles in the water column. Features such as estuarine plumes have higher particulate matter loading which increases the ocean colour signal. Phytoplankton blooms increase the absorption of light in selected wavebands and moreover result in fluorescence being detected in other wavebands. Some features do not record a CASI signal but have a difference in water temperature. The thermal video systems used in the baseline survey record only the surface temperature of the water, but clearly show features such as effluent discharges and outfalls from power station cooling systems, in addition to river plumes.

The underway data illustrates changes in temperature, salinity, dissolved oxygen, transmission and fluorescence. The longitudinal profiles from the underway systems have been investigated for major changes which may be associated with estuarine inputs or fronts between different water bodies. Data from the Skalar continuous monitoring nutrient analyser have been investigated to determine the geographical extent of elevated samples in the laboratory analyses.

Summaries have been produced for each littoral cell which provide a statement on the water quality of the region recorded by the baseline survey. The key local oceanographic features are also summarised.

Figure i. The Major Littoral Cells of England and Wales, After Motyka and Brampton, 1993.



* Motyka, J.M. and Brampton, A.H. (1993), "Coastal Management, Mapping of Littoral Cells", HR Wallingford.

Littoral Cell 3: The Wash to The Thames

Executive Summary

This littoral cell extends from The Wash to the Thames Estuary. Water quality is generally dependent on these major estuarine sources, with associated higher levels of contaminants.

Exceptionally high nitrite concentrations were found at sites within this cell. In Winter the national survey maximum value was found in this cell, equal to 13.5 µg/l N, and in Autumn many sites recorded abnormally high concentrations. The highest concentration was 459 µg/l N at Gorleston. The chlorophyll-*a* concentration was high at all seasons, but showed a typical seasonal cycle, with no exceptionally high Summer values.

Spatial chlorophyll-*a* results confirm this, with no areas showing results in July which are above 10 µg/l. The higher concentrations found coincide with the highest regions for nutrients, ie. the Wash and the Thames.

Dissolved metals concentrations showed little seasonal or geographical pattern. Moreover, the results were not high in comparison to the survey maximum values for the rest of the coastline and when compared with the Environmental Quality Standards.

The CASI imagery illustrates the large scale of sandbanks and other bathymetric features along this coast. Sediment transport patterns are clearly seen around the barrier islands of the North Norfolk coast. Coastal protection schemes are shown to be preventing the longshore drift of beach material near Clacton-on-Sea. Thermal video imagery clearly shows outfalls from two power stations, at Sizewell and in the River Blackwater. There are no major effluent plumes visible in the imagery. This is probably due to their discharge being into waters of a similar turbidity, and thus similar ocean colour signal.

1. Introduction

This littoral cell stretches from The Wash in the north to the Thames in the south, as shown in Figure 1. This constitutes approximately 3500 km^2 within that part of the coastal zone for which the Environment Agency has responsibility for controlled waters, of which 1125 km^2 are estuarine waters. This figure includes all waters within the Wash and the Thames as the littoral cell boundary does not extend offshore.

There is a residual westerly littoral flow from Sheringham to The Wash, with the drift divide at Sheringham marking the change in residual direction to south-easterly. Four vessel surveys for the collection of underway data and water samples for laboratory analysis were carried out by Sea Vigil in Winter (January), Spring (May), Summer (July) and Autumn (September). Two aircraft surveys were carried out in July and September.

2. Water chemistry results

2.1 Background

The chemistry of the waters of this littoral cell is dominated by the Wash to the north and the Thames to the south. In total there are 17 baseline sampling sites, distributed evenly along the coastline. The positions are shown in Figure 1.

2.2 Nutrients and chlorophyll-*a*

2.2.1 Total Oxidised Nitrogen (TON)

TON concentrations showed a clear seasonal cycle, with highest concentrations during the Winter and Autumn surveys, and extremely low concentrations during Spring when the bloom in phytoplankton has depleted the nutrient stocks. In Winter the highest results were recorded at the Wash (35) equal to 1210 µg/l N and the Medway Buoy (51) equal to 902 µg/l N. In Spring, only four sites recorded concentrations above the minimum reporting value (MRV). Of these, none exceed 100 µg/l N. In Summer, the results were generally below 200 µg/l N, but with an elevated concentration seen at the Medway Buoy (51), equal to 704 µg/l N. A number of sites recorded extremely high concentrations during the Autumn survey, with the maximum of 1731 µg/l N found at Gorleston (42).

2.2.2 Silicate

Silicate concentrations were again highest at the Wash (35) and the Medway Buoy (51) during Winter, with concentrations of 566 µg/l Si and 687 µg/l Si respectively, but there is less variation between these results and those found at other sites for TON results. No sites recorded concentrations above the MRV of 1 µg/l Si in Spring, and very few in Summer. The maximum Summer value is 72 µg/l Si at Kessingland (43). In Autumn the results are generally higher with a maximum of 229 µg/l Si at Jaywick (49).

2.2.3 Orthophosphate

Orthophosphate concentrations did not show such a seasonal cycle, but the lowest concentrations were still seen during the Spring survey. In Winter, the maximum concentration was found at Medway Buoy (51), but was only 126 µg/l P compared with a national survey maximum of 438 µg/l P. The Medway Buoy (51) was the only site to record a value above the MRV of 0.5 µg/l in Spring, with a concentration equal to 6 µg/l P. This site showed the maximum concentration for this cell in Summer and Autumn, equal to 92 µg/l P and 63 µg/l P respectively.

2.2.4 Total Ammoniacal Nitrogen (Ammonia)

Ammonia concentrations were low in Winter, with no concentrations above the MRV. In Spring results are recorded at three sites within this cell, with the maximum being 34 µg/l N at Winterton (41). During the summer survey results were generally higher, with sites to the south of the cell have the highest concentrations. A maximum concentration of 58 µg/l N was found at Jaywick (49) and Kessingland (43). These were low compared with the survey maximum of 552 µg/l N.

2.2.5 Nitrite

Nitrite concentrations recorded in this littoral cell were high, with the survey maximum for nitrite being recorded during two surveys. In Winter positive results were found at some sites, with the national survey maximum of 13.5 µg/l N being found at Sheringham (38).

In Spring there are no results above the MRV of 0.5 μg/l N. In Summer, the results mimic those of ammonia with the highest concentrations between Felixstowe (47) and the Medway Buoy (51). Great variability was seen in Autumn, with the magnitude of results such that they were revalidated by the laboratory. The maximum concentration was seen at Gorleston (42), equal to 459 μg/l, which is again the national survey maximum.

2.2.6 Chlorophyll-a
Chlorophyll-*a* results showed a seasonal cycle, with low concentrations, typically less than 1 μg/l in Winter. Two sites, however, recorded concentrations in excess of 2 μg/l, with the maximum at Jaywick (49) equal to 3.73 μg/l. Variability was high in Spring, with the minimum concentration recorded at Winterton (41), equal to 2.05 μg/l, and the maximum equal to 14.92 μg/l at Shingle Street (46). In total three sites were above 10 μg/l indicating the presence of phytoplankton blooms. Summer results are fairly high, with most sites having concentrations above 3 μg/l, although no sites record the presence of a bloom. In Autumn, a bloom is seen at Winterton (41), equal to 10.71 μg/l. This site also has a high Summer concentration.

2.2.7 Nutrients/chlorophyll-a Summary
Nutrient concentrations showed some geographical pattern with highest concentrations located at the Wash and the Thames. Elevated concentrations were recorded between these sites. There is no direct link between high nutrient concentrations and chlorophyll-*a*, although the cell recorded high chlorophyll-*a* in Summer which may be artificially stimulated Further investigation may be warranted in this region to establish whether the area is potentially subject to eutrophication. This coast has recorded high chlorophyll-*a* concentrations in the earlier baseline surveys.

2.3 Suspended solids
Suspended solids measurements showed a Winter maximum at Kessingland (43) of 162 mg/l, with very low concentrations being recorded at the Thames sampling sites, eg. 14 mg/l at Maplin. Kessingland (43) also recorded the maximum concentration in Spring and Summer, but with results of 14 mg/l and 26 mg/l respectively. In Autumn, the highest concentrations were found within the Thames, with a maximum of 162 mg/l at Jaywick (49). Kessingland (43) recorded a relatively low concentration of 45 mg/l during this survey. The differences are probably due to varying tidal state.

2.4 Metals

2.4.1 Total Mercury
Total mercury results are all below the MRV of 0.008 μg/l Hg in Winter and Spring, with only two sites recording values above this in Summer. In Autumn, results are higher, with a maximum of 0.021 μg/l at Jaywick (49).

2.4.2 Dissolved Cadmium
Only one sample from 1995 showed a dissolved cadmium concentration above the laboratory MRV of 0.042 μg/l Cd, this being equal to 0.054 μg/l Cd at the Medway Buoy (51) in Summer.

2.4.3 Dissolved Copper

The maximum recorded copper concentration in Winter was found at Lessingham (40) equal to 2.25 μg/l Cu which is close to 50% of the EQS value of 5 μg/l Cu. Other results were generally less than 1 μg/l. In Spring, Summer and Autumn, the maximum concentration was consistently found at the Medway Buoy (51), with the highest concentration being 1.45 μg/l in Summer.

2.4.4 Dissolved Lead

Dissolved lead concentrations were all below the laboratory MRV of 0.024 μg/l Pb in Winter, with similarly low concentrations in Spring. The maximum concentration in Summer was found at Maplin equal to 0.071 μg/l, compared with an EQS level of 25 μg/l and a survey maximum of 14.7 μg/l at Berwick. In Autumn most results were less than the MRV except for Jaywick (49) equal to 1.32 μg/l.

2.4.5 Dissolved Arsenic

No samples were found to be above the laboratory MRV of 2 μg/l As for dissolved arsenic.

2.4.6 Dissolved Zinc

Dissolved zinc concentrations in Winter were generally less than 10 μg/l, with one clear exception: at Gorleston (42) the concentration was equal to 31.1 μg/l compared with an EQS level of 40 μg/l. A similar peak was seen at Dunwich (44) in Autumn equal to 26.2 μg/l. This is close to the survey maximum of 32.4 μg/l. In Spring and Summer results were generally lower.

2.4.7 Dissolved Chromium

Dissolved chromium concentrations were low throughout the surveys, in comparison to the EQS level of 25 μg/l. No sites recorded chromium concentrations above the laboratory MRV of 0.35 μg/l Cr in Winter. In Spring the maximum concentration was 0.9 μg/l at Kessingland (43). The maximum Summer concentration was 2.23 μg/l at Gorleston (42).

2.4.8 Dissolved Nickel

Dissolved nickel concentrations were also low, with no results above the laboratory MRV of 0.058 μg/l in Winter. The maximum concentration recorded for this cell was 1.28 μg/l at Felixstowe (47) in Autumn, compared with an EQS level of 30 μg/l.

2.4.9 Metals Summary

Dissolved metals concentrations showed little seasonal or geographical pattern. Moreover, the results were not high in comparison to the survey maximum values for the rest of the coastline. No samples exceeded the EQS levels. Only samples for dissolved zinc showed concentrations which are of similar magnitude to those for other sections of the coastline of England and Wales, although none exceed the EQS level. Dissolved copper concentrations appeared to show some geographical pattern with highest concentrations at the Medway Buoy (51) in three surveys.

2.5 Organic determinands

Samples were analysed for twenty three trace organic determinands at nine sampling sites within this cell. Only γ-HCH and α-HCH gave positive analyses. The other 21 determinands were not detected at their laboratory MRV of 0.001 μg/l for the entire survey.

Three of these sites recorded a positive result for γ-HCH in Winter, with Spring results showing concentrations above the MRV for both γ-HCH and α-HCH at most sites. The maximum concentration for total HCH was 0.0072 μg/l compared with an EQS of 0.02 μg/l. γ-HCH concentrations were also recorded for the majority of sites in Summer and Autumn. Although no breaches of the EQS level were found, the occurrence of organic contaminants within this littoral cell was high compared to other areas.

3. Spatial chlorophyll-*a* results

The CASI imagery has been used in combination with the laboratory baseline samples and the underway fluorimeter to produce maps of chlorophyll-*a* concentration of the coastal zone. The technique used involves calculation of the Fluorescence Line Height (FLH) of the imagery and correlation of the three measuring techniques.

Figure 2 shows the calibrated CASI Fluorescence Line Height data for this littoral cell in July 1995. Data are missing around Felixstowe due to a combination of low water and high suspended solids effecting the action of the algorithm. This figure shows the concentration of chlorophyll-*a* to be between 2 and 8 μg/l for all areas covered by image data. In general the north coast of Norfolk shows lower concentrations than those found on the East coast. The Wash and the Thames show high concentrations of up to 8 μg/l. No areas are, however, in excess in 10 μg/l, which may be assumed to mark the presence of a phytoplankton bloom.

Figure 3 shows the calibrated underway fluorimeter data for this region. The results indicate concentrations between 4 and 8 μg/l, but with the same basic geographical pattern as that seen in the FLH data. This figure clearly shows the higher concentrations associated with the Wash and the Thames. Again there are no areas with chlorophyll-*a* concentrations in excess of 10 μg/l. There is no peak near to the Winterton baseline sampling site, which is to the north of Great Yarmouth, which recorded elevated concentrations in the laboratory data. This suggests that the baseline sampling site may be representative of a local feature.

These two techniques allow assessments to be made of areas of water which are potentially subject to eutrophication. In addition, collection and interpretation of such data over time allows changes to be mapped, which may for example be caused by anthropogenic effects, particularly from estuarine sources. The results recorded at the time of this survey do not exceed 10 μg/l. This coast has, however, recorded high concentrations of chlorophyll-*a* in previous baseline surveys, with the results in 1995 being high with respect to the national average figure at the time of survey.

4. Local oceanographic descriptions

The image data collected by the CASI and the thermal video system during July and September 1995 were investigated for variation in ocean colour signal or temperature signal, in order to identify key oceanographic features such as fronts and gyres. Additionally, the underway data from the four campaigns were investigated for any variation in the parameters measured: temperature, salinity, dissolved oxygen, transmission and fluorescence.

This allows an overview of the results to be presented and attention to be focused on areas of interest. From this investigation six areas were selected warranting further description:

1. Sediment movement on North Norfolk coast
2. Bathymetric features
3. Harwich harbour entrance
4. Power station outfalls
5. Clacton-on-Sea groynes
6. Nutrient concentrations on the East Anglian coast

4.1 Sediment movement on North Norfolk coast

The residual littoral flow direction across the North Norfolk coast is towards the west; from Sheringham in the East, to the Wash in the West. CASI imagery from September shows both mixing of sediment off the sandbanks between Hunstanton and Blakeney and the input of sediment plumes from river mouths (Plate 1). These plumes are a combination of riverine waters and coastal waters which have been circulated behind the barrier islands. Suspended sediment in the water column results in a higher ocean colour signal, due to the greater number of particles causing higher scattering of incoming light.

Although the general direction of flow in this image is to the west, it is apparent that a tendency exists for the development of a return flow to the east. This is probably due to the tidal stream when the image was collected, which is moving from slack water to a light westerly flow.

The CASI imagery also shows a variation in ocean colour signal off Brancaster Bay, marked X on Plate 1. This may represent a flow of higher suspended solids away from the coast, but there are no laboratory samples in the region to validate this suggestion.

4.2 Bathymetric features

Bathymetric features on the East coast of Norfolk are of a large scale, for example sandbanks located offshore. These are evident in CASI imagery collected during both July and September. Plate 2 shows the coastline off Great Yarmouth, the first figure showing the positions of Corton Sand and Holm Sand clearly, whereas on the second figure the features are not visible.

Baseline sampling data for suspended solids concentration were collected on 27th July and

14th September, with a similar tidal state. In July the area recorded a low concentration of solids, less than 3 mg/l. In September, in contrast, the concentration has risen to in excess of 50 mg/l. Thus the July image is recording the reflections from the underlying seafloor, or sandbanks, whereas the September image is recording the high suspended sediment concentration which is masking the sandbank features.

Another area in which the CASI imagery clearly detects the underlying bathymetry is Maplin Sands, as shown in Plate 3. The suspended solids concentrations recorded at this laboratory sampling site were fairly low at the time of both these images, meaning that the underlying bathymetry is not obscured by sediment, and it is the varying tidal state which results in the structures seen. In the first figure, the image was taken close to High Water, whereas in the second figure it was taken close to Low Water.

4.3 Harwich harbour entrance

Water flow from Harwich harbour is shown in CASI imagery of 6th July 1995 to be directed out of the harbour and to the north (see Plate 4(i)). Further imagery from September is shown in Plate 4 (ii) and (iii). Plate 4(ii) from 23rd September suggests a slight northerly flow of water around Landguard Point, with no particular direction evident in the image from 14th September. Both of these images were collected close to slack water.

The tidal streams from 6th July point to a flow of water into the harbour, with the imagery taken two hours after Low Water at Harwich. It is thus apparent that the currents within this harbour entrance are more complicated than simply tidally dependant.

The flow of water from this harbour would potentially have implications on the water quality recorded at the Felixstowe (47) sampling site marked on the image, and those to the north and south at Shingle Street (46) and Walton (48). This area marks the entrance of the Rivers Stour and Orwell, with the major conurbation of Ipswich located within the Orwell catchment. The results of laboratory analysis of water samples from Felixstowe (47) in 1995 show elevated concentrations of dissolved nickel in Autumn, and high nitrite and ammonia concentrations in Summer. None of these are particularly high in relation to the national averages. Thus local knowledge would be required to establish whether this is an area which requires further consideration.

4.4 Power station outfalls

Imagery from the thermal video system shows the large outfall of warmer than ambient temperature water from Sizewell power station. Data from both July and September is shown in Plate 5. It is difficult to assess the full extent of warming caused by the outfall for two reasons. Firstly the thermal video system is not at present calibrated to absolute temperatures. Secondly, the gain of the system does not allow a clear distinction of the land features, to enable the exact outfall position to be determined. It is apparent, however, that this warmer water is held close to the coast.

The thermal imagery gives a clearer indication of the extent of the River Blackwater power station outfall. In both cases the plume of warmer than ambient temperature water is flowing downstream towards Pewet Island. In Plate 6(i) from the 6th July, the warmer water is entering into Bradwell Creek. In Plate 6(ii) from 9th September, the flow is passing the entrance to this creek. The tidal stream direction is into the estuary in both cases, and the difference between the images is likely to be due to the strength of the flow, which is higher in the September image, resulting in a more direct flow. The increased water temperature has potential implications on the ecology of this region. It must be noted, however, that the thermal system records only the surface temperature and vertical profile data would be required to assess the depth of influence of the outfall.

These two examples illustrate the capability of thermal image data to assess the direction and extent of thermal effluent sources, in this case from power stations. Collection of thermal data over a full tidal cycle would allow a more thorough description to be made of the potential effected area of coastal waters. The optimum time for these measurements would be at Spring tides when the tidal stream is greatest.

4.5 Clacton-on-Sea groynes

CASI imagery from Clacton-on-Sea shows the successful action of groynes in controlling longshore drift of sediment around Jaywick (Plate 7). Sediment is clearly built up between the groynes and the beach. In addition, there is little sign of movement of sand away from the beach. In July there appears to be an area of clearer water between offshore and coastal waters.

Thermal video imagery from further along the shore at Clacton Pier shows the collection of sediment behind the groynes (Plate 8). This is shown by the warmer water to the west of each groyne. The warmer temperature of this water indicates a longer residence time, as still water is more susceptible to heating.

This data shows the advantage of remotely sensed data is assessing the actions of coastal protection schemes such as groyne systems. Many such systems are small scale, however, and may require data collection at a higher spatial resolution.

4.6 Nutrient concentrations on the East Anglian coast

Data from the Skalar continuous nutrient analyser are shown in Figures 4, 5 and 6 from the Spring, Summer and Autumn surveys. The figures show a clear geographical trend, with higher concentrations located in estuarine locations. In Spring, both TON and ammonia concentrations were highest at Great Yarmouth and Harwich, with ammonia concentrations greater than 80 µg/l N at Harwich and TON greater than 500 µg/l N at Great Yarmouth.

In Summer, TON concentrations were generally lower, but showed some increase to the south of Harwich. Ammonia concentrations remained high, with waters to the south of Lowestoft recording concentrations greater than 100 µg/l N. High ammonia concentrations, above 80 µg/l N were also found to the south of Harwich.

TON concentrations from Autumn showed a clear southerly increase in concentration, with few maxima associated with estuarine locations. Ammonia concentrations, however, were greatest at Lowestoft and Harwich, which both recorded concentrations greater than 100 μg/l N.

Nutrient concentrations on this coast are clearly linked to estuarine sources. Moreover, the nutrient concentrations are high with respect to national averages. Spatial chlorophyll-*a* results showed concentrations of chlorophyll-*a* to be between 4 and 8 μg/l in the Summer survey. These were high with respect to others recorded nationally, but did not exceed 10 μg/l which marks the presence of a phytoplankton bloom. Thus the high nutrient concentrations do not appear to result in eutrophic conditions at the time of the survey.

5. Conclusions

Water quality data from this cell show that the quality is affected by the major estuarine sources of the Thames and the Wash. The water quality in 1995 was generally high, with no sites recording dissolved metals concentrations in excess of the EQS levels. The area showed high concentrations of γ-HCH although the concentration of total HCH did not exceed the EQS.

The spatial chlorophyll-*a* results showed that the region had moderate Summer concentrations of chlorophyll-*a*, with most areas being above 4 μg/l. At the time of this survey, the region was not subject to eutrophication with no areas having concentrations greater than 10 μg/l of chlorophyll-*a*.

CASI imagery revealed sediment transport patterns along the North Norfolk coast associated with the islands parallel to the coast. Bathymetric features were noted on the east coast. Thermal video imagery showed the extent and direction of power station outfalls from the Sizewell and River Blackwater power stations. The plume from the River Blackwater power station has potential implications on the water quality of Bradwell Creek. CASI and thermal data both showed the action of groynes in restricted longshore drift of beach material.

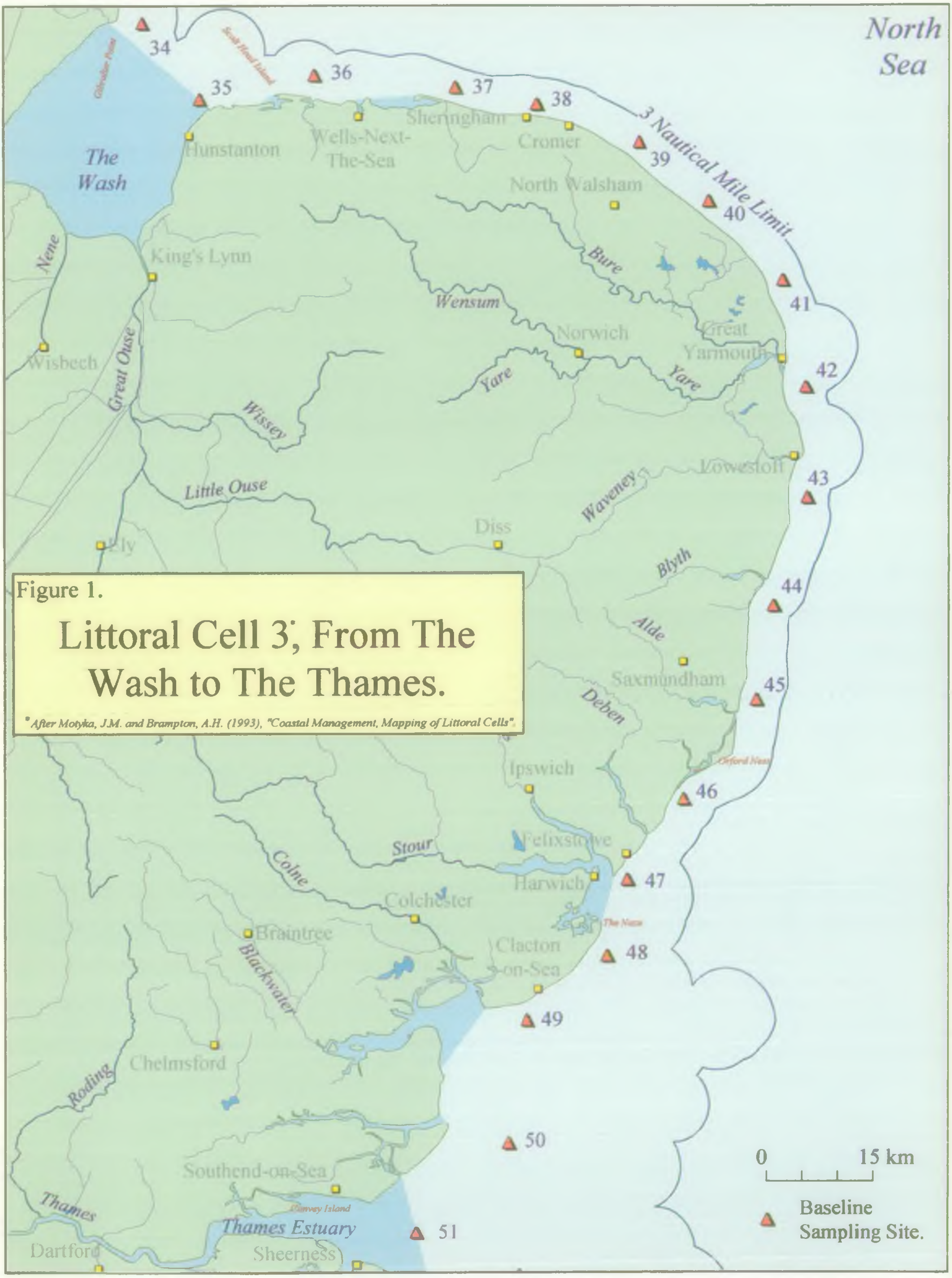


Figure 1.

Littoral Cell 3*, From The Wash to The Thames.

* *After Motyka, J.M. and Brampton, A.H. (1993), "Coastal Management, Mapping of Littoral Cells".*

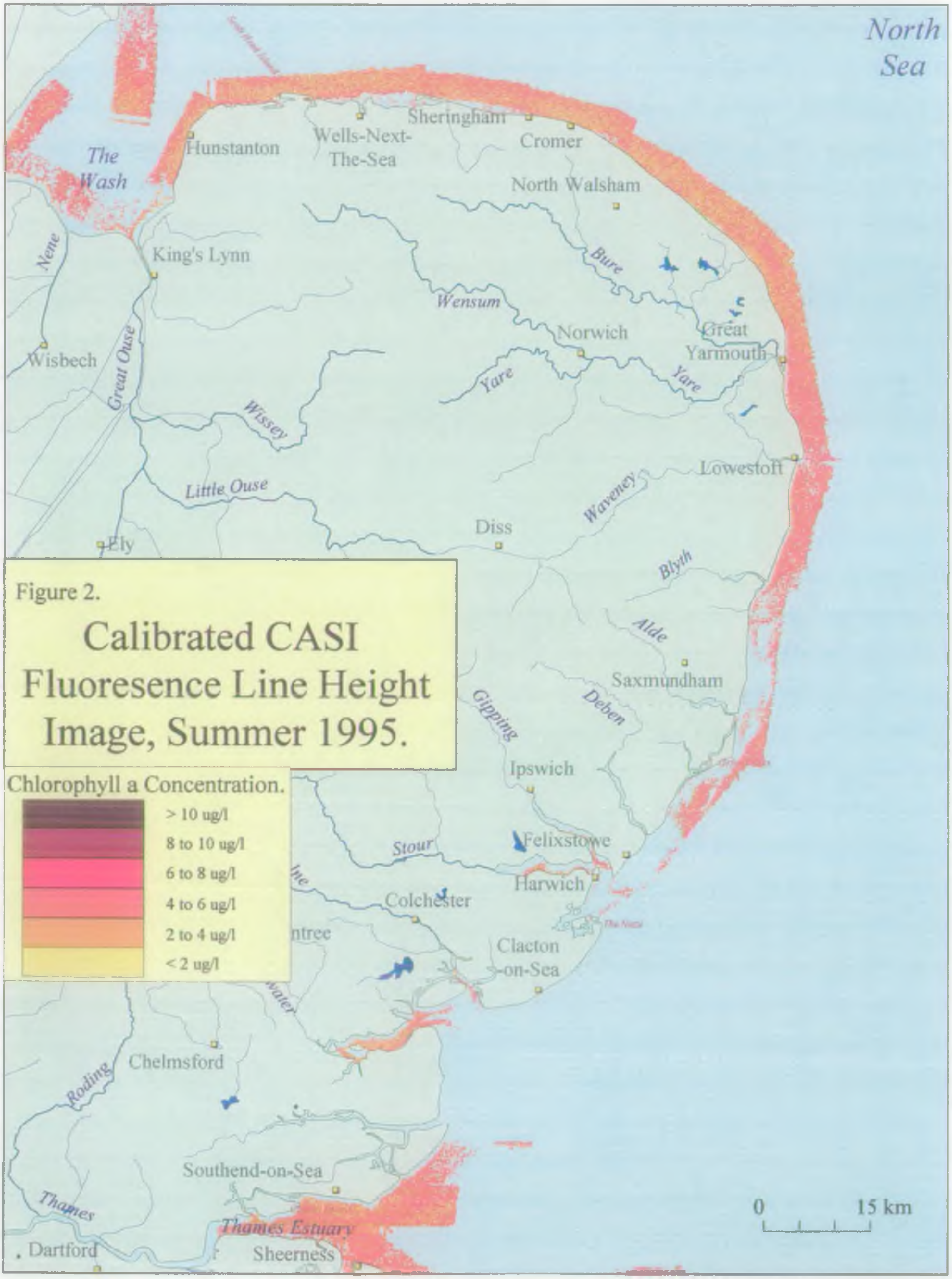


Figure 2.

Calibrated CASI Fluoresence Line Height Image, Summer 1995.

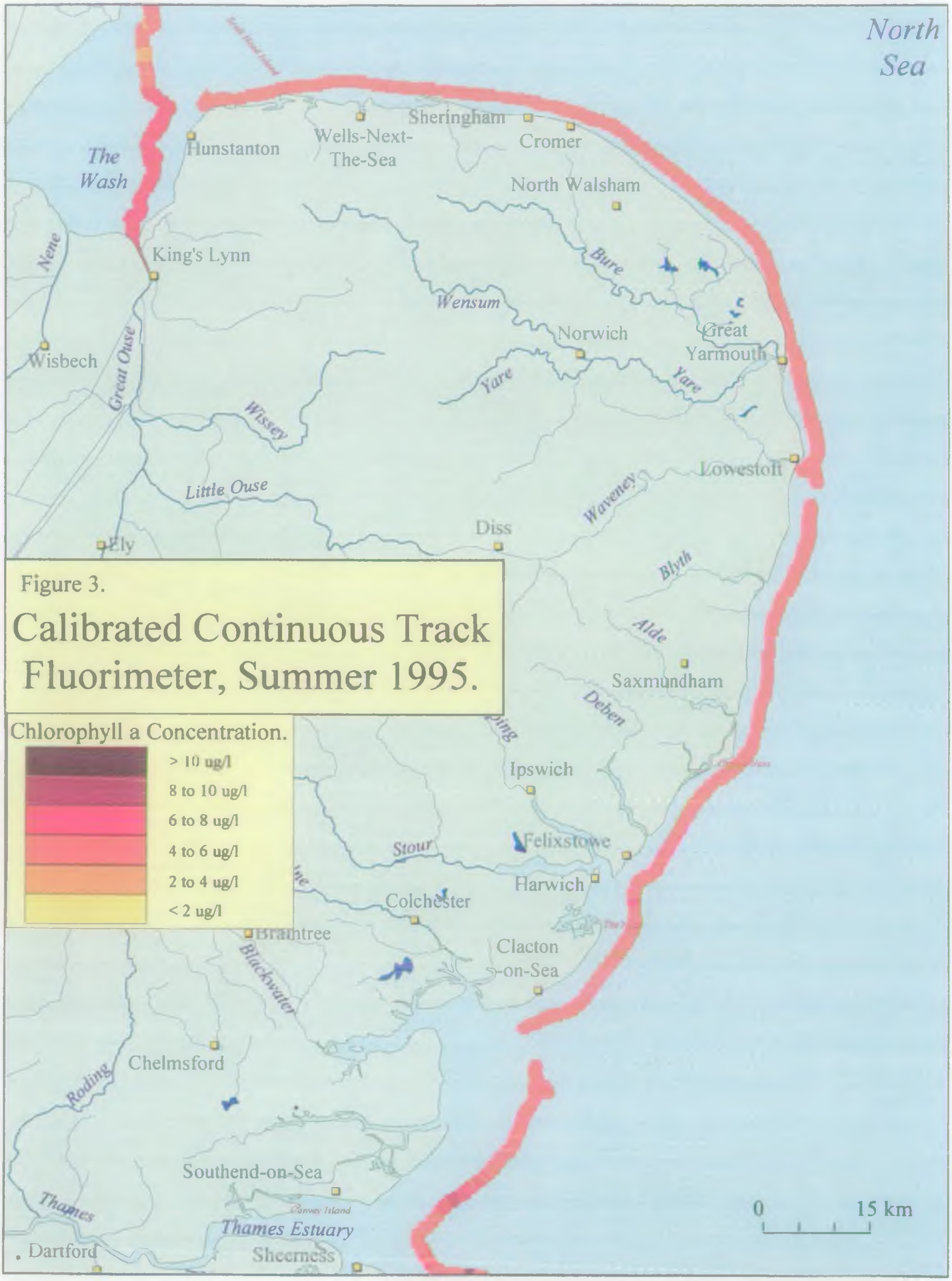


Figure 3.

Calibrated Continuous Track Fluorimeter, Summer 1995.

Figure 4.

Skalar Nutrient Data, East Anglian Coast, Winter 1995.

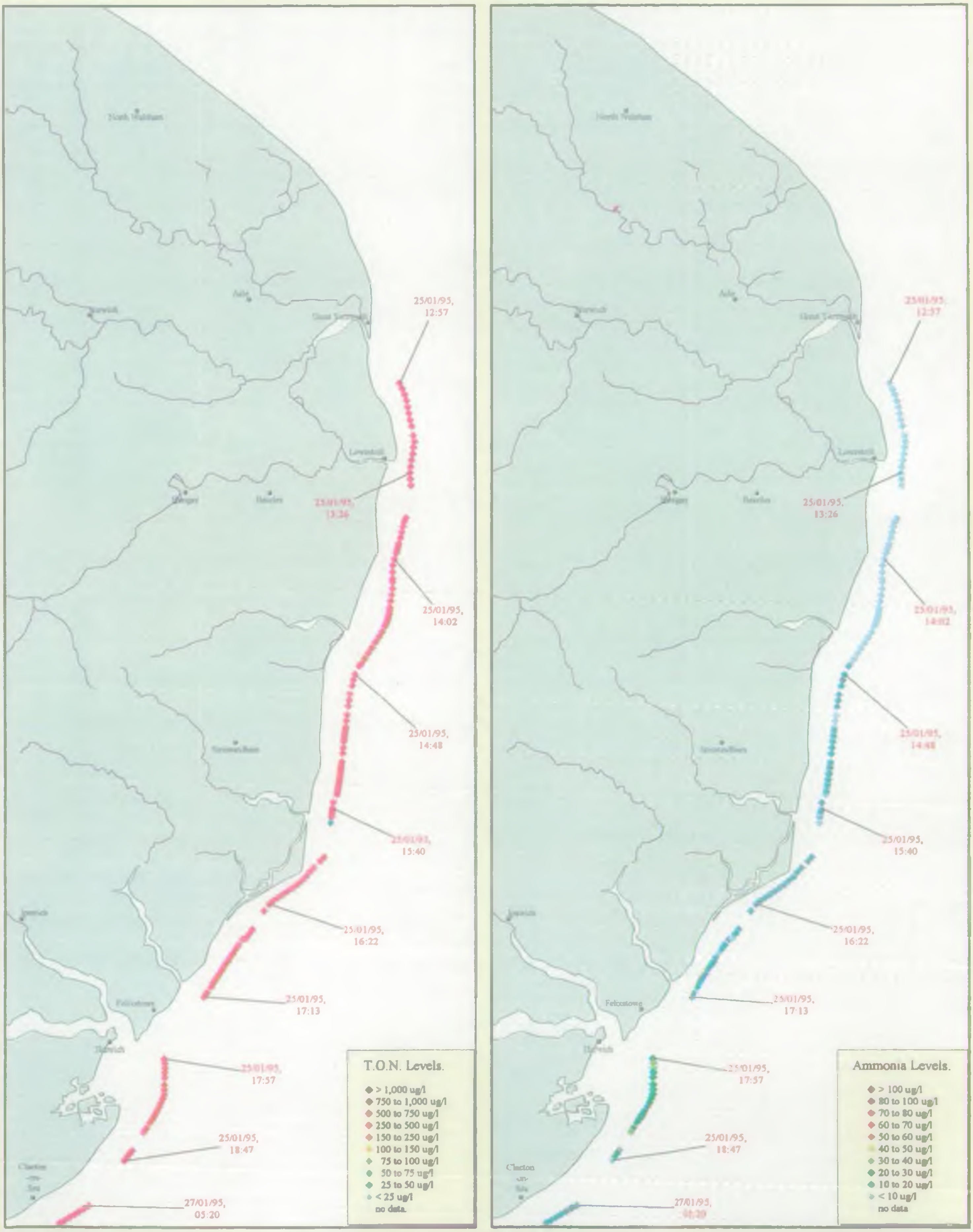


Figure 5.

Skalar Nutrient Data, East Anglian Coast, Spring 1995.

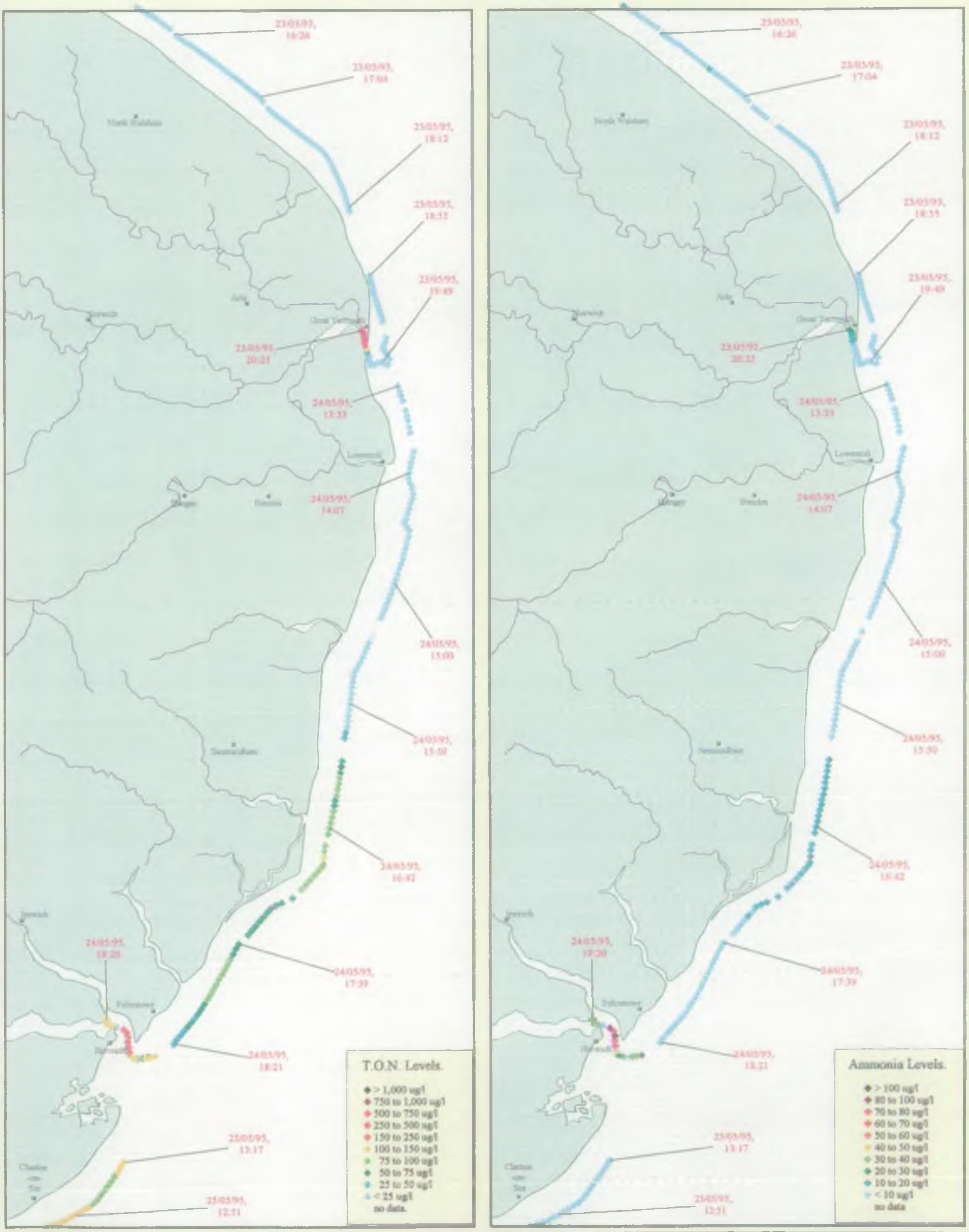
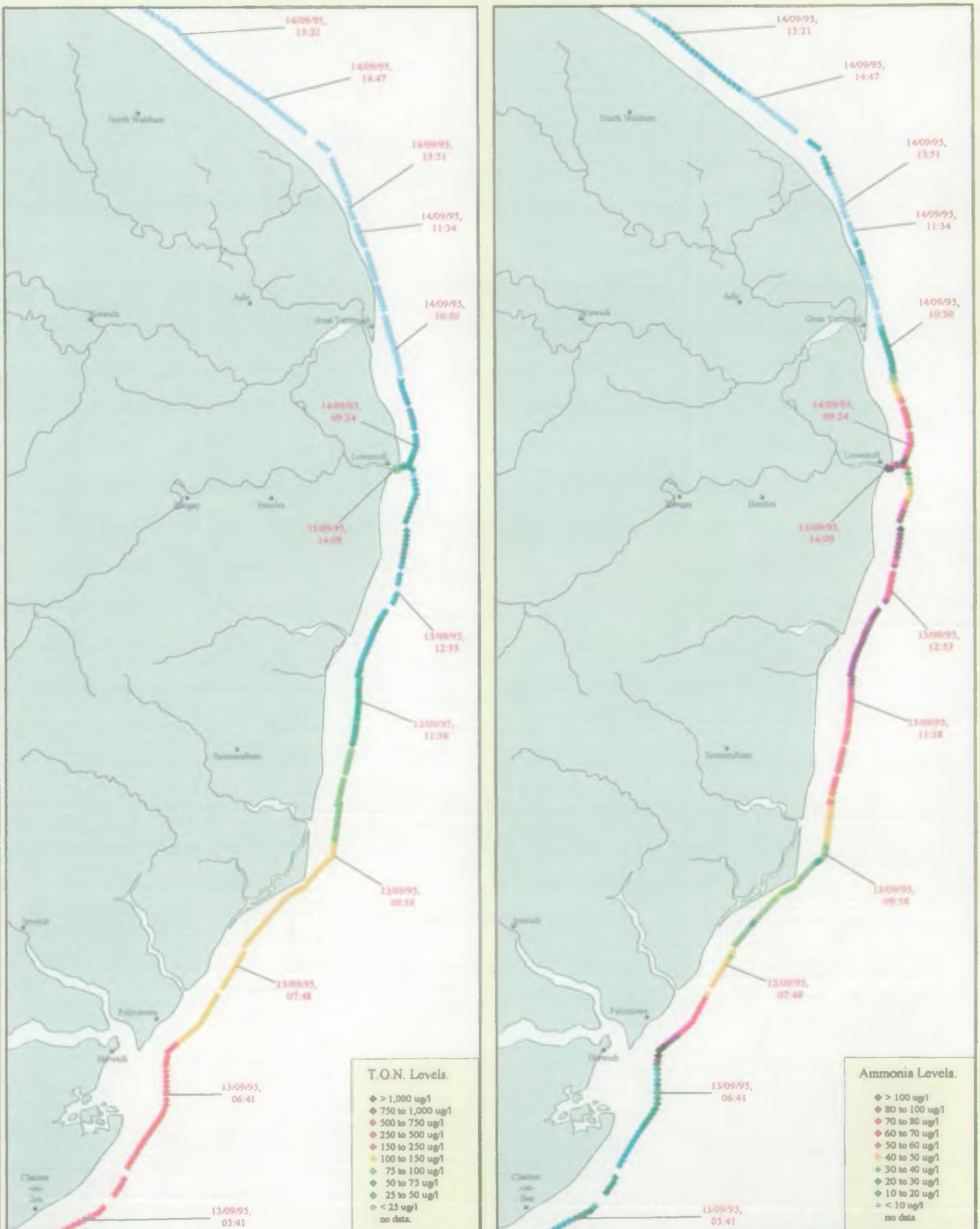


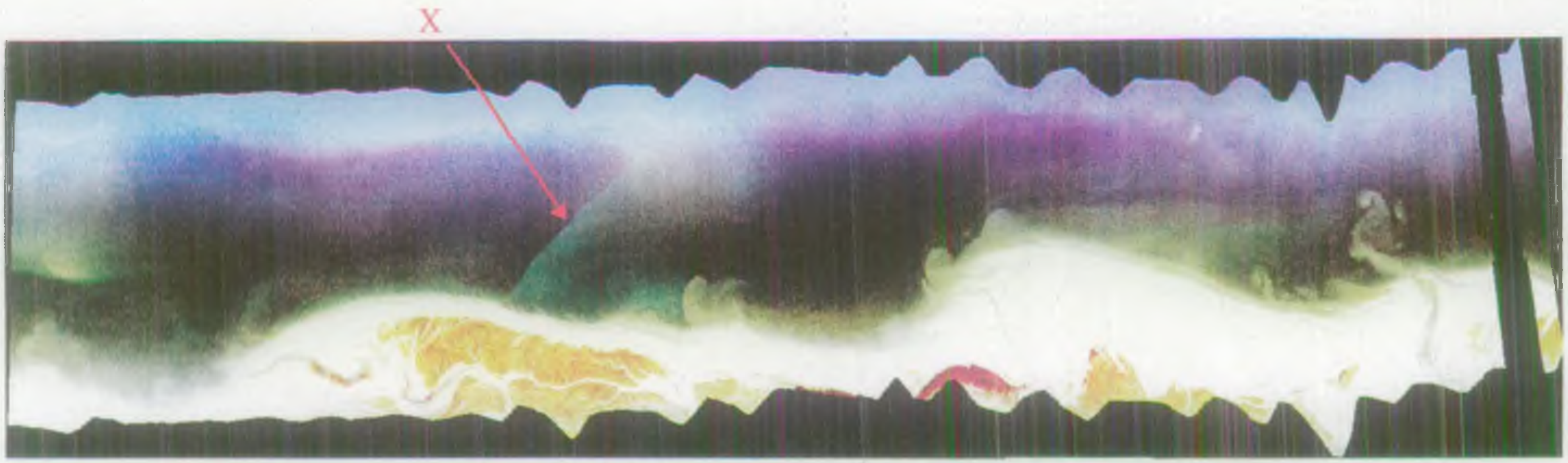
Figure 6.

Skalar Nutrient Data, East Anglian Coast, Summer 1995.

Figure 7.

Skalar Nutrient Data, East Anglian Coast, Autumn 1995.





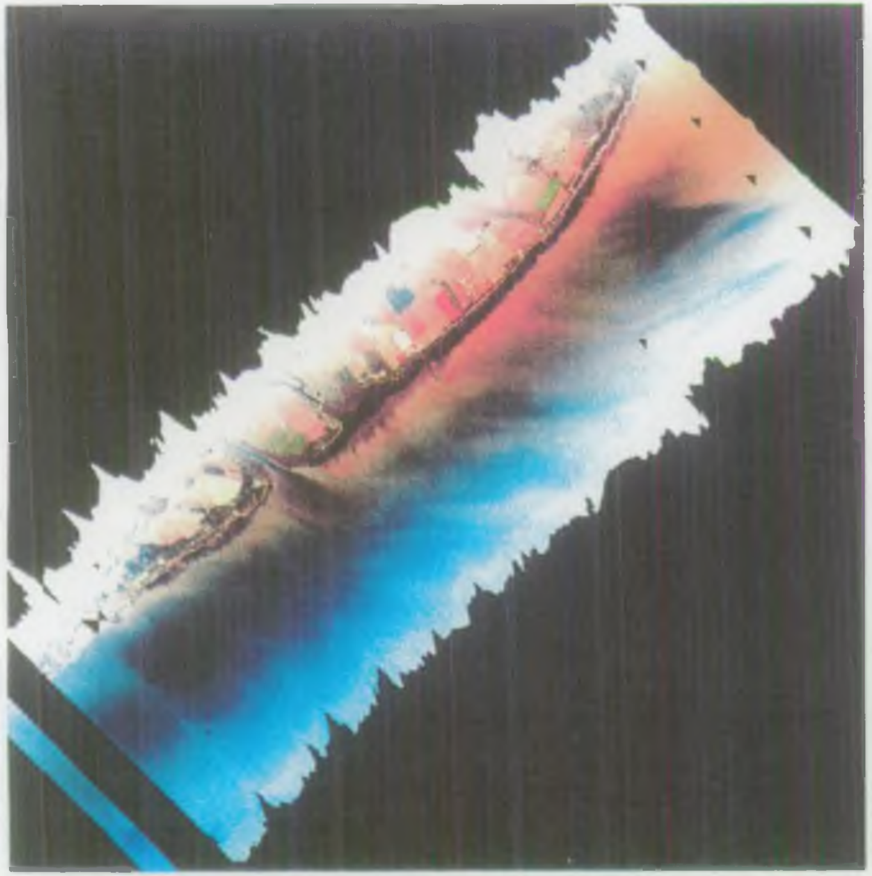
23rd September 1995, 09:50 GMT

Plate 1: Hunstanton to Blakeney
CASI enhanced true colour composite image

(i) 6th July 1995,12:19 GMT

(ii) 14th September 1995, 09:06 GMT

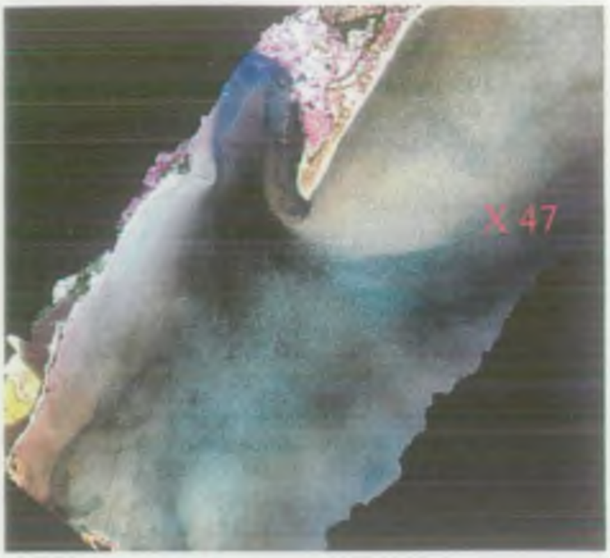
Plate 2: Great Yarmouth
CASI enhanced true colour composite images



1st August 1995, 17:00 GMT

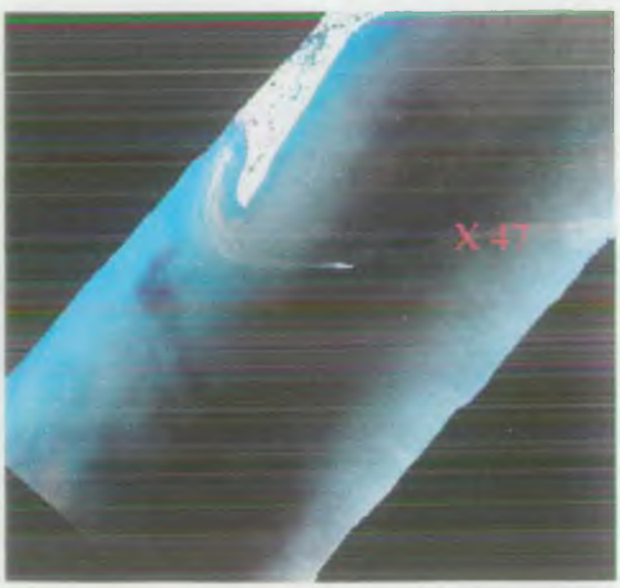
9th September 1995, 08:37 GMT

Plate 3: Maplin Sands
CASI enhanced true colour composite images



6th July 1995, 12:56 GMT

14th September 1995, 08:39 GMT



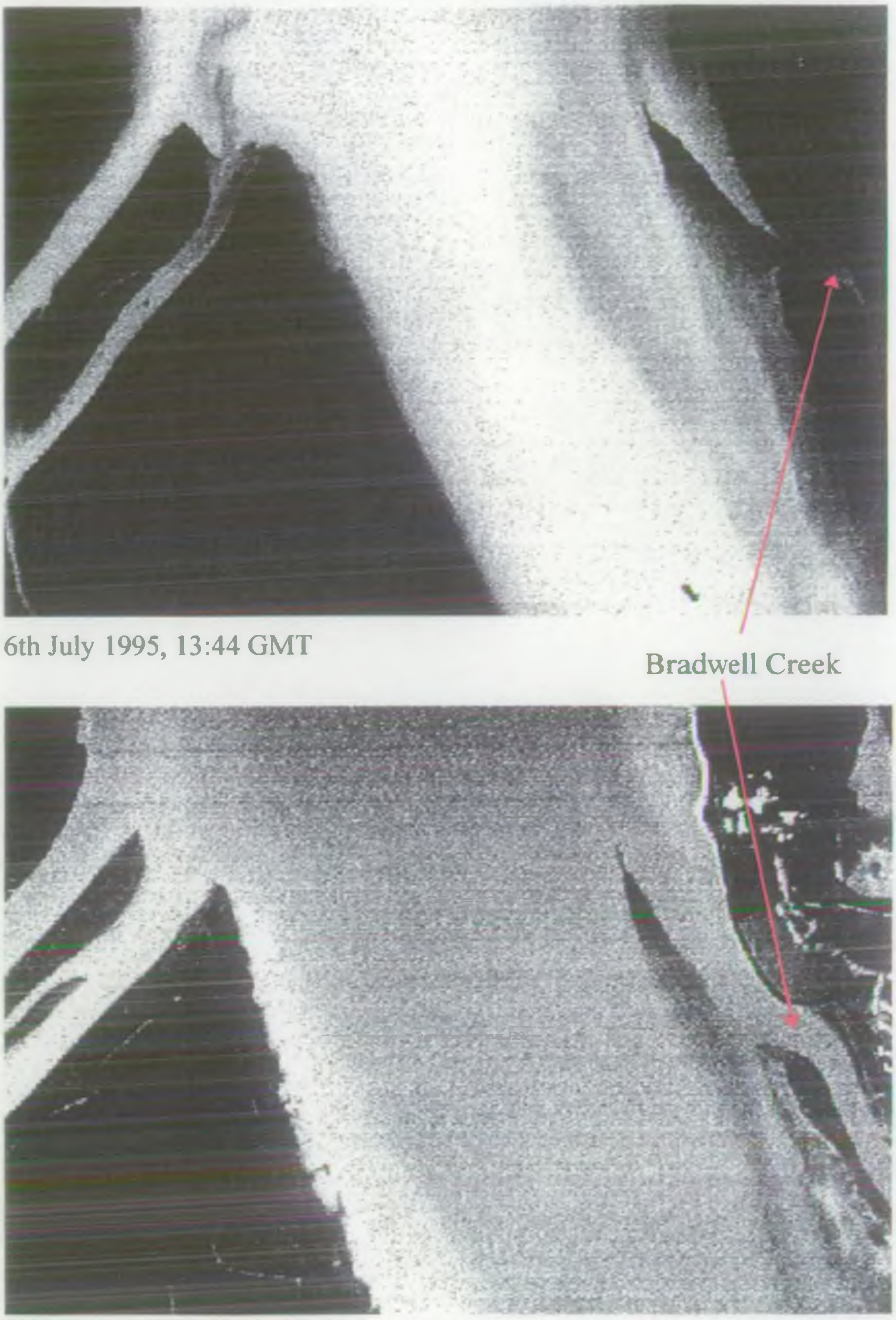
23rd September 1995, 10:24 GMT

Plate 4: Harwich harbour entrance
CASI enhanced true colour composite images
The Felixstowe baseline sampling site is marked X

6th July 1995, 12:44 GMT

14th September 1995, 08;52 GMT

Plate 5: Sizewell power station outfall
Thermal video composite images



6th July 1995, 13:44 GMT

9th September 1995, 08:59 GMT

Plate 6: River Blackwater
Thermal video image composites

14th September 1995, 08:12 GMT

6th July 1995, 13:24 GMT

Plate 7: Clacton-on-Sea
CASI enhanced true colour composite images

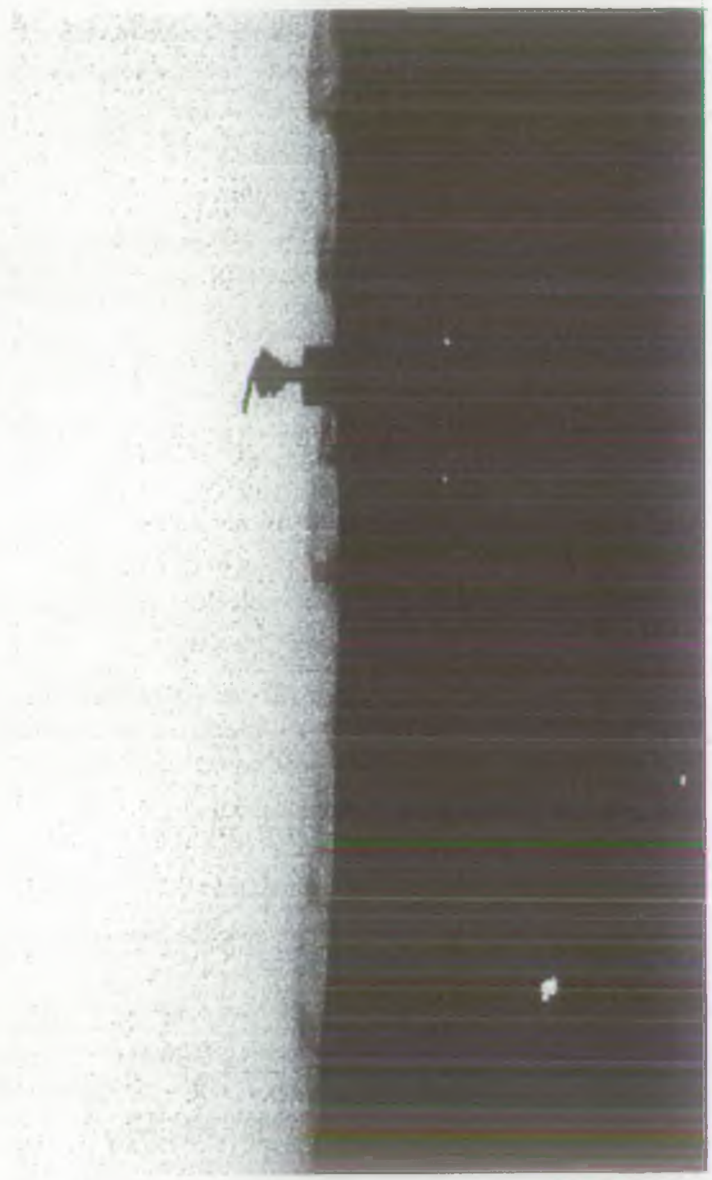


Plate 8: Clacton-on-Sea
Thermal video composite images
6th July 1995, 13:27 GMT