MARINE CASE STUDY 3: PHYTOPLANKTON DYNAMICS

National Centre for Environmental Data and Surveillance

Draft for discussion with project team

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1. BACKGROUND

1.1 Although background concentrations of chlorophyll-*a* are required for large scale estimates, the highest chlorophyll-*a* concentrations are found during phytoplankton bloom events. Such events may cause a nuisance to tourism and aquaculture and as such an understanding of their dynamics is advantageous. Such knowledge will allow an assessment to be made of whether the region may be Sensitive under the provisions of the Urban Waste Water Treatment Directive (91/271/EEC) and will aid the Environment Agency in forming an opinion of the general state of pollution of the marine environment (Section 5, Environment Act, 1995).

2. PREVIOUS WORK

2.1 The ability to identify and monitor algal blooms in the highly dynamic coastal zone is hindered by the speed of sampling offered by traditional sampling techniques. Remote sensing offers the potential for the retrieval of wide scale, synoptic estimates of chlorophyll-*a* concentration, as well as identification and tracking of specific bloom events.

2.2 Remote sensing systems record reflected sunlight, which is altered by interactions within the water column, particularly absorption and scattering. The presence of chlorophyll-*a* within phytoplankton cells causes absorption of blue light and scattering of green light, and this spectral variation is recorded by the sensor.

2.3 The use of remote sensing technology to provide information on the location of algal bloom and spatial estimates of chlorophyll-*a* concentration has been ongoing since the launch of the Coastal Zone Colour Scanner (CZCS) in 1979. This sensor had wavebands specifically designed for the detection of chlorophyll-*a*, with a dual algorithm developed allowing for changes in the chlorophyll-*a* concentration. The algorithms used depended on the ratio of the green channel (550 nm) to one of the blue channels (443 nm or 520 nm) (Gordon *et al.* 1980).

2.4 This type of algorithm relies on the absorption properties of chlorophyll-*a*. Chlorophyll-*a* absorbs visible light in blue wavelengths, reflecting the green wavelengths, which results in the green colouration seen to the human eye. Thus an algorithm based on the ratio between these two wavelengths will be related to the chlorophyll-*a* concentration. Successful comparisons with *in-situ* data were carried out (Gordon *et al.* 1980).

2.5 CZCS data proved unsuitable for working in the coastal zone, due to the low spatial resolution. Coastal phenomena are often at scales smaller than the 0.85 km square pixel size. Aerial systems combine a finer spatial resolution (dependent on altitude) with temporal flexibility. Algorithms of the form developed for CZCS were therefore applied to data from aircraft systems by a number of workers (for example Moore and Aiken, 1990, Matthews *et al.*, 1992). These were found to be applicable for the site at which the algorithms was developed, but were not portable between sites. This was due to two key factors: atmospheric interference and the presence of suspended sediment.

3. ENVIRONMENT AGENCY DEVELOPMENTS

3.1 The National Centre for Environmental Monitoring and Surveillance has previously used airborne platforms to characterise the protected waters (out to 3 nautical miles) of the England and Wales. This involved the collection of 189 flight lines around the coastline in nine different survey campaigns in the period between 1993 and 1995.

3.2 The survey has relied on the sensitivity of the Compact Airborne Spectograpic Imager (CASI) instrument to resolve small changes in the colour of water bodies that can then be linked to algal activity, suspended solids and other oceanic phenomena.

3.3 During these aerial surveys a small number of coastal algal blooms have been periodically identified. The purpose of the surveys was not to search for such blooms, but it was likely that occasional blooms would be recorded by chance.

3.4 The identified blooms were in different stages of life cycle development. Figure 1 shows a bloom off the coast of Pwthelli, Wales. This bloom (choetocerous) is characterised by a green colouration in the water, with a definite centre of activity. Analysis of the spectra (figure 2) shows that the "centre" of activity exhibits strong fluorescence, which is consistent with *in-vivo* fluorescence of chlorophyll-*a* in the red part of the spectrum. A small percentage of the visible light absorbed by chlorophyll is re-emitted as fluorescent energy after undergoing transition to a higher wavelength. This emission is manifested in the reflectance spectrum as a narrow peak at approximately 685 nm (Neville and Gower 1977).

3.5 Another bloom was identified off Exmouth in 1994 (figure 3). This bloom did not exhibit the same levels of fluorescence as the Pthwelli bloom and was already in the stage of decomposition. Later images showed detritus on the water surface and near the shore which could cause a nuisance, especially if the bloom had become toxic (in this case it had not)

3.6 Further blooms have been sensed on freshwater lakes, especially lake Coniston (figure 4) and Lake Bala. These images showed features that were similar to the coastal blooms, though the blooms were constrained by the topography and meteorological situation.

3.7 In addition to the identification of blooms in the aerial imagery, laboratory water samples recorded some regions with consistently high nutrient concentrations, which may result in high chlorophyll-*a* concentrations. For examples, the Mumbles, on the south coast of Wales, recorded elevated nutrient concentrations at all seasons but did not result in high chlorophyll-*a* concentrations at the time of the baseline surveys. Figures 5 to 7 show the average chlorophyll levels for 1993 to 1995 shown as the Spring, Summer and Autumn surveys.

3.8 Given this previous experience, this case study sought to identify the presence of phytoplankton blooms in coastal waters, and to map their spatial extent and temporal variability. This may be attained using CASI data calibrated for chlorophyll-*a*, to identify the full extent of the bloom, with subsequent integration into a Geographical Information System (GIS). In addition, changes in the balance of species within the bloom could to be studied.

4. SURVEY STRATEGY

4.1 The success of this study hinges on finding a marine algal bloom that is in the early stages of development. This can then be intensively surveyed to provide an insight into the dynamics of the bloom. The initial phase of the project includes the creation of an information network on the location of algal blooms and proactively surveying areas of known algal activity for signs of developing blooms.

4.2 Previous baseline survey data was mined for areas where chlorophyll values were frequently high. Regional opinion was also sought on areas where algae were likely to be encountered. Two areas were catered for in the original proposal. The north Norfolk coast and the Cumbrian coast. North Wales was considered as an area where algae were prevalent, but local opinion in the North West region swayed the area to the Cumbrian coast.

4.3 Figure 8 shows the main sections of this information network. Environment Agency Coastal Survey Vessels and external vessels (such as the Port Erin Laboratory vessel) notified the National Centre if they encountered elevated levels of chlorophyll. Regional biologists were asked to inform the Centre of any blooms or anticipated blooms. In addition, the routine beach monitoring reports were supplied to the Centre. These vary from region to region, with the most detail being supplied by Welsh Region.

4.4 It is well known that the maximum algal activity in the coastal zone is in the spring season, especially May, when the maximum nutrient supply is available to trigger blooms as the weather warms the waters. It was imperative to start the project as soon as possible to maximise the chances of finding a suitable bloom in the spring season. Further blooms do occur in the Summer and Autumn seasons, but these are likely to be a continuation of high populations from the spring season, and may have different dynamics as a result.

5. SURVEY RESULTS

5.1 The project received final permissions on 7th June. The recognised season for algal blooms is May. It was decided that despite the late start that there are areas that have high likelihood of algal blooms throughout the year and there is often an Autumn resurgence of algae there was a good chance of finding an algal bloom in the early stage of formation that was suitable for this project.

5.2 A series of investigational flights were programmed using the information network and in areas of known high algal activity, using the information system outlined above.

5.2.1 **Mission 1** 30 May 1996 North Norfolk Coast and the Wash.
Approximately fifty miles of coast line were flown in four lines parallel to the coast between Kings Lynn and Cromer. The weather was hazy, but good quality data was produced. The coastal lines showed no evidence of local blooms. Figure 9a shows a CASI image for the north east Norfolk with little or no variation apparent in the water. Figure 9b shows a part of the Wash data, near Hunstanton. The

Wash data showed a large amount of structure due to sediment, mud banks and bottom reflections. No discernable aggregations of algae were found.

5.2.2 **Mission 2** 5 June 1996 North Devon / Somerset Coast/ Bristol Channel
Approximately sixty miles of coast line were flown in four lines, three parallel to the coast between Bridgwater Bay and Ilfracombe and one perpendicular to the coast 15 km out to sea. The data suffered from cloud shadow and glint, with two images out of the 13 gathered passing the first quality control steps. Patches of cloud shadow make interpretation difficult as patches of darker water cannot safely be attributed to variations within the water as they could be due to variations in illumination caused by clouds. Figure 10 shows a part of the Severn estuary with cloud shadow and glint.

5.2.3 **Mission 3** 6 June 1996 Poole to Southampton Coast
Approximately sixty miles of coast line were flown in six lines parallel to the coast between Poole Bay and Selsey Bill. Six images were collected, with only one passing the quality control steps. The image shown in figure 11 is of the Studland Point area. Sediment plumes can be seen around the head. There is sun glint in the centre of the image. Rocks and bathymetry can be seen as red and light blue features close to the shore. No features that would be consistent with algal blooms were seen.

5.2.4 **Mission 4** 13 June 1996 North Norfolk Coast and the Wash
Approximately fifty miles of coast line were flown in three lines parallel to the coast between Kings Lynn and Cromer. The imagery showed some haze. There were no discernable features in the water that could be attributed with algal blooms.

5.2.5 **Mission 5** 24 June 1996 North Devon / Somerset Coast
Approximately sixty miles of coast line were flown in four lines, three parallel to the coast between Bridgwater Bay and Ilfracombe and one perpendicular to the coast 15 km out to sea. 8 images were generated, with 3 of top quality. Figure 12 shows the offshore line from the North Somerset coast. Even though there was cloud on the image sediment patterns could be seen. No aggregations of material with spectral characteristics consistent with chlorophyll were seen.

5.2.6 **Mission 6** 10 - 12 July 1996 Fal Estuary *Alexandrium tamerense event*
A report was received from Agency biologists in the Bodmin office that there were high levels of the red algae *Alexandrium tamerense* in the Fal estuary and nearby Carrick Roads. The samples that were analysed suggested that there were in excess of 450 algal cells per ml and this was likely to increase to the bloom levels of 1000 per ml during the next few days or weeks. After a further day it was reported that the algae, although not at bloom levels was releasing the paralytic shellfish poison that occasionally accompanies such events, and it was decided that this incident was worth examining.

5.2.6.1 Although the weather was less than perfect the plane was dispatched and arrived on scene on the 10 July to begin a survey at various states of the tide. Carrick Roads and the tributaries of the Fal and Truro Rivers were imaged to try and

detect any high algal concentrations. A boat, equipped with continuous towed instruments was deployed to investigate any potential target sites identified for the air. The boat crew were protected from any possible toxic effects with dry suits, goggles and respirators. The algae appeared to cover the entire area of Carrick Roads, with a homogenous layer. The boat homed in on one potential site but this was found to be a sand bank with deposited sediment from the Wheal Jane mine that gave a similar spectral signature. Figure 13 shows an overview of the eastern part of the estuary and a close up of the outer areas. The generally purple tinge to the water column was investigated, and shown to cover the whole estuary. Image 14 shows a high tide situation, where the channel and bathymetry (lighter blue) can be seen.

5.2.6.2 Live algal samples were collected for examination on the RV Vigilance but no counts in excess of 1000 per ml were recorded. It was reported that there were other algae present including *Gyrodinium sp.*, *Polykrikos*, and *Chaetoceros.*

5.2.6.3 The weather did not improve and at one tidal state the plane had to fly at 500 feet to gather imagery under the clouds. This makes processing and interpretation of the 250 metre swath difficult. The plane remained in the area for three days and flew eight surveys before it was withdrawn due to poor weather and the seeming lack of the onset of true bloom conditions. The algae did not produce an aggregation that was consistent with a bloom. If a bloom did occur it would not have been suitable for this case study as it was an estuarine bloom that would have been constrained by the topography and estuarine water chemistry, rather than an open sea bloom that would have different factors contributing to its development.

5.2.6.4 Laboratory samples were also taken at several sample sites around the estuary and the results indicated some elevation in nutrient and chlorophyll levels but nothing suggesting bloom condition. Figure 15 shows the results from the day with maximum chlorophyll levels sampled, with chlorophyll values consistently below 10µg/l, a level which can be used to indicate bloom conditions in sea water.

5.2.7 **Mission 7** 15 June 1996 Coast of Wales

The south and west coastline of Wales was flown at 10000 feet between Chepstow and Pwllheli. This was flown to assess if the bathing beach reports indicating bloom levels were showing any algal activity in the coastal zone. 23 images were collected, with 18 of good quality. No direct evidence of bloom structures was found. Figure 16 shows the Pwllheli area (also see figure 1 from 1995). The variations in the blue can be accounted for by bathymetry and rocks. The redder tinge to the left of the image may be due to elevated chlorophyll levels. Investigation of the spectra showed this area to have an elevated spectra throughout the spectrum in comparison to the water to the right of the image (see figure 17), though some variation is seen in the red part of the spectrum. This does not tie up with the spectrum of the confirmed bloom structure shown in figure 1. The confirmed bloom showed much more variation in the green and red wavelengths than this image.

5.2.8 **Mission 8** 16 July 1996 Holdeness Coast

Approximately thirty miles of coast line were flown in two lines, one parallel to the coast between Bridlington and Spurn Point and one perpendicular to the coast 15 km out to sea from Spurn Point. 4 images were taken, of which 3 were of good quality. Figure 18 shows a line taken out to sea across Spurn Point. As with all the images from this mission, all structures seen in the sea were consistent with sediment patterns rather than algal activity.

5.2.9 **Mission 9** 16 July 1996 Cumbrian Coast

Approximately one hundred and twenty miles of imagery were flown in four lines, three parallel to the coast between Morecombe Bay and St. Bees Head, and one perpendicular to the coast fifteen miles out to sea. The three parallel lines were flown adjacent to each other to cover a band approximately eight miles wide. The lines were flown at 10000 feet. All the imagery was gathered twice to improve the chance of gathering data coincident with the boats and counteract the effects of the weather. Of the nine images gathered 4 were of good quality. Figure 19 shows an offshore line. The features in the water are rocks. No variations that can be assigned to algae were identified.

5.2.10 **Mission 10** 19 July 1996 North Norfolk Coast and the Wash

Approximately fifty miles of coast line were flown in four lines parallel to the coast between Kings Lynn and Cromer. Four images resulted, all with cloud or cloud shadows making interpretation difficult. No algal patterns were seen. Figure 20 shows an offshore line around the Scolt Head island area. No features can be seen in the water column.

5.2.11 **Mission 11** 3 August 1996 Weymouth Harbour

The plane was dispatched to examine the report of an algal bloom in Weymouth Harbour and Bay. 4 lines were programmed and were flown twice. The first three images were of good quality, the remaining 4 being subject to partial cloud cover and shadow. Previous algal blooms in Weymouth were of the "red tide" type as was this report (Jamieson 1994). Previous blooms were restricted to the inner harbour area and manifested themselves as "occasional red slicks". Careful examination of the imagery revealed no such features. Figure 21 shows the harbour. Careful examination of imagery and spectra revealed no trace of the algae.

5.2.12 **Mission 12** 11 August 1996 North Norfolk Coast and the Wash

Approximately fifty miles of coast line were flown in four lines parallel to the coast between Kings Lynn and Cromer. Seven images were recorded, all of good quality. Careful examination showed some patches in the imagery that may be concentrations of algae. Figure 22 shows an offshore line that has blue patches offshore, outside the influence of the beach slope. It was decided to return to the area as soon as weather allowed (mission 14)

5.2.13 **Mission 13** 13 August 1996 North Wales Coast

In response to a report from the Coastal Guardian that there appeared to be some elevated fluorescence values at a position north west of the Little Orme near Colwyn Bay. The plane was deployed to try and home in on the position of the suspected bloom. 5 images were generated, all of poor quality (due to low cloud).

The plane flew the coast from Angelsey to the mouth of the Mersey. Although some features were seen in the water column they were faint and inconclusive. Figure 23 shows some features in the water column in Red Wharf Bay, Anglesey. It was decided to return to this area as soon as weather permitted (mission 15).

5.2.14 **Mission 14** 19 August 1996 North Norfolk Coast and the Wash

In response to mission 12 eight days earlier a second visit was organized. Approximately fifty miles of coast line were flown in four lines parallel to the coast between Kings Lynn and Cromer. Ten images were sensed, of which seven were of good quality. Figure 24 shows the Scolt Head Island Area, which showed the only possible algal feature (lighter area to top left of zoomed view). Investigation of spectra showed that this feature to have a consistently raised spectra from the surrounding water. This is consistent with atmospheric interference rather than algal activity. In addition, this area did not show the patchiness of those seen on mission 12 (figure 22).

5.2.15 **Mission 15** 4 September 1996 North Wales

A return visit to the coast from Angelsey to the mouth of the Mersey produced 11 images of very good quality. The mission was flown at between 2,000 and 4,000 feet, producing images with a narrow swath width that did not cover the area of reported high algal concentrations that lead to mission 13. Some inshore variations were identified, including a large area of suspended solids off the Little Ormes head (Figure 25). It was decided to re-fly at a higher altitude as soon as possible so that suspected areas could be assessed.

5.2.16 **Mission 16** 6 September 1996 North Wales

This mission was a repeat of mission 15 at 10,000 feet. 5 images of good quality were recorded. Figure 26 shows the Little and Great Ormes Head area. No features were seen in the water column.

5.2.17 **Mission 17** 12 September 1996 North Devon / Somerset Coast

Approximately sixty miles of coast line were flown in four lines, three parallel to the coast between Bridgwater Bay and Ilfracombe and one perpendicular to the coast 15 km out to sea. The lines were flown at 10000 feet. 7 images were recorded, with three classes as good quality. Figure 27 shows the offshore line,. This image showed an increase of suspended solids out to sea, hence the whitening of the image. No small scale features consistent with high algal concentrations were seen in these images.

5.2.18 **Mission 18** 13 September 1996 Cumbrian Coast

Approximately thirty miles of imagery were flown in two lines, one parallel to the coast between Morecombe Bay and St. Bees Head, and one perpendicular to the coast fifteen miles out to sea. 2 images were recorded at 10000 feet, both of good quality. Large scale sediment patterns consistent with those seen in previous years were identified (Figure 28, overview image). In shore inspection shows features which are most likely consistent with the tidal streams moving sediment from the shore (figure 28, zoomed view). However, it was decided to re-fly as soon as

weather permitted.

5.2.19 **Mission 19** 17 September 1996 Cumbrian Coast
After quality controlling the previous data gathered a week earlier and finding interesting features on it, a return mission was arranged in the same area between Morecombe Bay and St. Bees Head and one perpendicular to the coast fifteen miles out to sea. Unfortunately, all four images collected were hazy, and no features other than suspended solids could be seen in the water column (Figure 29)

5.3 **Coastal Bloom Monitoring Reports**
Welsh region produce the most comprehensive beach algal monitoring service in the Agency. Table 1 and Figure 30 provide a summary of the north and south Wales reports through 1995 and 1996. Comparing 1995 and 1996 shows that 1996 had only 79% of the reported blooms of 1995. In addition the spread of blooms in the season is worth examining. As stated previously (section 4.4), the majority of blooms occur in May. In 1996, only 26% of the blooms that were seen on the beach occurred after the project had received final permission (June 7th).

6. CONCLUSIONS

6.1 Despite much information gathering and proactive searching, the project failed to find a suitable early stage algal bloom and therefore did not proceed from the reconnaissance phase to the study phase. A number of reasons contributed to this.

6.2 In previous years, algal blooms had been identified using CASI, but only rarely. As the CASI has a 5Km swath width and surveys usually include land then blooms that have developed further offshore may not be seen. Those blooms previously identified from CASI could be small fragments of other blooms offshore or the bloom coming in shore as the algae develop into their later stages and come to the surface. As the coastal zone has complex and frequently strong currents, any localised aggregation of algae may quickly be dispersed. This would make them transient features difficult to identify using remote surveillance in the coastal zone.

6.3 According to the beach reports, the majority of algal blooms in 1996 occurred before the Agency was able to give permission to start the project. Indeed, the beach monitoring reports may give a false picture of the likelihood of suitable blooms as the bloom usually reaches the beach once the population have reached their maximum. This study needed to find a bloom in the early stages of development.

6.4 1996 was not as good a year for bloom development as some. Baseline monitoring of nutrients in the winter revealed lower figures than normal, with subsequently lower recorded beached blooms (21% less in 1996 than 1995 in Wales) and lower chlorophyll values shown in the baseline surveys (see figures 31 to 33). This may be due to the lack of sustained, settled, warm weather conditions. Jamieson (1994) attributed the break up of red tides in Weymouth to a breakdown in settled weather conditions.

6.5 1996 was a difficult year for aerial surveillance. Clear weather conditions are needed to positively identify blooms in the early stages of development. High preponderance of

clouds and haze conditions made interpretation of images difficult. For every day where flying was undertaken (frequently in marginal conditions), there were three days where weather conditions were not suitable for flying.

6.6 Despite these factors, and given the elevated levels of chlorophyll in some areas, especially North Wales, which were covered by repeated flying sorties, it is surprising that no algal blooms were identified. There are two possible reasons that the blooms are not visible to the CASI system. Firstly that they are not there: they are located further offshore. Secondly, they are there and the CASI cannot identify them. This may be due to masking of the spectral effects of algae by the relatively large spectral effects of sediment and other suspended matter, or that the Algae are too far down in the water column to be identified by the CASI.

7 RECOMMENDATIONS

7.1 Given that considerable effort was expended in attempting to identify blooms in areas where elevated chlorophyll levels were present, despite the missing of the early season blooms, it is recommended that this exercise is not repeated in further years as it was in 1996.

7.2 A wider view is required to evaluate wether the algal blooms are located further offshore than the 5 km swath that the CASI can be deployed to record. The CASI could be used to perform long recognisance flights across the Irish Sea to attempt to identify blooms offshore, but this could not be targeted and would be inconclusive if none were found.

7.3 A new series of space borne sensors that provide a wide field of view (at least 800 km) with a good repeat time (usually daily) in the correct spectral channels to identify elevated levels of chlorophyll are soon to become available. It is recommended that a project is undertaken using these CZCS like sensors to identify elevated chlorophyll levels, as they have been proved capable of (see section 2.3), in the waters around England and Wales.

7.4 If such a project is successful and data showing blooms is available quickly enough, then the CASI system can be deployed to study the development of such blooms in more detail than the space borne sensors can provide. Their influence on coastal regions can be assessed and their development studied.

8.0 References

Gordon ... (1980)

Jamieson, B.J. 1994 "A marine algal investigation in relation to the occupance of a red tide at Weymouth harbour, Dorset", NRA Technical memo

Matthews ... 1992

Moore and Aitken ... 1990

Neville and Gower 1977

1996 North Wales

Date w/e	Number of blooms	phaeocyst	chaetocer	asterionella	noctiluca
10-May-96	8	8	0	0	0
17-May-96	17	17	0	0	0
24-May-96	11	11	0	0	0
31-May-96	10	10	0	0	0
07-Jun-96	7	7	0	0	0
14-Jun-96	5	5	0	0	0
21-Jun-96	0	0	0	0	0
28-Jun-96	0	0	0	0	0
06-Jul-96	0	0	0	0	0
12-Jul-96	0	0	0	0	0
19-Jul-96	2	0	0	0	2
26-Jul-96	0	0	0	0	0
02-Aug-96	0	0	0	0	0
09-Aug-96	1	0	0	1	0

1996 South Wales

Date w/e	Number of blooms	phaeo	chaet	asteronella	noctiluca
03-May-96	3	3	0	1	0
10-May-96	3	1	0	2	0
17-May-96	9	8	1	1	0
24-May-96	7	5	2	0	0
31-May-96	6	6	0	0	0
07-Jun-96	10	8	2	0	0
14-Jun-96	6	6	0	0	0
21-Jun-96	6	6	0	0	0
28-Jun-96	4	0	4	0	0
06-Jul-96	0	0	0	0	0
12-Jul-96	1	0	1	0	0
19-Jul-96	0	0	0	0	0
26-Jul-96	0	0	0	0	0
02-Aug-96	1	0	1	0	0
09-Aug-96	0	0	0	0	0
16-Aug-96	0	0	0	0	0
23-Aug-96	5	0	5	0	0
30-Aug-96	0	0	0	0	0
06-Sep-96	1	0	1	0	0
13-Sep-96	1	0	1	0	0
20-Sep-96	0	0	0	0	0

1995 South Wales

Date w/e	Number of blooms	phaeo	chaet	asteronella	noctiluca
05-May-95	9	8	0	1	0
12-May-95	15	15	0	0	0
19-May-95	26	26	0	0	0
26-May-95	21	21	0	0	0
02-Jun-95	8	8	0	0	0
09-Jun-95	9	9	0	0	0
16-Jun-95	1	0	0	1	0
23-Jun-95	1	1	0	0	0
30-Jun-95	0	0	0	0	0
07-Jul-95	0	0	0	0	0
14-Jul-95	4	0	4	0	0
21-Jul-95	3	0	3	0	0
28-Jul-95	5	0	5	0	0
04-Aug-95	1	0	1	0	0
11-Aug-95	0	0	0	0	0
18-Aug-95	1	0	1	0	0
25-Aug-95	5	0	5	0	0
01-Sep-95	0	0	0	0	0
08-Sep-95	1	0	1	0	0
15-Sep-95	3	0	3	0	0

1995 North Wales

Date w/e	Number of blooms	phaeo	chaet	asteronella	noctiluca
14-Apr-96	0	0	0	0	0
21-Apr-96	1	1	0	0	0
28-Apr-96	2	2	0	0	0
06-May-95	3	3	0	0	0
13-May-95	6	6	0	0	0
20-May-95	5	5	0	0	0
27-May-95	10	10	0	0	0
03-Jun-95	9	9	0	0	0
10-Jun-95	6	6	0	0	0
17-Jun-95	2	2	0	0	0
24-Jun-95	3	3	0	0	0
01-Jul-95	3	3	0	0	0
08-Jul-95	0	0	0	0	0
15-Jul-95	0	0	0	0	0
22-Jul-95	2	0	2	0	0
29-Jul-95	0	0	0	0	0
05-Aug-95	0	0	0	0	0
12-Aug-95	0	0	0	0	0
19-Aug-95	0	0	0	0	0
26-Aug-95	0	0	0	0	0
02-Sep-95	0	0	0	0	0
09-Sep-95	0	0	0	0	0
16-Sep-95	0	0	0	0	0

Tables E 1

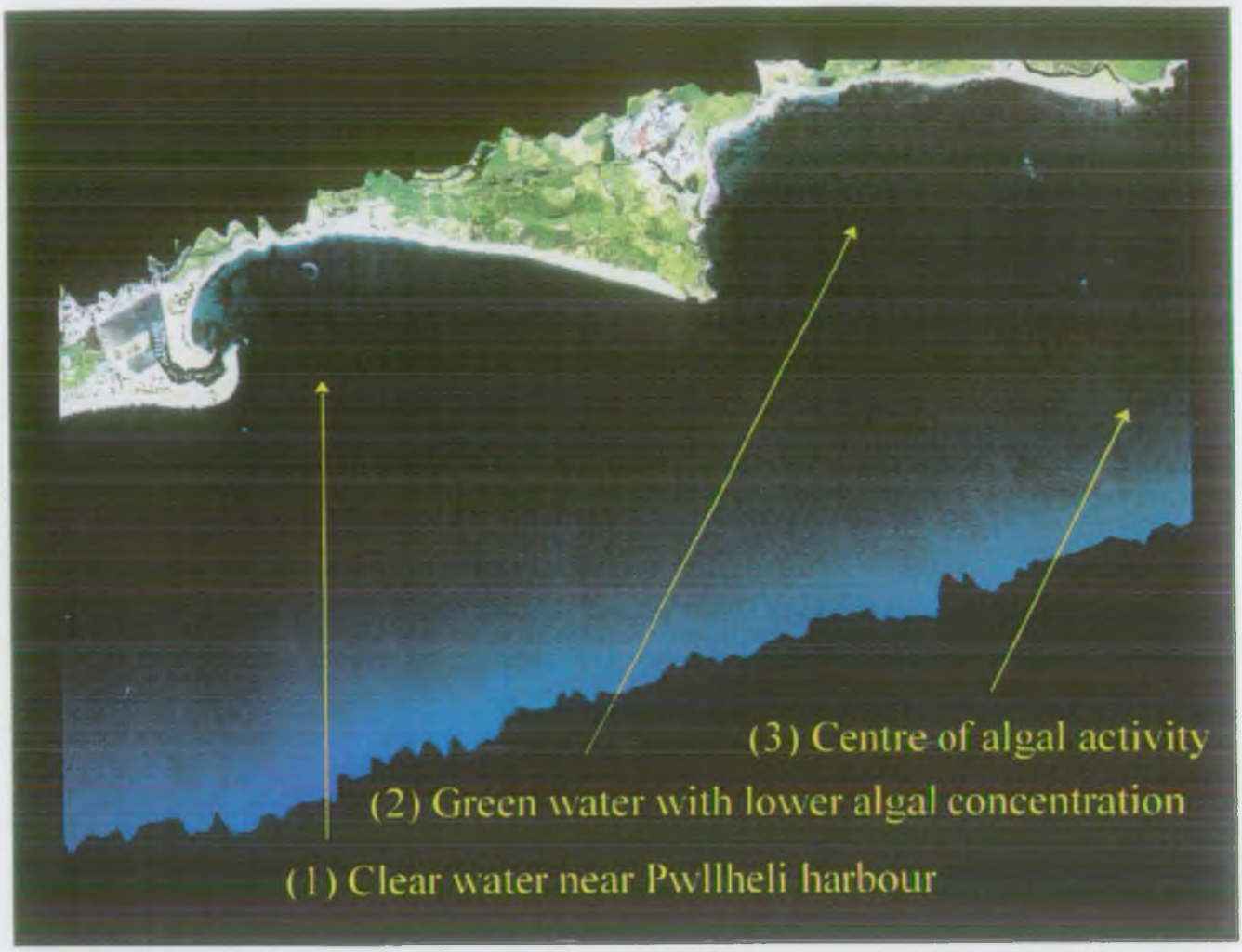


Figure 1

CASI image of Pwllheli area showing confirmed algal bloom

27th July 1995

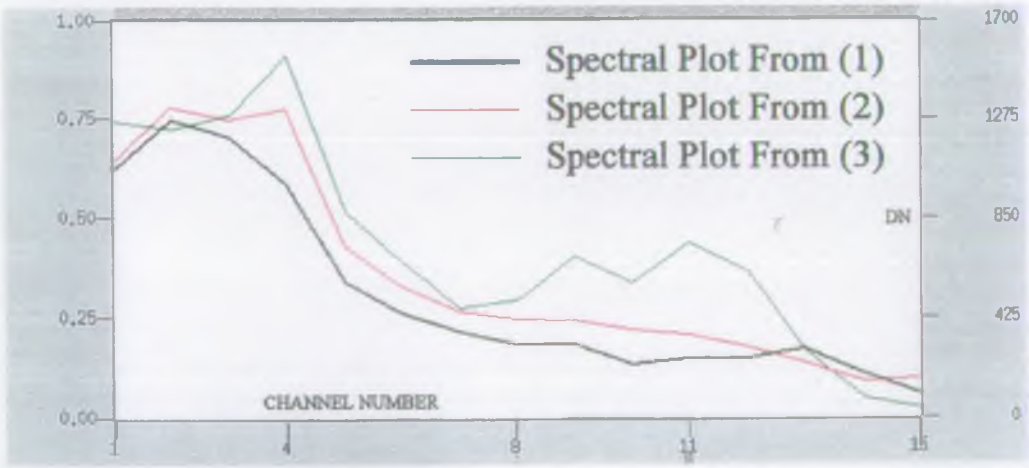


Figure 2

Spectra derived from image shown in figure 1 (see key)

Figure 3

Exmouth, 28th May 1994, 10:27GMT
Bloom clearly visible directly off Exmouth (3Km)

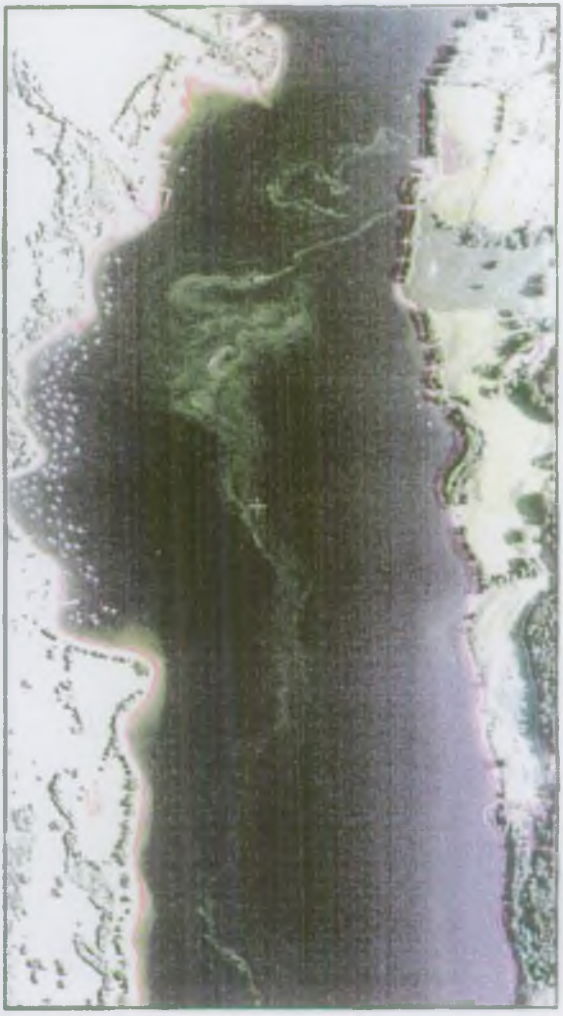


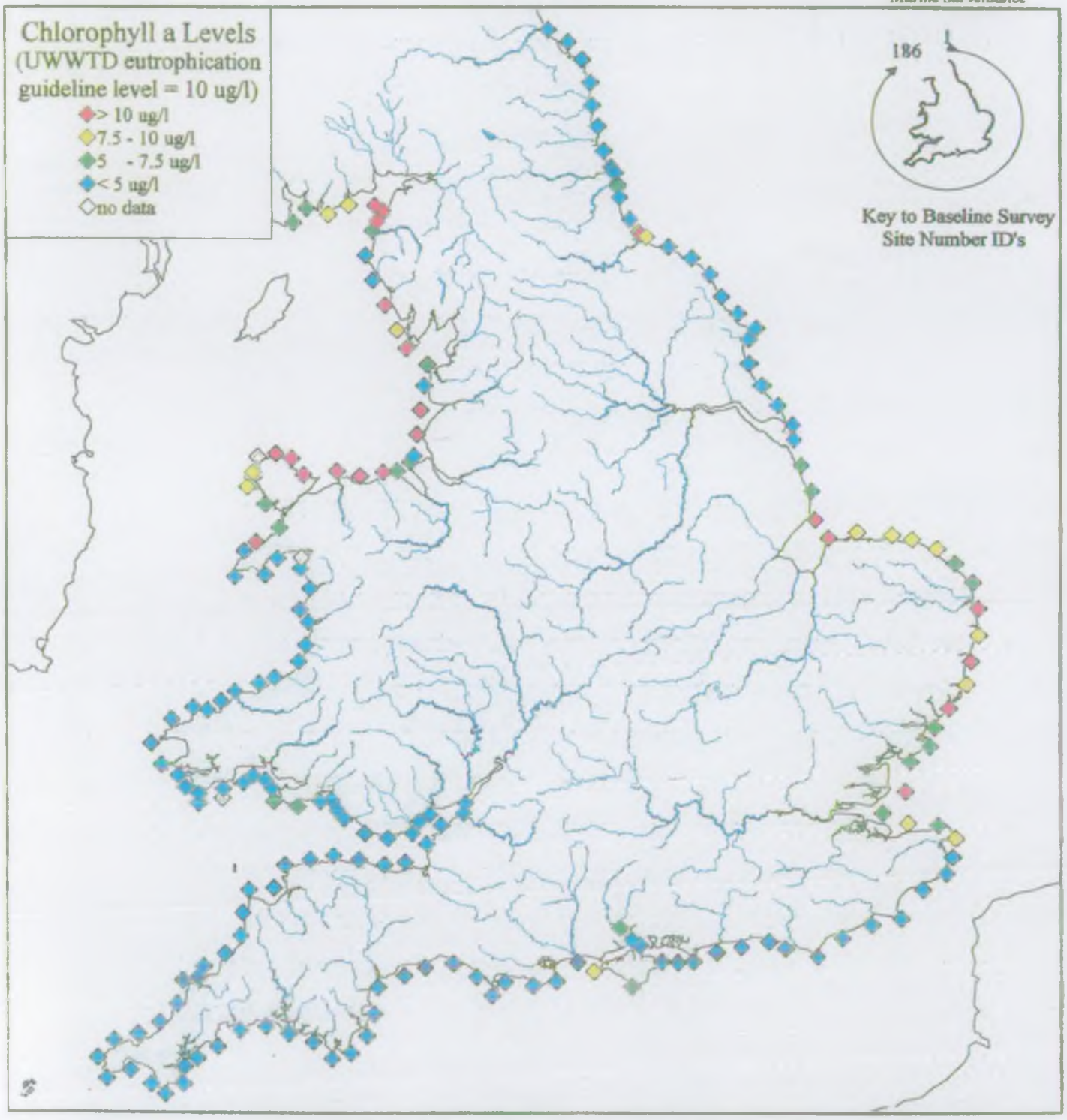
Figure 4

Coniston Water, 22nd June 1995
Bloom clearly visible in the centre of the lake.

Figure ~~3.1~~ 5

Chlorophyll a Levels, National Baseline Survey, Spring Average 1993 to 1995.

NRA
National Centre for Instrumentation and Marine Surveillance



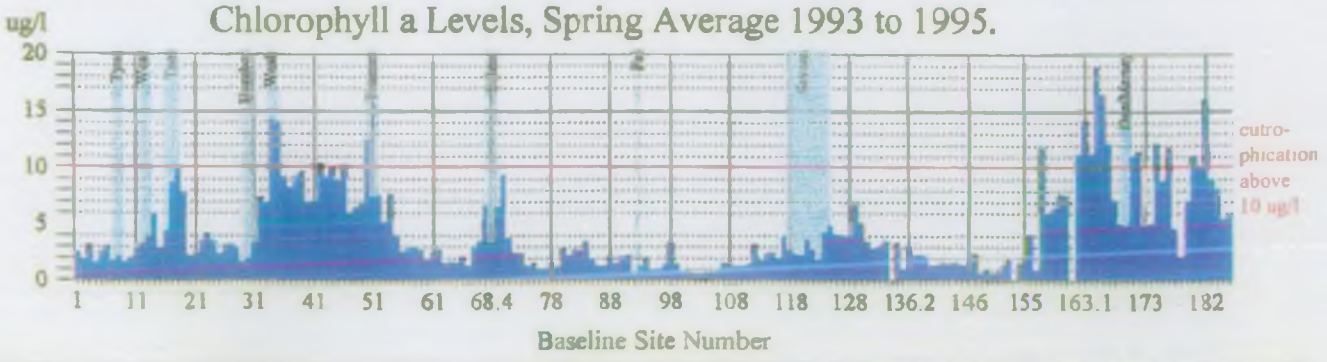
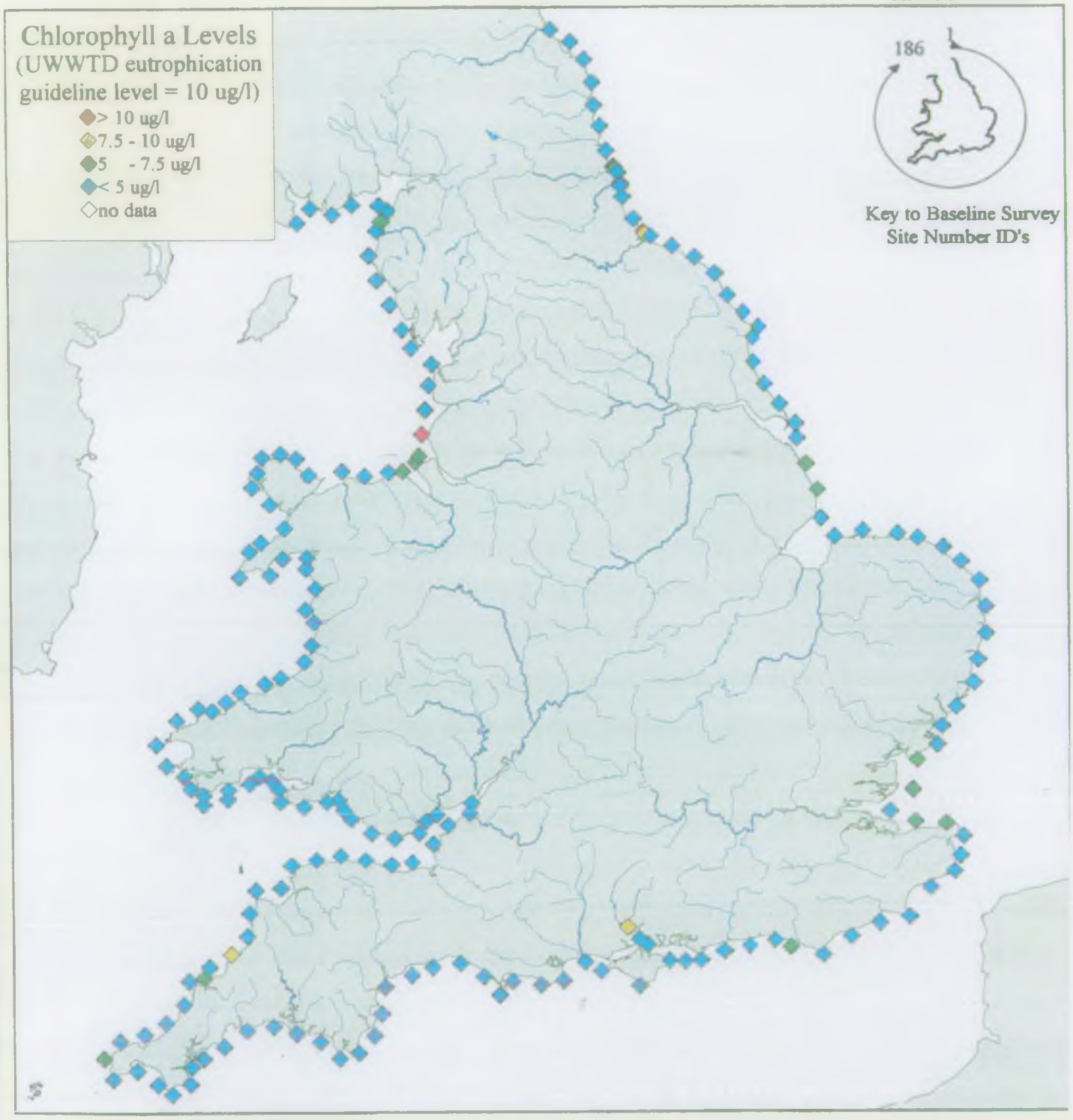


Figure 3.2 6

Chlorophyll a Levels, National Baseline Survey, Summer Average 1993 to 1995.

NRA
National Centre for Instrumentation and Marine Surveillance



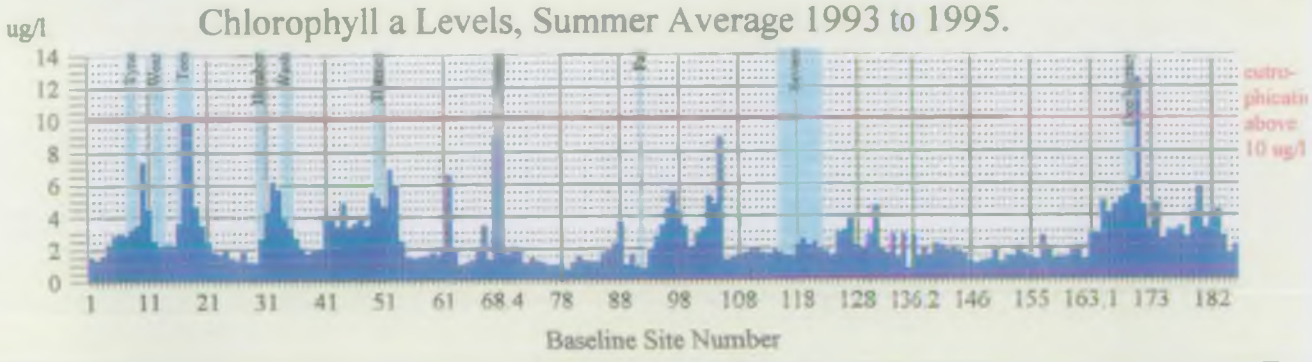
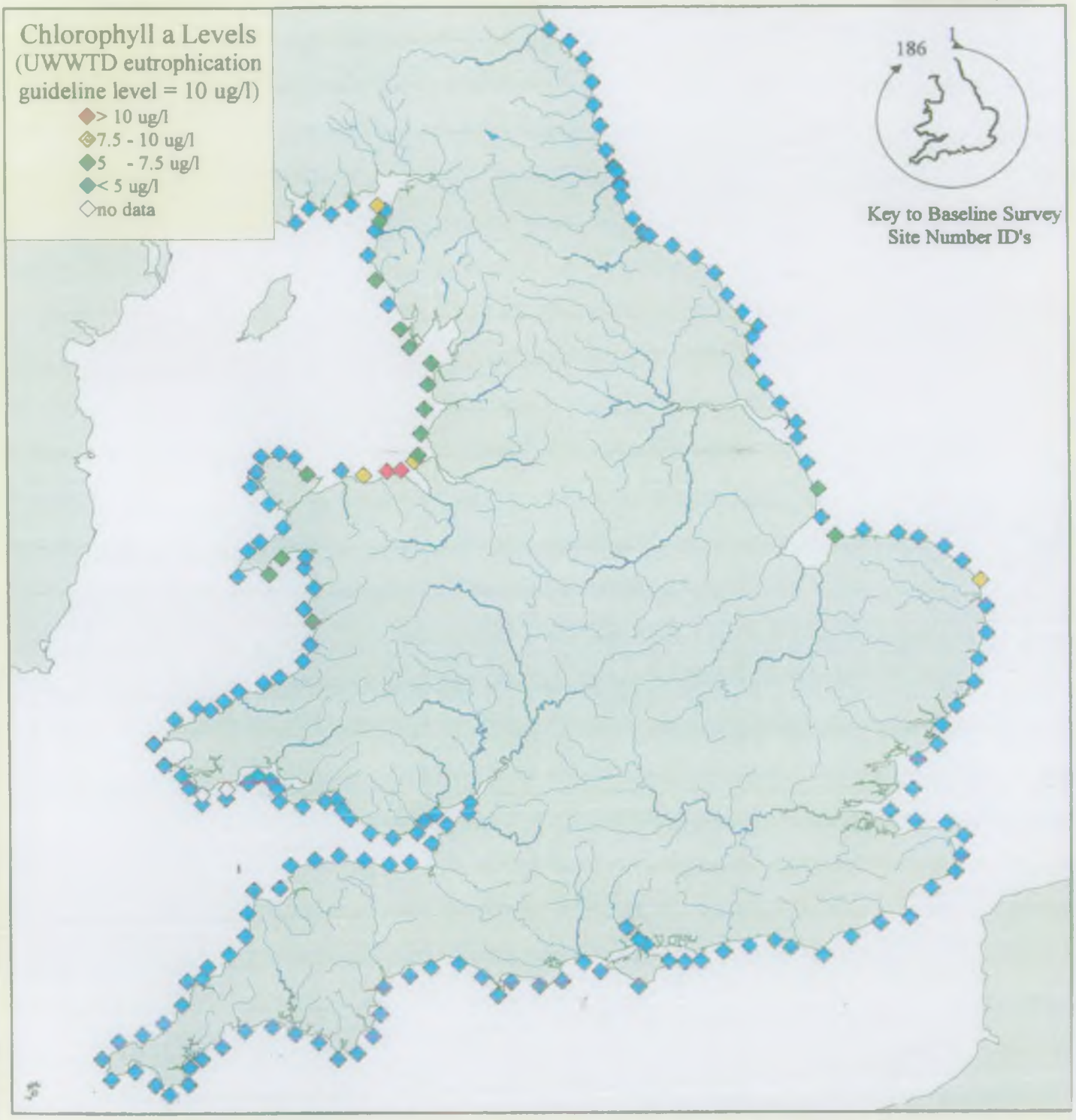
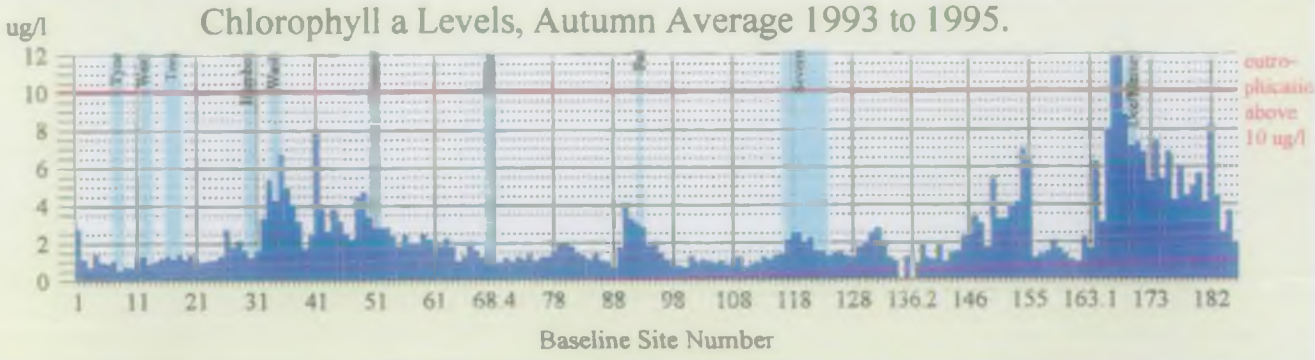


Figure ~~3.3~~ 7

Chlorophyll a Levels, National Baseline Survey, Autumn Average 1993 to 1995.

NRA
National Centre for Instrumentation and Marine Surveillance





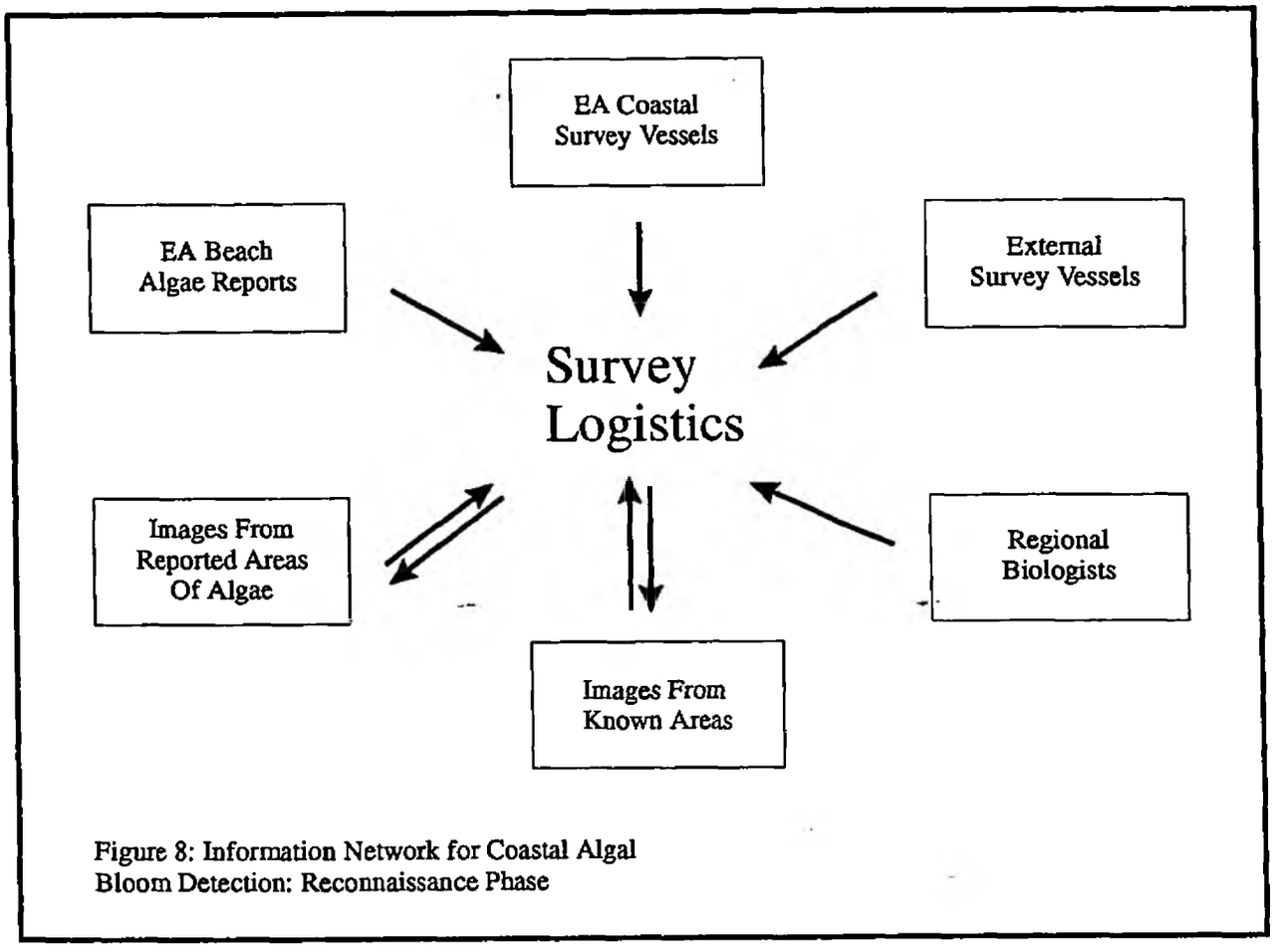


Figure 8: Information Network for Coastal Algal Bloom Detection: Reconnaissance Phase

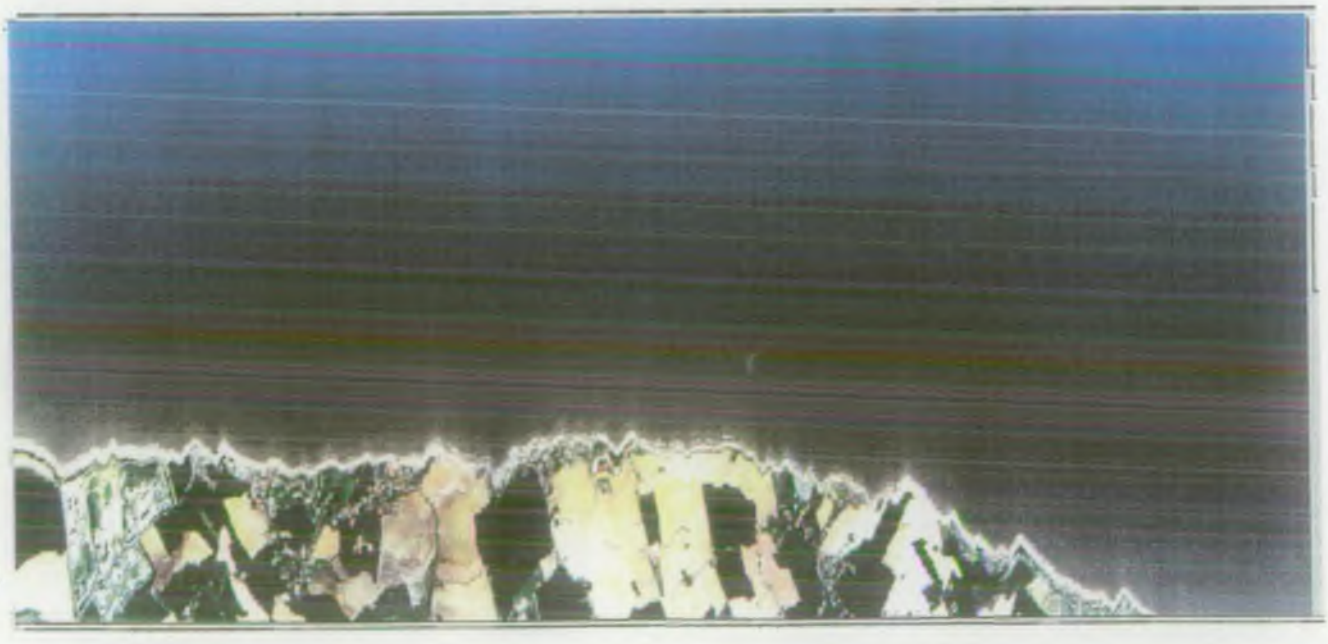
Figure 9

Mission Number: 1
Date: 30/05/96
Target Area: North Norfolk / Wash

Image A:
Image 1863: Noth East Norfolk

Image B:
Image 1875: The Wash: Hunstanton area

B



A

Figure 10

Mission Number: 2
Date: 5/7/96
Target Area: Upper Severn
Archive Number 1890

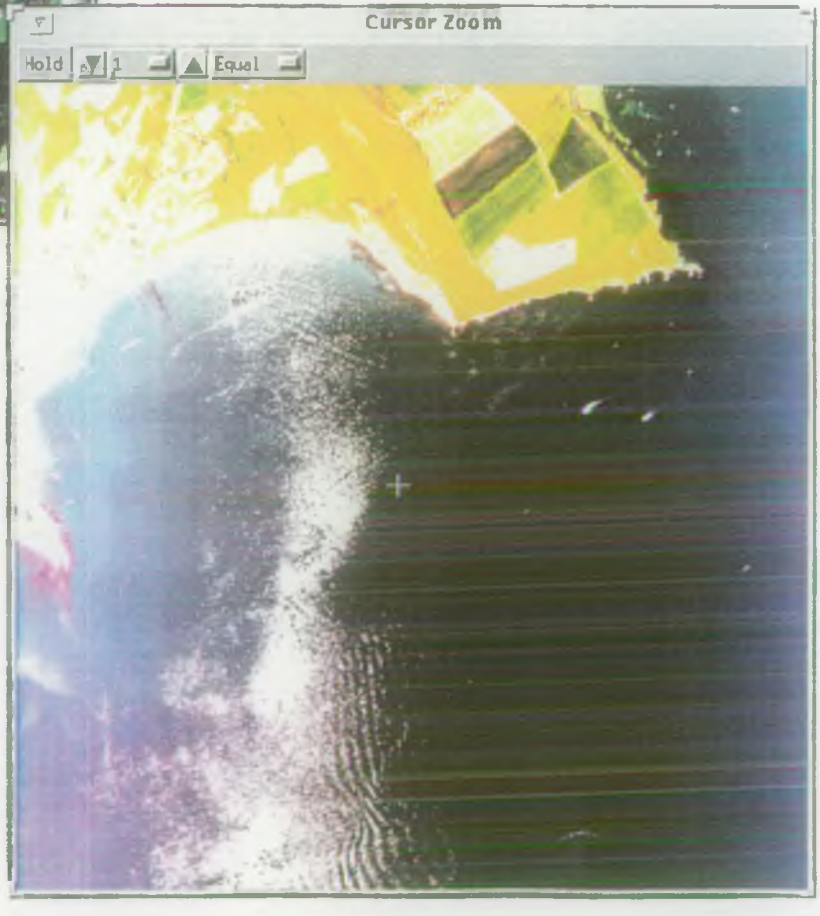


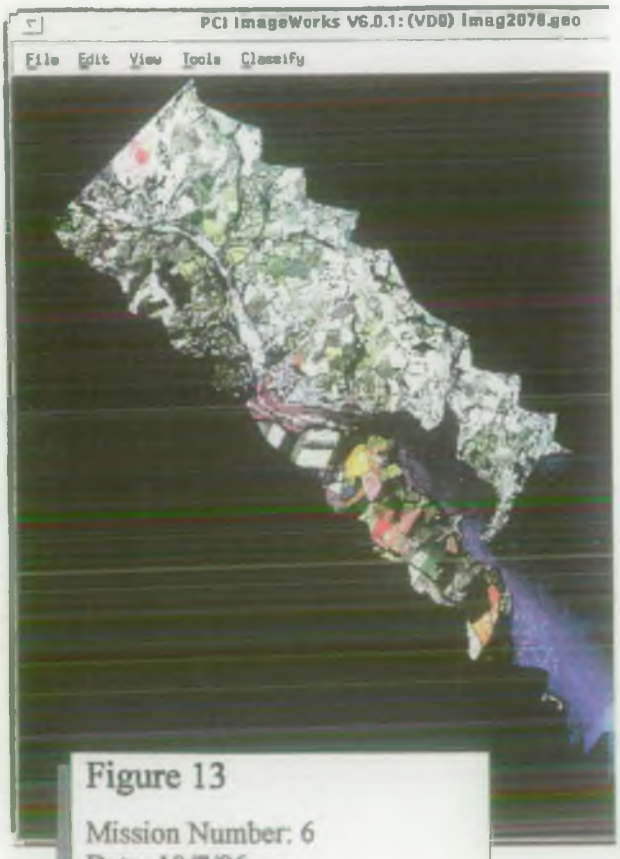
Figure 11

Mission Number: 13
Date: 6/7/96
Target Area: South Coast
Image number 1901: Studland point

Figure 12

Mission Number: 5
Date: 24/6/96
Target Area: North Devon
Archive Number 2037: Porlock bay

A



B

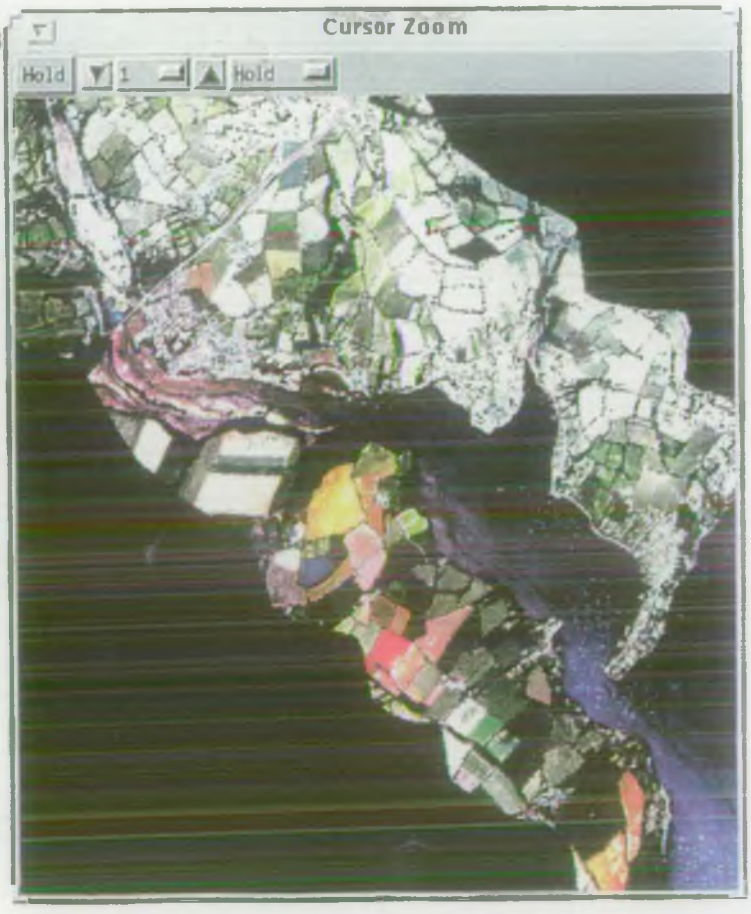


Figure 13

Mission Number: 6
Date: 10/7/96
Target Area: Fal

Image A:
Low tide image (no. 2068)

Image B
Close up of A

A

B

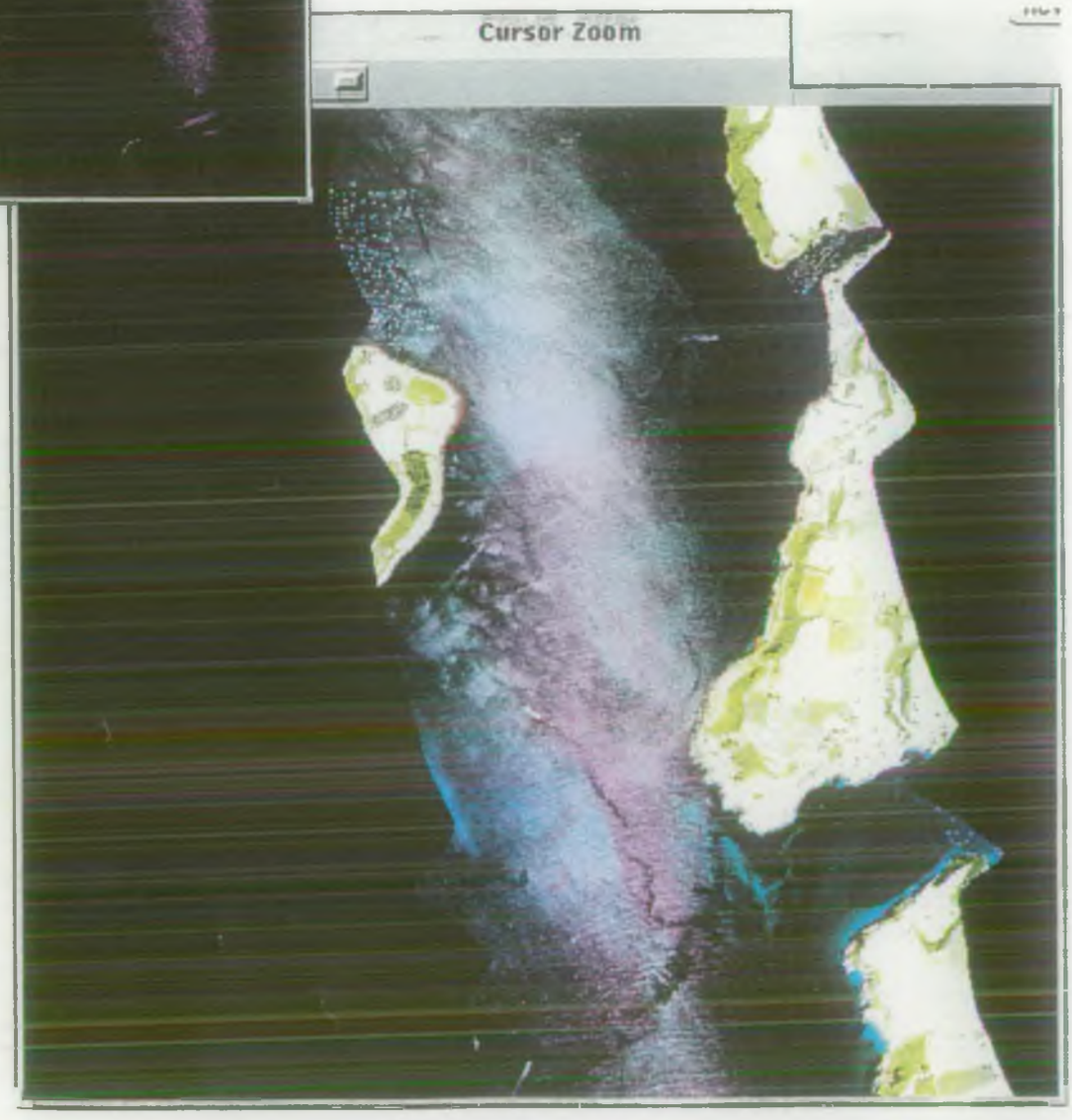


Figure 14

Mission Number: 6
Date: 11/7/96
Target Area: Fal

Image A:
High tide image (no. 2078)

Image B
Zoom of image A

Figure 15

Chlorophyll a Levels
Fal Estuary 12/07/96

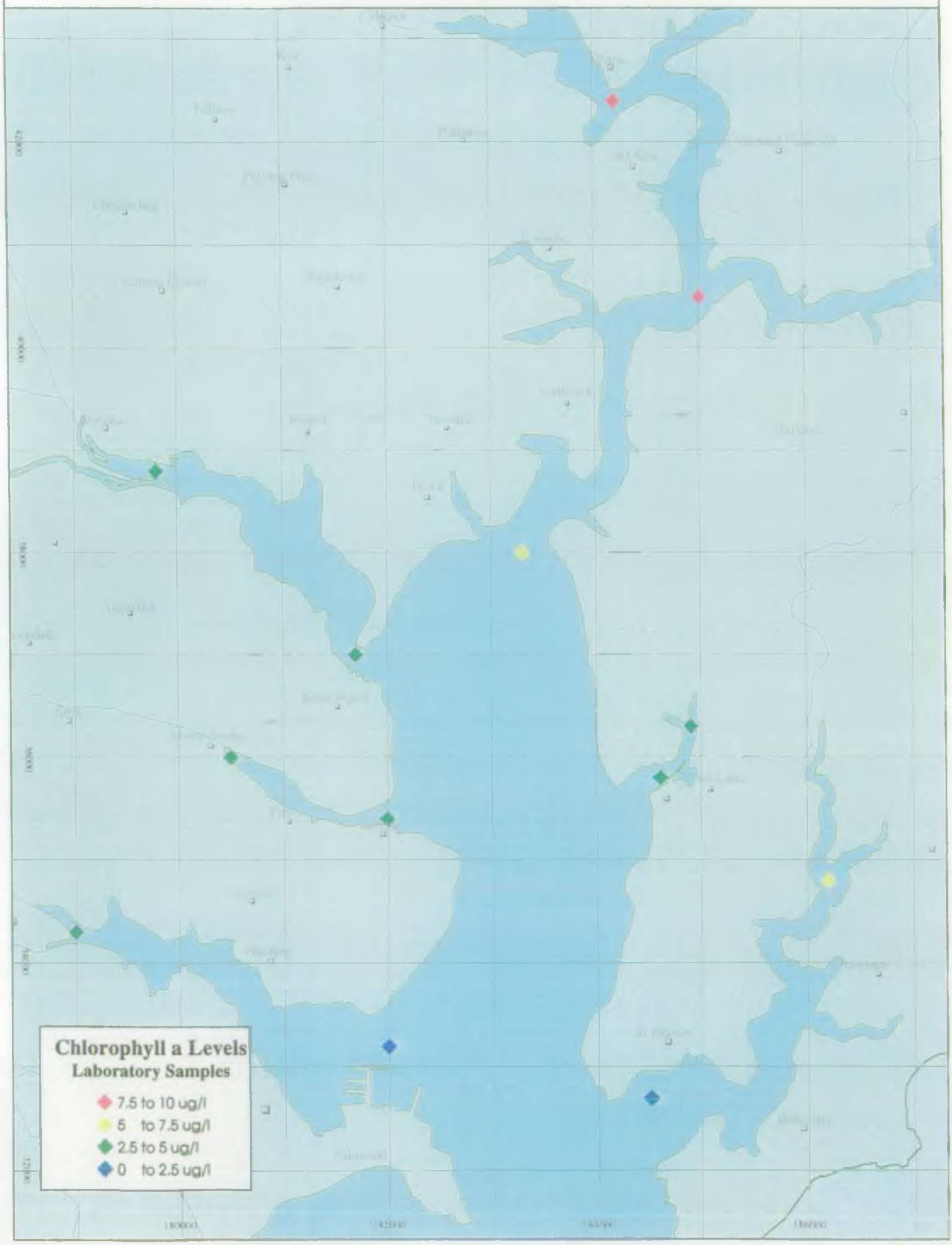
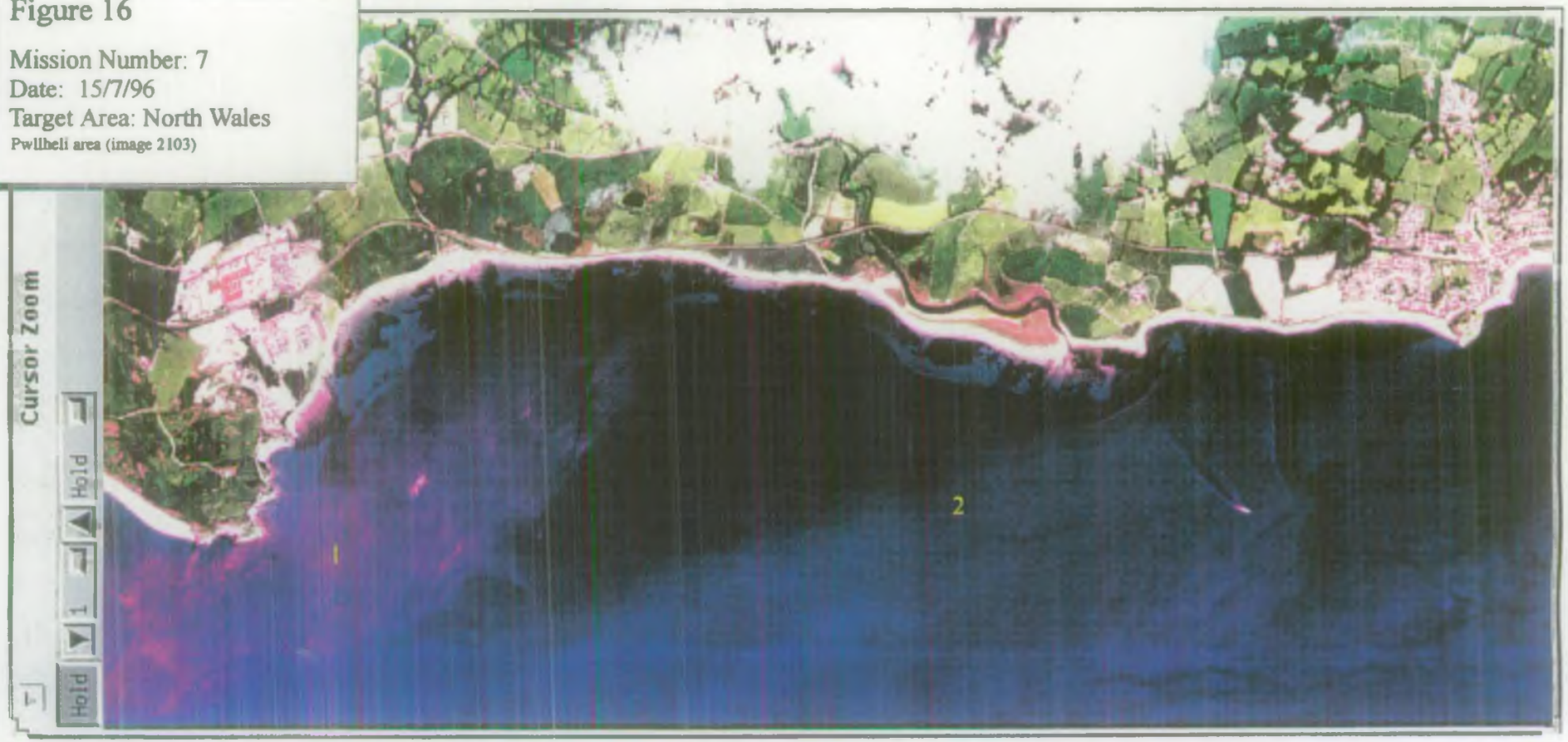


Figure 16

Mission Number: 7
Date: 15/7/96
Target Area: North Wales
Pwllheli area (image 2103)



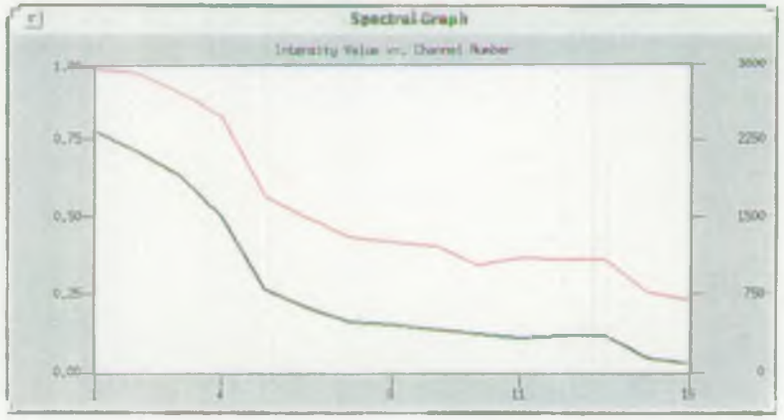


Figure 17

Spectral plots (brightness vs channel number) for two areas on image 2103 (fig 16)

Spectra from area 1
Spectra from area 2

Figure 18

Mission Number: 8
Date: 16/7/96
Target Area: Holdeness Coast
Image 2139, Spurn Head

Figure 19

Mission Number: 9
Date: 16/7/96
Target Area: Cumbrian Coastline

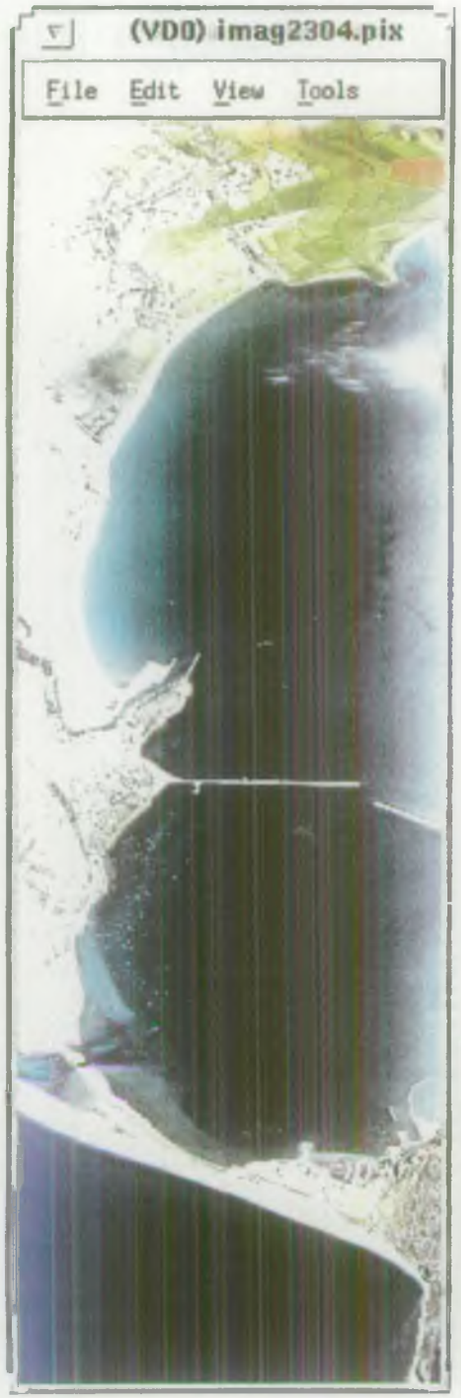
Image 2146

Figure 20

Mission Number: 10
Date: 19/7/96
Target Area:
North Norfolk Coastline

Image 2203: Scolt Head Island

A



B

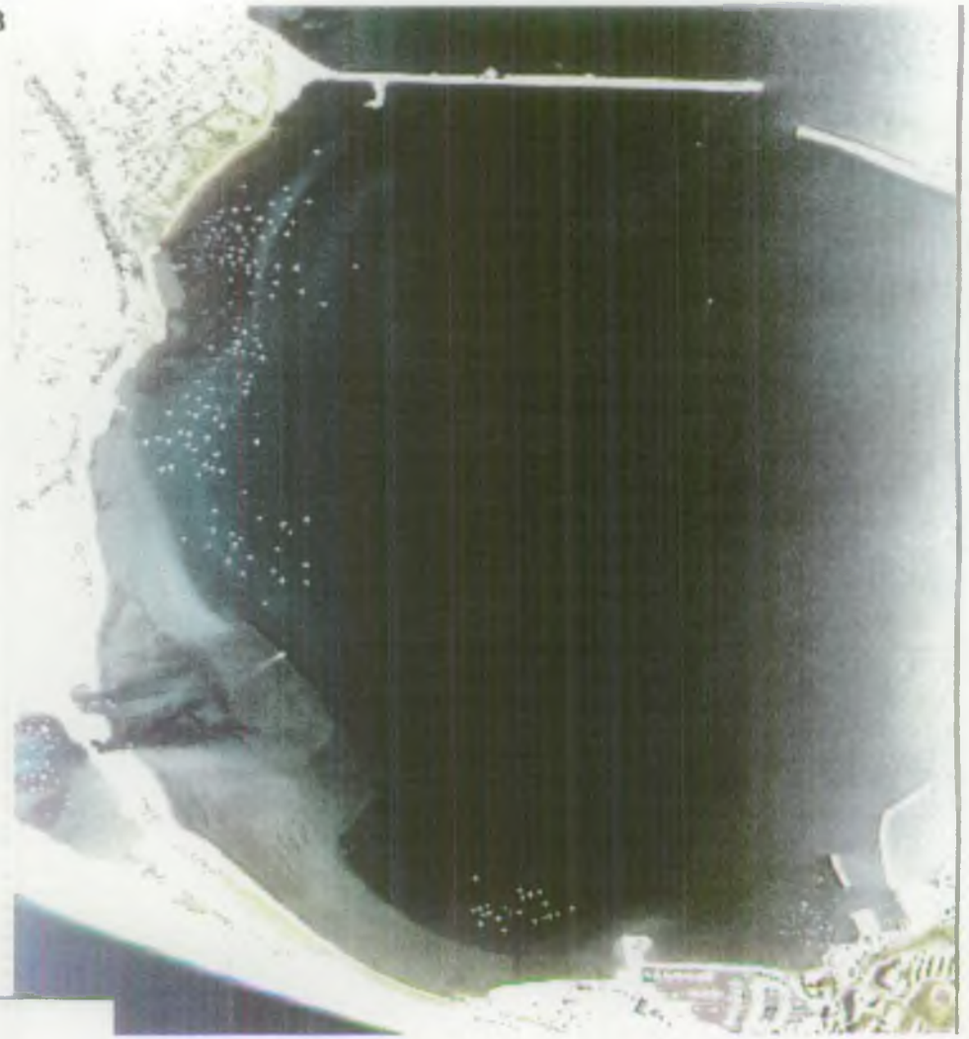


Figure 21

Mission Number: 11

Date: 3/8/96

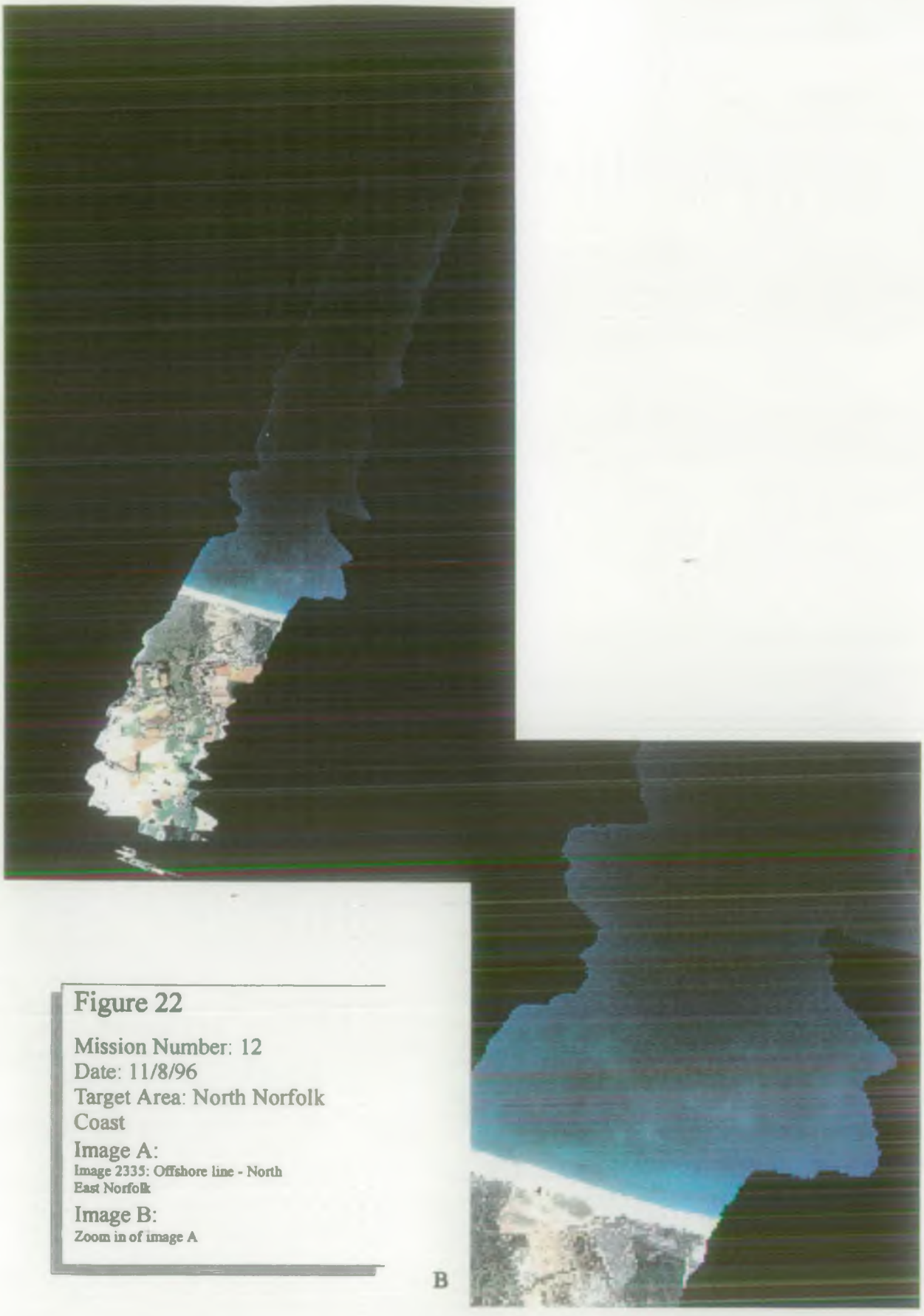
Target Area: Weymouth

Image A:

Overview image (no 2304)

Image B

Detail of Harbour



A

B

Figure 22

Mission Number: 12
Date: 11/8/96
Target Area: North Norfolk Coast

Image A:
Image 2335: Offshore line - North East Norfolk

Image B:
Zoom in of image A

A

B

Figure 23

Mission Number: 13
Date: 13/08/97
Target Area: North Wales

Image A:
Red Wharf bay, Anglesey. Image 2343

Image B:
Zoom in of image A

A

B

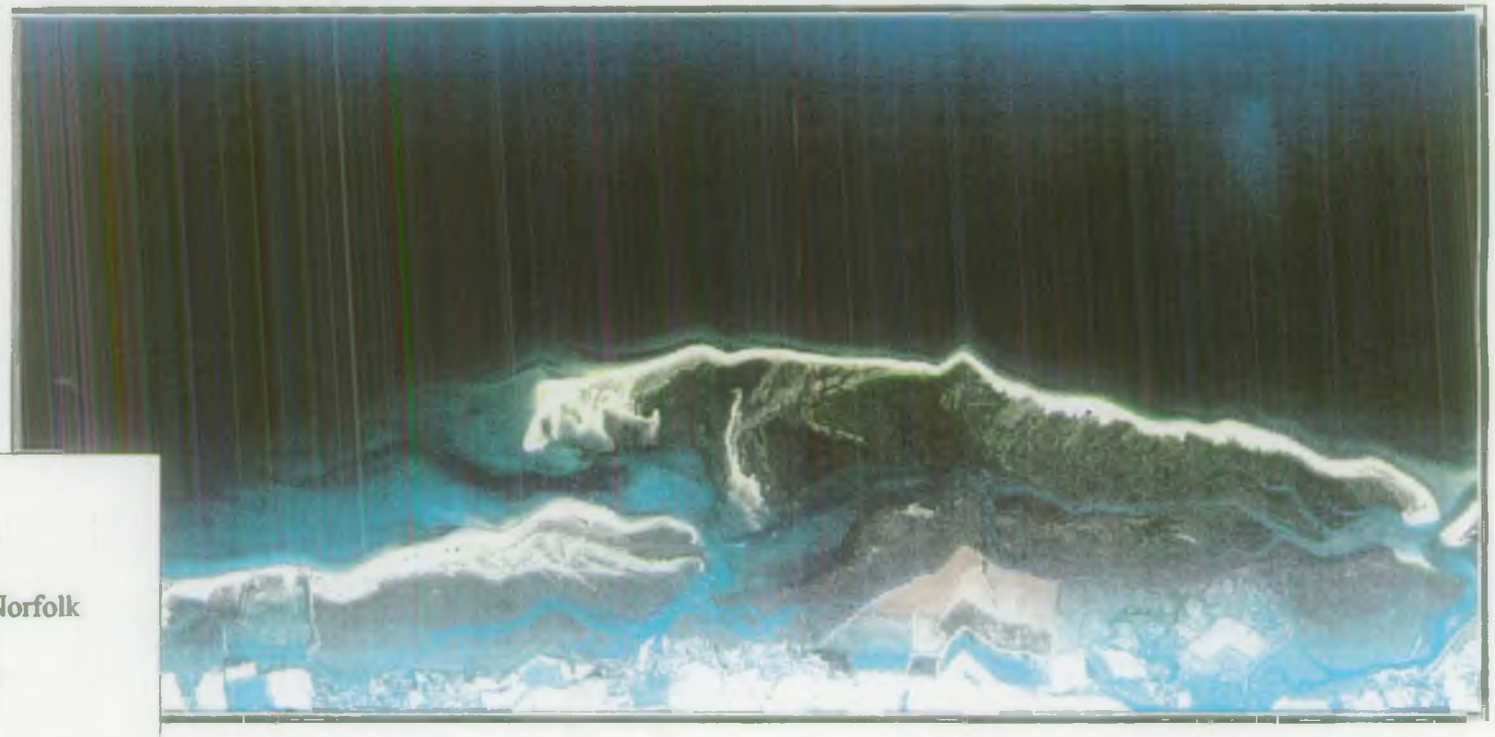


Figure 24

Mission Number: 14
Date: 19/8/96
Target Area: North Norfolk

Scolt Head Island: Image 2349

Close up of image A

Figure 25

Mission Number: 15
Date: 4/9/96
Target Area: N.Wales

Image A:
Little Ormes head: (image 2398)

Image B:
Zoom in of A: Sediment off Lt. Ormes head

A

B

Figure 26

Mission Number: 16
Date: 6/9/96
Target Area: North Wales

Image A:
Lt. and Gt. Ormes Head (image 2403)

Image B:
Zoom of image A

Figure 27

Mission Number: 17
Date: 12/09/96
Target Area: North Devon

Image A:
Image 2426: Offshore line from Porlock bay

Figure 28

Mission Number: 18
Date: 13/9/96
Target Area: Cumbrain Coast

Image A:
Overview of image 2448

Image B:
St. Bees Head area

A

B

A

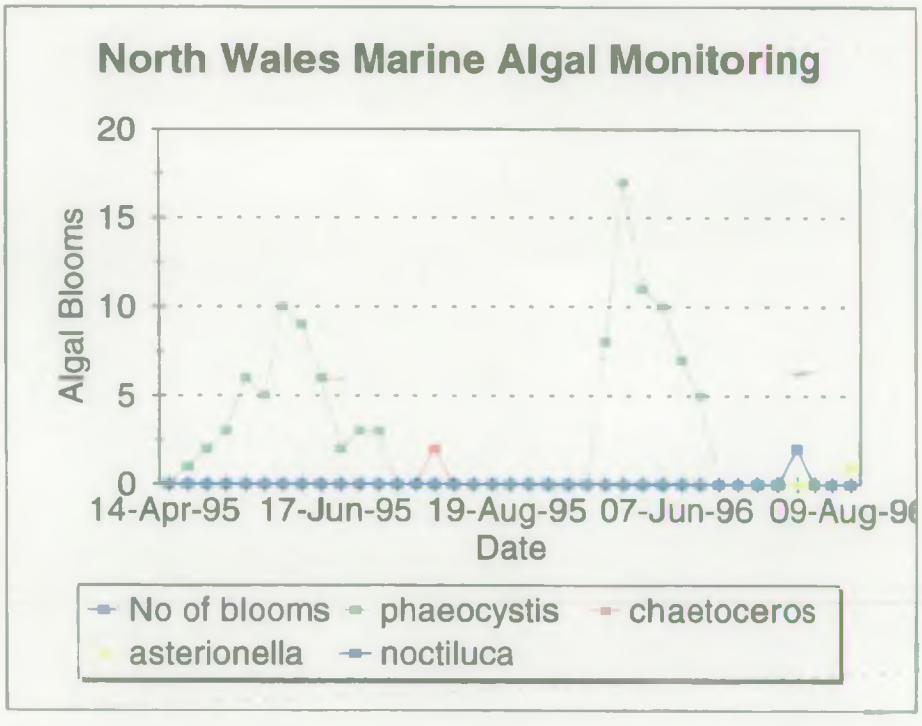
B

Figure 29

Mission Number: 19
Date: 17/9/96
Target Area: Cumbrian Coast

Image A:
Overview of river Esk area (image 2555)

Image B:
Close up of A (lower segment of image)


North Wales Marine Algal Monitoring
Algal Blooms
20
15
10
5
0
14-Apr-95
17-Jun-95
19-Aug-95
07-Jun-96
09-Aug-96
Date
No of blooms
phaeocystis
chaetoceros
asterionella
noctiluca

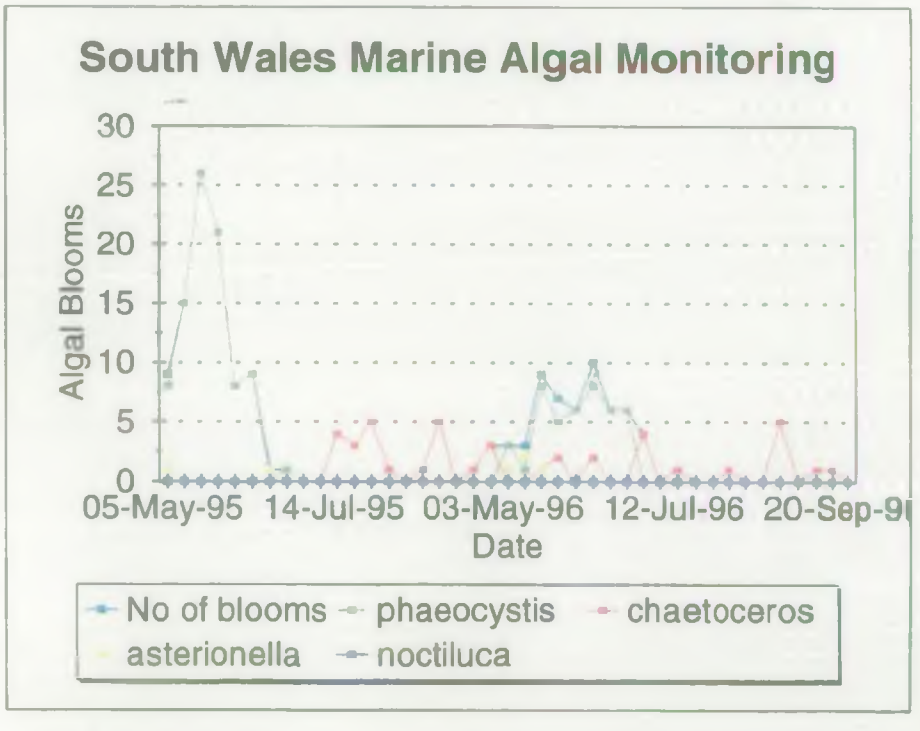
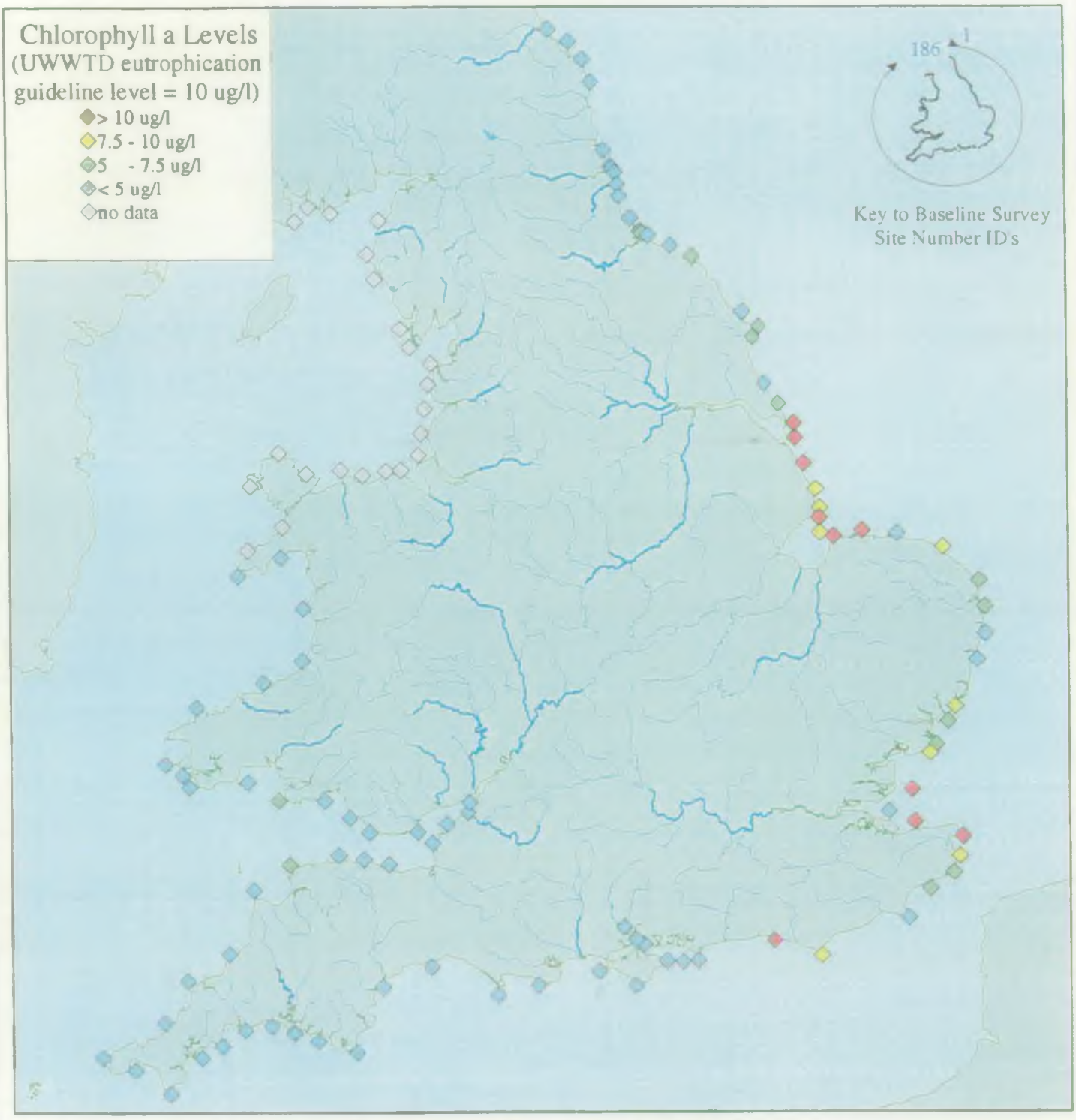
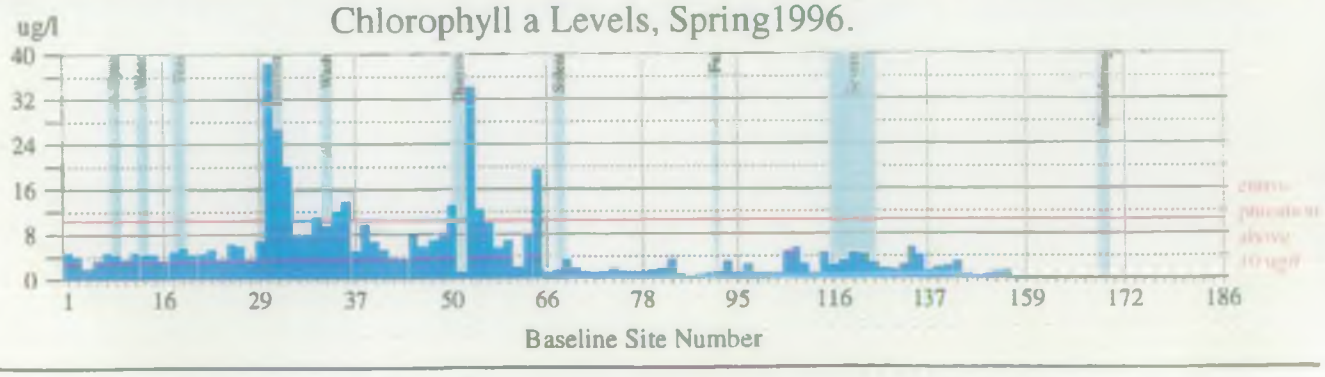

South Wales Marine Algal Monitoring
Algal Blooms
30
25
20
15
10
5
0
05-May-95
14-Jul-95
03-May-96
12-Jul-96
20-Sep-96
Date
No of blooms
phaeocystis
chaetoceros
asterionella
noctiluca

Figure 30

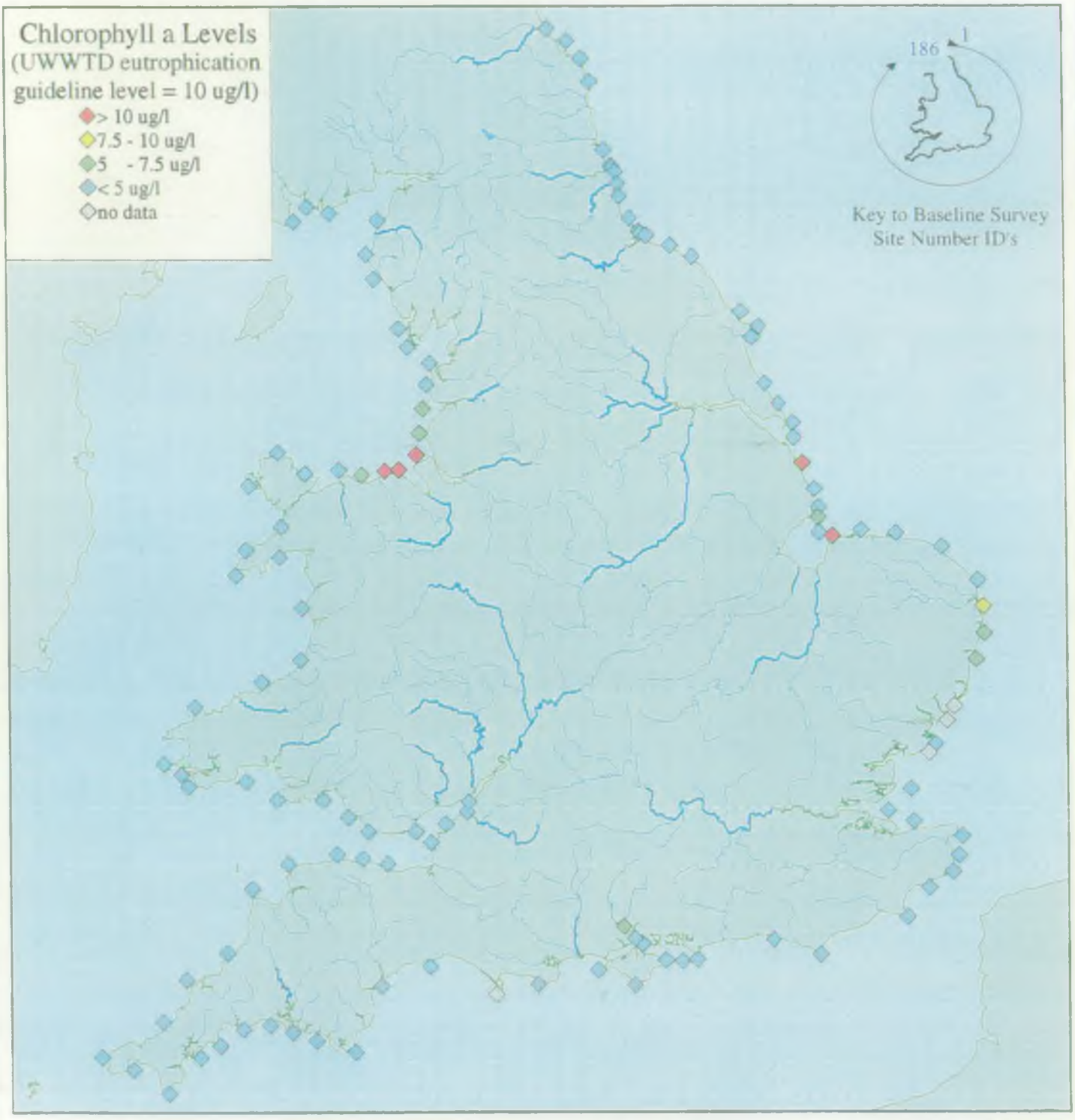
Fig 81

Chlorophyll a Levels, National Baseline Survey, Spring 1996.





Chlorophyll a Levels, National Baseline Survey, Summer 1996.



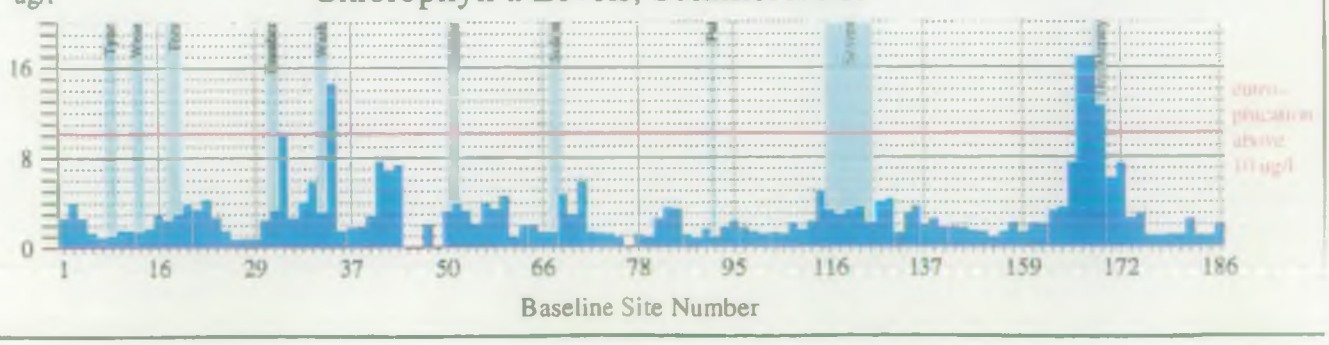


Fig 33

Chlorophyll a Levels, Northwest Baseline Survey, Autumn 1996.