Karenia mikimotoi: AN EXCEPTIONAL DINOFLAGELLATE BLOOM IN WESTERN IRISH WATERS, SUMMER 2005.

November 2005

J.Silke, F.O'Beirn and M. Cronin

Marine Institute
Marine Environment and Food Safety Services
Galway.

ISSN NO: 1649-0053

Marine Environment and Health Series, No 21, 2005

Acknowledgements

The authors wish to thank the following:

- Personnel from the Sea Fisheries Division of the Department of the Communications Marine and Natural Resources for assistance in sample collection, and for information on locations and extent of natural and wild fish mortalities.
- Dave Clarke, Glenn Nolan, Guy Westbrook, Tara Chamberlain and Terry McMahon, Marine Institute for the collection and analysis of samples.
- Micheál O'Cinneide and Terry McMahon of the Marine Institute for reviews and advice.
- Brendan O'Connor, Aqua-Fact International Service ltd.
- Caroline Cusack, Martin Ryan Institute NUI Galway
- Mark Norman and Paul Casburn, Taidge Mara Teo. for observations on cod culture
- Bord Iascaigh Mhara (Peter McGroary; Mary Hannon; Tomás Burke; Catherine Butler) for statistics on aquaculture impacts.
- Kevin Flannery, Sea Fisheries Division, DCMNR for photos and information in the Dingle Bay area.
- Peter Millar, MCEIS Service, Plymouth Marine Lab for satellite images.
- Shane O' Boyle, EPA.

Copies of this report may be obtained from:

Marine Institute
Communications Section
Galway Technology Park
Parkmore, Galway, Ireland.
+353 (0)91 730400

Or online at:
http://www.marine.ie

ABSTRACT

A protracted bloom of *Karenia mikimotoi* was present in summer 2005 along the northern half of the western Irish coastline. The onset of this bloom was identified in late May / early June. This event subsequently dissipated over the month of July and was succeeded by a bloom of the same species in the southwest in late July. The bloom was very intense and resulted in discolouration of seawater and foaming in coastal embayments. Major mortalities of benthic and pelagic marine organisms were observed and a complete decimation of marine faunal communities was reported and observed in several locations. Deaths of echinoderms, polychaetes and bivalve molluscs were observed in County Donegal and Mayo, while farmed shellfish and hatchery raised juvenile bivalve spat suffered significant mortalities along the Galway and Mayo coasts. Reports of dead fish and crustacea were received from Donegal, Galway, West Cork and Kerry.

Karenia mikimotoi is one of the most common red tide causative dinoflagellates known in the Northeast Atlantic region, and is also common in the waters around Japan. Blooms of this species often reach concentrations of over several million cells per litre and these densities are often associated with marine fauna mortalities. Although cytotoxic polyethers have been extracted from cultures of the species, the exact mechanism of the toxic effect and resultant devastating damages yet remains unclear. It is known in the literature under several different names as the taxonomy and genetics have been studied. It is now known that previously reported names including *Gyrodinium aureolum*, *G*. cf. *aureolum*, *G. nagasakiense* and *G*. *mikimotoi* are synonymous with the current name given to the organism.

The visible effects following the mortalities included noticeable quantities of dead heart urchins (*Echinocardium cordata* L.) and lugworms (*Arenicola marina* L.) deposited on beaches. Several species of wild fish were also found dead. The bloom coincided with a period of fine weather and tourists visiting the seaside were concerned about the safety of swimming in waters that were obviously harmful to marine organisms on this scale. A public awareness programme was mounted by the Marine Institute with several radio broadcasts, press releases and a website provided to give up to date pronouncements on the event.

While there have been several instances of *Karenia mikimotoi* blooms reported in Ireland over the past 30 years, this scale of mortalities associated with the 2005 bloom were not previously observed. Recording the scale of this event was facilitated by satellite imagery while direct counts of the cells in seawater by the Marine Institute monitoring programme gave very useful information regarding the size and intensity of this event. The mortalities of marine organisms were documented from reports made by various observers and by Marine Institute field surveys.

TABLE OF CONTENTS

1. INTRODUCTION

1.1 Background and context

A bloom of the dinoflagellate *Karenia mikimotoi* (see Figure 1) originated along the west coast of Ireland during June 2005 and persisted for approximately two months. During that time, mortalities were reported of vertebrate and invertebrate species along the length of the western seaboard. Marine Institute (MI) scientists conducted comprehensive surveys of the coastline. High cell counts were related to subsequent mortalities.

MI took responsibility for the provision of public information during the harmful algal event. A number of public information services were put in place, including:

- response to phone queries from the public and state agencies
- a website to provide daily updates on the event
- several press releases was prepared and published
- news bulletins broadcast on national and local radio

MI agreed with the Department of Communications, Marine and Natural Resources (DCMNR) to produce a full report on the phenomenon.

This report documents the origin and development of the bloom and the reported mortalities. It also details the investigation by MI into the protracted and intense bloom of the ichtytoxic dinoflagellate along the west coast of Ireland during summer 2005.

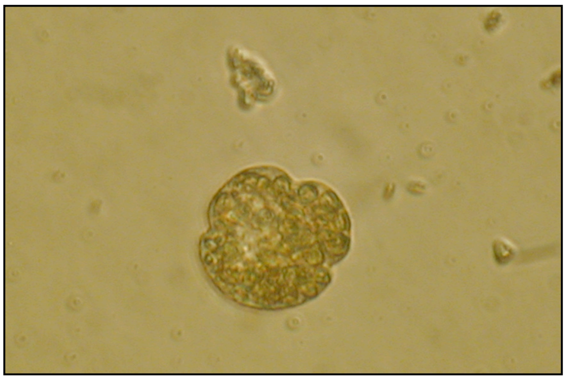


Figure 1: The dinoflagellate *Karenia mikimotoi*, observed at x200 magnification (Picture MI)

1.1.1 Normal periodic blooms

Blooms of phytoplankton are regular occurrences of the natural cycle of the marine flora. A bloom is said to occur when the population of planktonic organisms becomes sufficiently abundant resulting in visible discolouration the sea. These blooms are mostly associated with phytoplanktonic autotrophs (organisms self-sufficient in food production) and the resultant discolouration is due to high concentrations of photosynthetic and accessory pigments.

Normal levels of chlorophyll-a in summer European waters are in the order of a few mg/m^3 but blooms of *Karenia mikimotoi* can result in dramatic increases of chlorophyll resulting in spectacular water discolouration. Visible discolouration becomes noticeable when chlorophyll concentrations exceed approximately 10 mg/m^3, whereupon the pigments can absorb and algal cells scatter a substantial fraction of submarine light. Holligan (1979) observed chlorophyll levels due to a bloom of this species above 100 mg/m^3 in the approaches to the English Channel. Jones *et al.* (1984) describe a red tide in western Scotland where chlorophyll levels reached 2200 mg/m^3.

1.1.2 Exceptional blooms

An "exceptional" bloom is defined as being an irregular event, and hence unpredictable, unlike the spring diatom bloom. Exceptional blooms include those that are outside of the usual dinoflagellate summer succession, and blooms that are unusual in their consequences. Some of these consequences include acute toxicity, such as result from toxin producing species such as

Alexandrium spp., and marine organism mortality events, such as those following blooms of *Karenia mikimotoi,* often accompanied by discoloured water due to its potential high biomass.

1.2 Introduction to *Karenia mikimotoi*

1.2.1 Mechanism of toxicity

While many fish killing phytoplankton are known worldwide, the actual toxicity of these species is not fully understood. Only the brevetoxins produced by *Karenia brevis* and prymnesins produced by *Prymnesium parvum* have been shown to kill fish to date. *Karenia mikimotoi* is one of the most notorious red tide species causing devastating damage to aquaculture and marine ecosystems worldwide, however the mechanism of the toxic effect to marine organisms as yet remains largely unknown. The mortalities have been suggested to be due to a combination of decreased levels of oxygen saturation, or anoxic conditions that result from the decomposition of the algae in the latter stages of the bloom and the presence of a toxin. Respiration by the algae themselves as well as bacterial respiration associated with the breakdown of the bloom consumes oxygen. In estuaries and bays, the bottom waters may become deficient in oxygen and, in extreme cases, anoxic (i.e., totally devoid of oxygen), causing mass mortalities of benthic fauna. The process is exacerbated if the water column becomes stratified, either by freshwater inputs to estuaries or through seasonal heating of the surface waters.

In recent papers by Satake *et al.* (2002 and 2005), an investigation into the toxic principal causing mortalities associated with *K. mikimotoi* was conducted. Using a cytotoxicity assay instead of more elusive fish toxicity assays used in the past, and by improving extraction and purification conditions, they isolated new toxins named Gymnocins A and B. These compounds are structurally similar to certain Brevetoxins (BTX), however it was shown that, while they are cytotoxic, they are only weakly toxic to fish. When a mixture of the Gymnocins was tested on a fresh water fish, *Tanichthys albonubes*, the toxicity was 250 times less potent than that of 42-dihydro BTXb . The discrepancy between the observed massive fish kills in the field and the weak toxicity in the laboratory assay may arise from the fact that the extremely low solubility of the Gymnocins in water prevents them from reaching the fish gills. In the red tide events, *K. mikimotoi*, cells were observed to stuff the fish gills, enabling thereby direct contact of the Gymnocins to the gills. A similar mechanism may apply to many other red tide species that kill fish in the field but appear to be non-toxic when extracts are tested by conventional fish assays.

1.2.2 History of Karenia mikimotoi blooms

Vertebrate and invertebrate mortalities associated with large algal blooms (of a variety of species) are not unusual and have been reported from New Zealand (Chang *et al.,* 2001), Hong Kong (Lu and Hodgkiss, 2004), South Africa (Horstman, 1980) and, the US (Smith, 1975 & 1979). The scale of impact of these events have varied considerably and have been realised both on a broad geographic scale e.g. 2,162 square miles impacted on west coast of Florida (USA) during 2005 (Florida Fish and Wildlife Commission, 2005), and on an economical scale e.g. US$40,000,000 worth of losses in caged fin-fish in Hong Kong (Lu and Hodgkiss, 2004).

First recorded as "*Gyrodinium aureolum* Hulbert" from samples collected in a coastal lagoon close to Woods Hole, Massachusetts USA, (Hulbert, 1957), it was subsequently found in 1966 by Braarud and Heimdal (1970) to be responsible for a red tide along Norwegian coasts. Here it was described as "brown water accompanied by sea trout mortalities". There are two further uncertain occurrences in the late 1960s (identification not confirmed); in the Helgoland Bight (North Sea) in 1968 (Hickel *et al.*, 1971), and off the coast of Jutland, also in 1968, (Vagn Hansen *et al.,* 1969). The latter was also associated with fish mortalities. In 1971 Ballentine and Smith (1973) reported a bloom on the North Wales coast, which was associated with the characteristic extensive lugworm mortalities. Ballentine also recorded that *G.aureolum (K. mikimotoi)* had been identified in the Plymouth area in south-west England.

A North Sea bloom of *K. mikimotoi* was also described in the North Sea by Tangen (1977) and this was also associated with marine organism mortalities. Other than the report from Woods Hole lagoon, all the sightings seemed to occur around the latter part of the Summer and early autumn. Fine calm weather appeared to be an important precursor to these blooms.

There were two distinct morphotypes described using the same species name *Gyrodinium aureolum*; one on the east coast of the USA and the other in Europe. Hulbert described the North American type under the original description in 1957. Neither red tides nor mass mortalities were described in North America, but extensive red tides with mass mortalities were reported in the North Sea (Tangen, 1977).

Tangen and Bjorland (1981) observed the morphology of European *G. aureolum* in detail. Comparing their description to that of Hulbert the position of the nucleus apparently differs. The position of the nucleus is one of the key identifying features of this species lying laterally across the hypocone. Many taxonomists considered it inadequate to describe the North American and European morphotypes as *G. aureolum*. Consequently it was decided that the European morphotype was not *G. aureolum* and similarities to the Japanese fish killing species *Gymnodinium mikimotoi* were made.

During 1975, Evans (1975) described the progress of a bloom of a virtual monoculture of *K. mikimotoi* throughout most of Liverpool Bay, and particularly along the north Wales coast. This year was notable for a fine extended summer, and this bloom was well established towards the middle of September just as the weather broke with strong gales and heavy rain. The resultant mixing of Liverpool Bay, rather than diminishing the intensity of the bloom, extended its geographical distribution to Morecambe Bay, reaching a peak on 15th October. Cell counts reached a density of 0.92x 10^6 and a chlorophyll a level of 40.7 mg/m^{-3}. This bloom tailed off gradually and had disappeared from the phytoplankton completely by mid November. The effects of this bloom were reported to include large-scale lugworm mortalities, luminescence in the water and a seaweed-type odour during the period of bloom decline.

1.2.3 History of Karenia mikimotoi blooms in Irish waters

In Irish waters there have been several reports of blooms. The earliest recorded publication on an Irish bloom of *Karenia* was made by *Ottway et al.* (1979) following observations of mortalities of littoral and sub littoral organisms associated with an algal bloom in 1976. This bloom was located in Wexford Harbour and extended along the south coast to Youghal where discolouration of the water persisted for 10 days from the 5th July 1976. Mortalities of organisms included lugworms (*Arenicola marina*), ragworms (*Nereis* sp.), sole (*Solea* sp.), plaice (*Pleuronectes platessa* L.) flounder (*Platichthys flesus* L.), sandeels (*Ammodytes* sp.) gapers (*Mya* sp.), razor fish (*Ensis* sp.), cockles (*Cerastoderma (Parvicardium) edule* L.) and Palourdes (*Tapes decussata* L.)

In August 1978, a bloom was recorded, located in Roaringwater Bay, inside the Fastnet Rock, and extending some 100km eastwards along the south coast to Kinsale Harbour (Roden *et al.,* 1980). Chlorophyll-a concentrations of 32 mg m^{-3} were estimated at the peak of the bloom (Pybus, 1980). The following year a further exceptional bloom was recorded, again in the month of August (Roden *et al.,* 1981).

In both cases, these blooms were associated with mortalities of marine organisms including benthic invertebrates and farmed fish. In 1984, a bloom up to 0.5x 10^6 cells/litre was recorded also in Roaringwater Bay, with a similar density reported in 1987 in Bantry Bay (Raine *et al.,* 1990). The above studies suggested for the first time that the frontal regions between the upwelling zone and adjacent thermally stratified waters off the southwest coast could be an ideal site for bloom formation. These are similar to the tidal front regions of the Irish Sea, which have been associated with large *Karenia* populations in the summer.

A study to investigate the link between surface wind stress and upwelling in the promotion of *K.mikimotoi* blooms in coastal areas was carried out in July and August of 1991 in Bantry Bay (Raine *et al.* 1993). This survey indicated that the effects of upwelling in promoting dinoflagellate blooms might be due to the shallowing of the pycnocline outside of the coastal bays into the euphotic zone (due to upwelling), thereby promoting phytoplankton growth at this discontinuity. This shallowing may reach the sea surface where dinoflagellate communities can predominate. Wind stress acting along this surface coastal front and its resident bloom of dinoflagellates can move the community shorewards by moving a large surface inflow and bottom outflow into the bays that are axially aligned to the predominant wind direction.

The work was highly significant in explaining the sudden occurrence of large populations of dinoflagellates, including *Karenia*, which regularly present themselves into coastal embayments during the summer months when upwelling and stratification may occur offshore. These advective processes accompanying large-scale movements of *Karenia* from offshore adjacent shelf areas into the bays of the south west of Ireland are related to axial component of the wind stress i.e. the resumption of southwesterly winds following a short period of north easterly winds is known to cause considerable water exchange in Bantry Bay. In the August 1991 event it was estimated that 75% of the bay volume was exchanged with water on the shelf within two days. The physical mechanism by which these populations were transported into the bay was by way of a strong two way oscillatory flow in a stratified (two-layer) water column (Edwards *et al.* 1996) The alignment of Bantry Bay to the prevailing wind direction explained the sudden appearance of *Karenia mikimotoi* into the Bay.

In further studies in the south of Ireland between 1995 and 1996 the subsurface chlorophyll maximum between Sherkin Island and Cork Harbour contained cell counts of 4x 10^6 cells/litre of *K.mikimotoi* (Raine & McMahon, 1998).

A similar sudden appearance of *Karenia mikimotoi* was observed in Rosses Point in Co Sligo in 1998 and 1999 (O'Boyle, 2002). An increase in salinity on both occasions suggests physical control of these events rather than *in situ* growth. The role of the Irish Coastal Current (ICC), which travels northwards along the coast of Ireland, was suggested to play an important transport vector in moving these developing blooms northwards along the coast. Measurements of wind, taken at Erris Head, suggested that the ICC is strongest under southerly and southwesterly airflows. In 1999, a large population of *K. mikimotoi* was observed in the shelf waters to the west and southwest of the Aran Islands between the 8th and 11th of July. Later that month concentrations were observed to increase rapidly within a three-day period around the 26th of July reaching a maximum of 750,000 cells/l on the 29th July. The northwards coastal current was measured to give maximum current speeds of 15-20 cm/s and under these conditions the population west of Aran could have reached the shelf waters to the west of Sligo Bay in this time period. Transport into the bay was explained by westerly and northwesterly wind conditions.

2. METHODOLOGY

2.1 Surveys

Methods for the investigation were many and varied. They can be divided broadly into 3 areas of assessment:

(a) Assessment of the scale of the blooms

- The scale of the bloom was determined from the satellite imagery and phytoplankton counts.
- A review was carried out of environmental conditions measured along the western seaboard during the bloom event.

(b) Assessment of the intensity of the blooms

- Samples of seawater were collected from along the western coast to identify and enumerate the phytoplankton present, resulting in seawater discolouration and marine mortalities.
- RV Celtic Voyager Survey of West Galway coast (July 13-14), for phytoplankton, fluorescence and oceanographic conditions.

(c) Assessment of the impact of the blooms

- The scale of the impact was evaluated by discussion with staff from public agencies, as well as private individuals concerned about, or affected by the blooms.
- Numerous information sources were investigated with a view to documenting the intensity of mortalities in areas as well as the geographic scale of the impacts.
- Shore sites visits in Donegal Bay (July 1).
- MI Dive investigations in Kilkieran Bay July (4-5)
- MI's RV Celtic Voyager Camera Survey of Donegal Bay (July 10-11).
- Phytoplankton and benthic grab survey of Killary Harbour (August 7).
- A survey of aquaculture installations and surrounding environment in Killary Harbour was commissioned by MI (Aqua-Fact International Services Ltd.).

Specific investigations by the Marine Institute were supplemented by additional input from a variety of other sources (See Appendix 1). The reports of these additional investigations are summarised in the following Results section.

2.2 Methods

2.2.1 Phytoplankton Assessment

<u>2.2.1.1 Phytoplankton enumeration</u>

In the course of these investigations a suite of methods were employed to estimate the scale of the bloom. Weekly samples were collected from shellfish and salmon farms around the coast as part of the National Phytoplankton Monitoring Programme. The samples were collected using a Lund tube to integrate the top 10m of water in a single sample. Where water depth precluded the use of this equipment, a surface sample was collected. The samples were settled, identified and counts made under an inverted microscope.

<u>2.2.1.2 Phytoplankton toxicity</u>

The toxicity of the cells was investigated to see if there were any human health implications present. In particular the presence of Brevetoxins was of concern, as the closely related species *Karenia brevis* causes widespread respiratory and in some cases neurological problems through direct consumption of shellfish and through inhalation of aerosolized particles in coastal areas in the Gulf of Mexico and in New Zealand. To eliminate this problem, samples of phytoplankton were concentrated from the southwest bloom and were sent to the Cawthron Institute in New Zealand, and Mote Marine Lab in Florida. These were analysed using Liquid Chromatography – Mass Spectroscopy.

2.2.2 Assessment of benthos

2.2.2.1 Grab survey

A survey of benthic infauna was carried out in Killary Harbour, Co. Galway on August 7, 2005. The survey was carried out in an attempt to estimate the impact of the algal bloom on the infauna by comparing the data with those derived from a similar survey in August 2003.

The survey was carried out aboard the MV Connemara. A 0.01 m^2 Van Veen grab was used in the survey and each sample was washed through a 1mm sieve. In total, 4 replicate samples were taken from each of 3 locations within Killary Harbour (Table 3.1). The samples were fixed in 4% neutral buffered formalin and ultimately preserved in 70% ethanol. The fauna were identified to the lowest taxonomic group possible.

2.2.2.2 Dive surveys

During the course of the bloom a number of dive surveys were carried out to observe the extent of the impact of the bloom. These surveys were carried out by MI in Kilkieran Bay, Co. Galway on July 5 and 6, 2005 (Section 3.3.2 following). A second dive survey is described and was carried out by Dr. Rowan Holt of the Countryside Council for Wales. This was carried out in Killary Harbour on July 3, 2005. The report was published online at (http://www.glaucus.org.uk/News2005Summer.htm) and is included in this report as Appendix 4. A separate dive survey was carried out in Killary Harbour on July 20 2005 by Aqua-Fact International Services Ltd. This survey was commissioned in order to document the impact of the algal bloom in the vicinity of finfish culture cages located therein. A summary of the findings is provided in section 3.3.2.

2.2.2.3 Sediment Profile Imaging Survey of Killary Harbour

The Marine Institute commissioned Aqua-Fact International Services Ltd. to carry out a survey of Killary Harbour. In order to obtain a more accurate account of the conditions in the selected areas in Killary Harbour after the oxygen depletion process caused by the recent algal bloom in the area, Sediment Profile Imagery (SPI) was used to support the findings of the dive survey (described above).

The primary objectives of the SPI survey were:

- To analyse sediments for grain size, degree of compaction and depth of bioturbatory activity (re-working or irrigation of sediment by animals).
- To document infauna (animals living in the sediment) and epifauna (animals living on the bottom) and to infer from their presence the health of the benthos.
- To assess the overall conditions of the seafloor after the algal bloom phenomenon.

Sediment Profile Imaging (SPI) was carried out by means of a specially constructed camera that can photograph a profile of the top layer of the seafloor. Sediment Profile Imaging can remotely identify the stage of succession of the benthic fauna and its subsequent development or destruction. The physical disturbances responsible for driving succession can also be remotely detected. It is a non-destructive method, such that comparisons can be directly made with baseline and previous SPI studies. An additional downward-looking surface camera mounted on the SPI frame is used to obtain a pre-penetration photograph of the seafloor where the profile shot is to be taken. Additional information can be obtained from these surface shots-when combined with information already recorded in the profile shots this helps to build a complete picture of the seafloor being studied.

The sampling stations were located in the same area were the dive transects were laid out, that is the north shore of Killary Harbour, directly opposite the fish farm buildings, 50m, 100 m and on a control site near the Ocean Spar and PolarCirkel™ cages. In all, 7 stations were sampled on July 20 2005. One station was sampled on the north shore of Killary Harbour. Three stations were sampled on a southwest direction from the Ocean Spar cage: 50 metres, 100 metres and a control site. Finally, another three stations were sampled off the PolarCirkel cages (50 metres, 100 metres and control on a southwest direction). Sediment Profile Images and ancillary seafloor surface images were taken at each station. Four replicates were taken at each station.

2.2.3 RV Celtic Voyager Surveys

In response to reported mortalities of invertebrate and fish species throughout the Donegal Bay area in the early part of July, the MI mobilised the RV Celtic Voyager to carry out an underwater video survey of the bay on July 10 and 11, 2005.

Underwater video footage was acquired by an OE14-366 Kongsberg Simrad™ Underwater Video Camera mounted on a custom made tubular aluminium sledge. Camera and lights were powered via a 300m NC13 real time cable and the sledge was towed behind the vessel by a separate towing wire at approximately 0.5 to 1.5kn, with optimum speed of 0.8kn.

In total 11 stations were visited (see Figure 11), wherein a 10 minute transect of video images of the seabed was acquired. Upon acquisition of the video they were fully reviewed and all features noted.

An additional survey was carried out using the Celtic Voyager along the Galway coastline in the vicinity of Killary Harbour on July 12-13, 2005 (Figure 12). The objective of this survey was to establish if the bloom was dissipating. Two transects were run on the survey. On both of these transects CTD casts were performed with the addition of a Fluorometer in determining the depths of Chlorophyll maxima. Phytoplankton samples were taken from discrete depths using the rosette sampler. In addition, phytoplankton net hauls and Lund tube samples were taken to observe integrated qualitative and bulk phytoplankton samples.

2.2.4 Site Visits to Inner Donegal Bay (July 1, 2005)

In response to reports of dead invertebrate fauna being found on beaches and dredged up during fishing activities in Donegal Bay site visits were carried out by MI. The survey consisted of visits to intertidal locations along the inner parts of Donegal Bay. In total, six locations were visited. Observations were made on the sea conditions and the presence of any fauna on the shore. Details are listed in section 3.3.

3. RESULTS

3.1 Phytoplankton assessment

3.1.1 Phytoplankton abundance

Samples analysed as part of the National Phytoplankton Monitoring programme identified the onset of the bloom from the end of May to the beginning of June. This first bloom was present in the northern and northwestern part of the country and a subsequent bloom developed in the southwest (Figure 2). The monthly maximum cell counts at the locations of the sample points taken as part of this programme are given in Figures 3 (a-d)(Appendix 2). Early development of the bloom during the month of May showed highest counts observed in western County Galway (Fraochoilean 17,600 cells/l). The bloom continued to develop in this area during the month of June up to 692,714 cells/l recorded in Hawks Nest, but extended northwards into Donegal Bay where exceptionally high counts in the inner part of the bay reached over 3 million cells/l. The bloom dissipated in Donegal during August.

Meanwhile in the southwest, a second bloom had established during July where high concentrations of up to 3.7 million cells were observed in the Glenbeigh area of Dingle Bay. The bloom in the southwest was not as persistent as in the north and had significantly decreased by the start of August. Castlemaine Harbour showed the highest levels of the month at only 2000 cells/l on the 2nd August. However typical levels were between 40 and 200 cells/l along the northwest, west and southwest coasts, apart from 840cells/l found in McSwynes Bay on 22nd August. The bloom continued to dissipate through the month of August back to background levels by the end of the month (Figure 3a-d).

The extent of these blooms was also apparent from satellite images. A suite of images of 7 day composite images (Figure 4 a-e) taken from the MODIS aqua sensor revealed the presence of elevated sea surface chlorophyll levels, greater than 9 mg m^{-3} during the first half of June. This bloom was very extensive covering the western coastline north of Slyne Head, and developing as the month progressed to an area west of Donegal extending to approximately 100 km offshore. The levels were concurrent with the high cell counts observed in the area of *K. mikimotoi*. Elevated chlorophylls were also visible in Dingle Bay in August, although not as extensive and not as striking in the images due to its localised presence in a coastal area where the land effects interfere with satellite imagery.

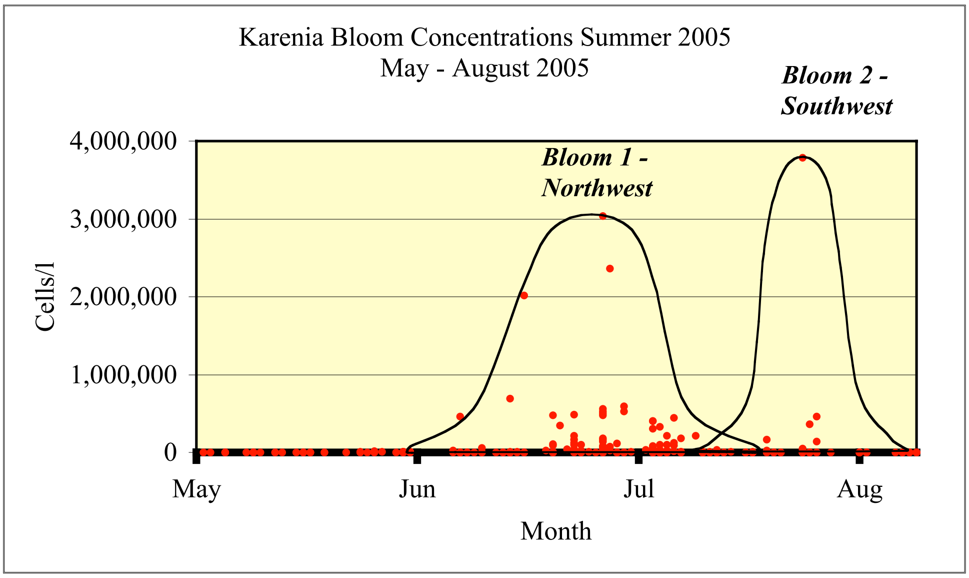
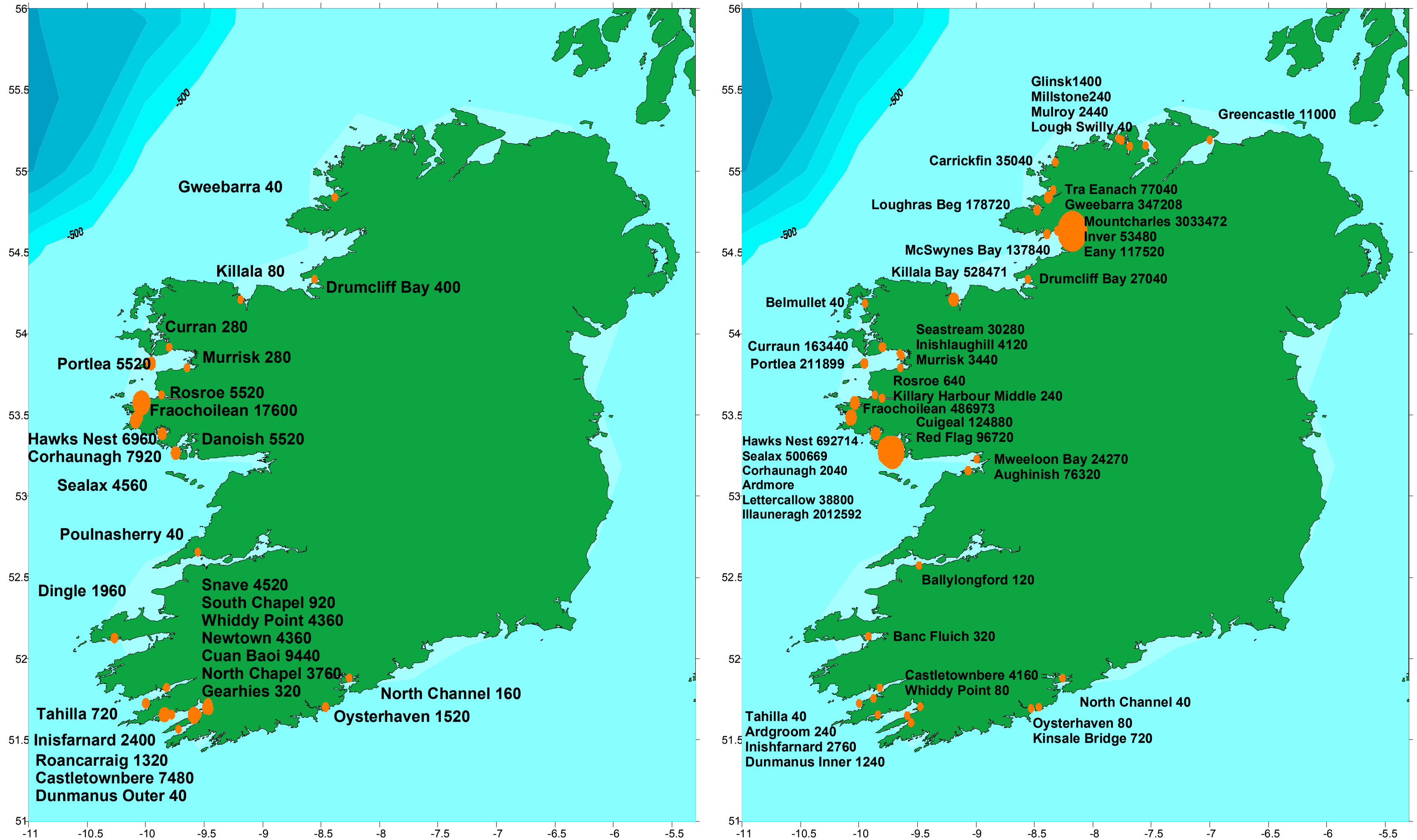
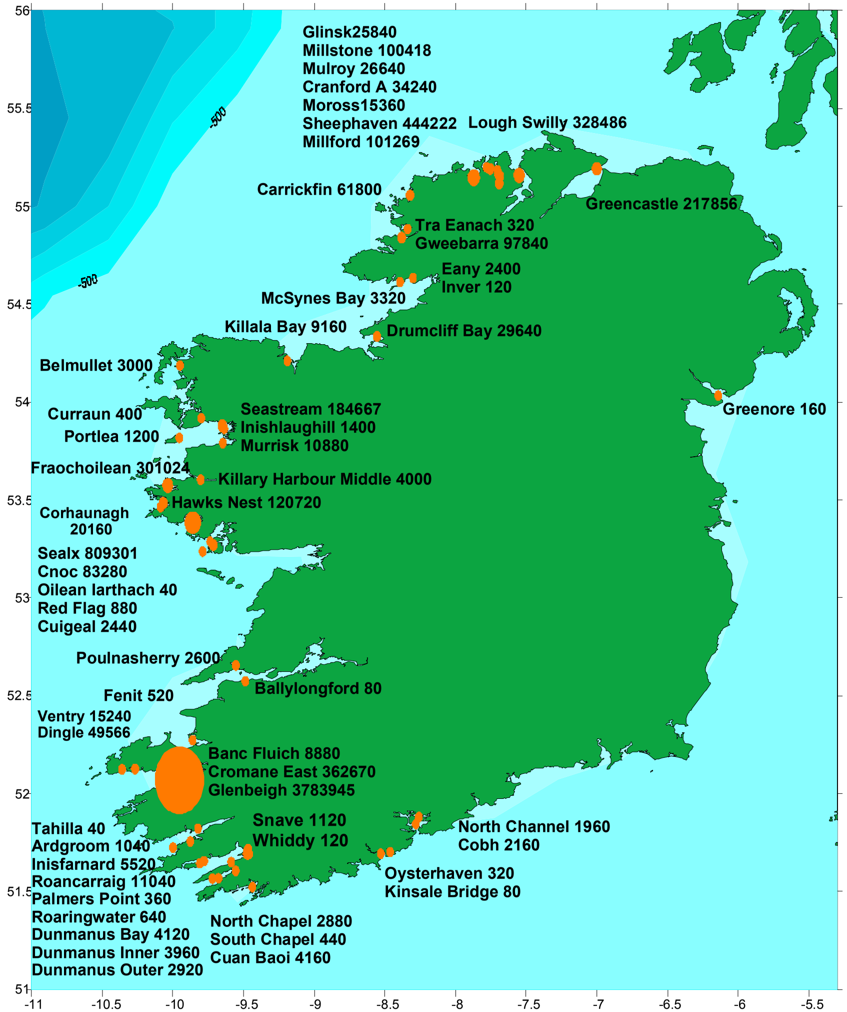


Figure 2: Cell count concentrations Summer 2005

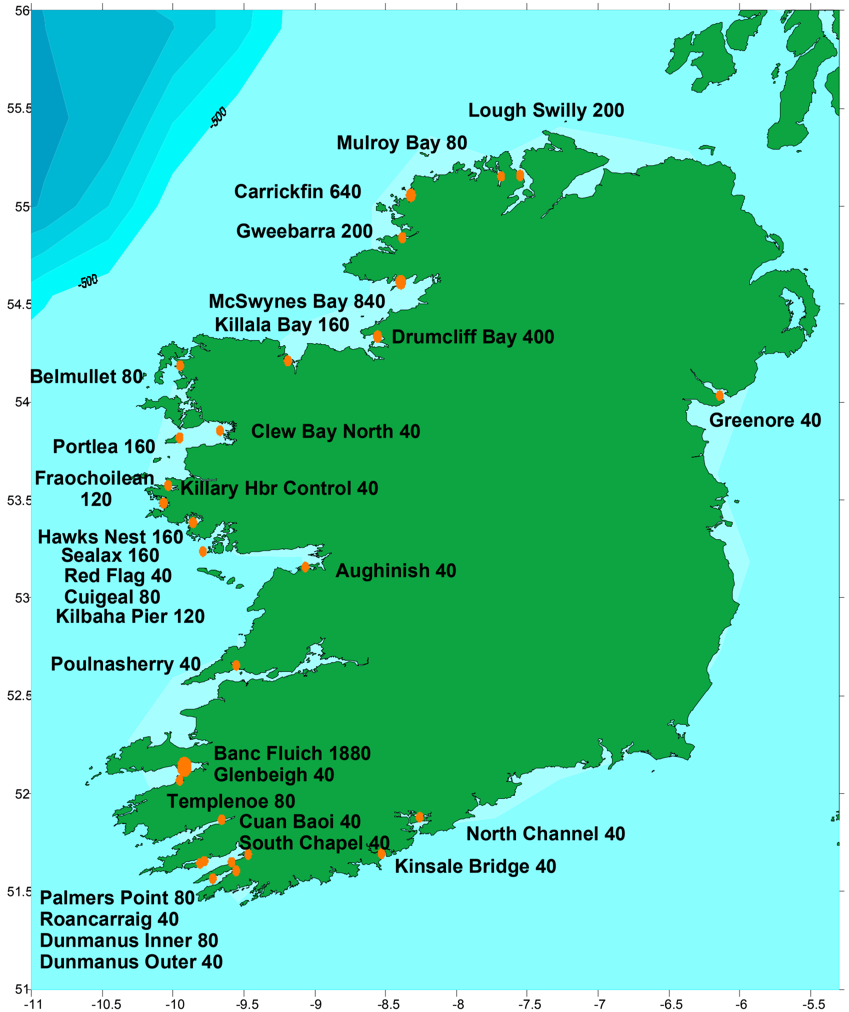


(a) May (b) June

Figures 3: (a-b). Monthly maximum cell counts observed in national monitoring programme locations (cells/litre) May /Jun



(c) July



(d) August

Figures 3 (c-d). Monthly maximum cell counts observed in national monitoring programme locations (cells/litre) Jul – August

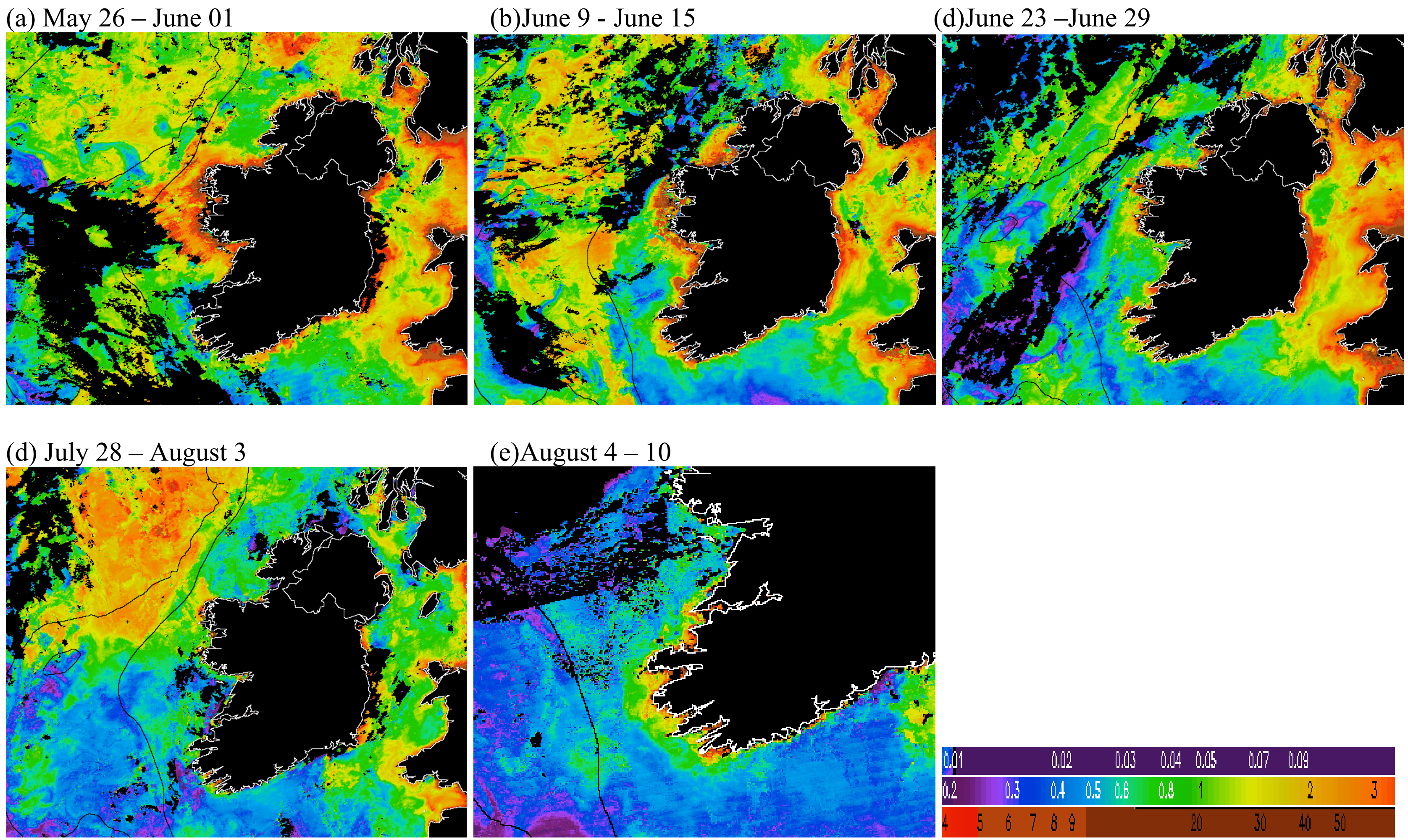


Figure 4: (a-l) Sea surface chlorophyll taken from MODIS Aqua satellite sensor.

3.1.2 Phytoplankton toxicity

The toxicity of the cells was investigated to see if there were any human health implications present. Concentrated samples were analysed by the Cawthron Institute in New Zealand, and by Mote Marine Lab in Florida. Analyses were carried out by Liquid Chromatography – Mass Spectroscopy. Both sets of results confirmed the absence of any Brevetoxins in the samples.

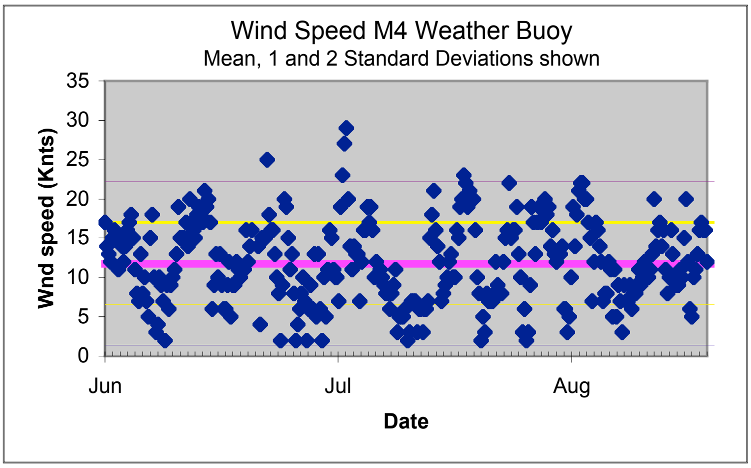
3.2 Environmental Conditions

3.2.1 Rainfall / Temperature

The weather on the west coast in Summer 2005 was noticeably different to the 30-year average as recorded by Met Eireann (Appendix 6). The month of July was generally a fine and sunny month. The north of the country was appreciably drier in July where the weather station at Malin Head reported rainfall of 24.3mm compared to the 30-year average of 71.8mm. In contrast there was considerable more rain recorded in the south where Cork Airport recorded 107.1mm compared to the 30-year average of 65.4mm. The temperature was also slightly warmer in all areas with Belmullet one degree warmer than the normal average while in Cork the temperature in July averaged 15.5°C degrees compared to 14.9°C 30 year average.

3.2.2 Wind

The wind speed and direction in the period leading up to these blooms was consistent with the normal speed and directions for this time of the year. At the M4 weather buoy (54° 40'N 09° 04'W) there was broadly a similar story (Figure 5*)*, the wind speed average was slightly less than at the South West at 11.78 knots. The higher winds seen in the start of July were also observed at M4, with speeds up to 30 knots recorded. At the M3 weather buoy (51° 13'N 10° 33'W), the wind speed averaged 12.52 knots between June and August (Figure 6).



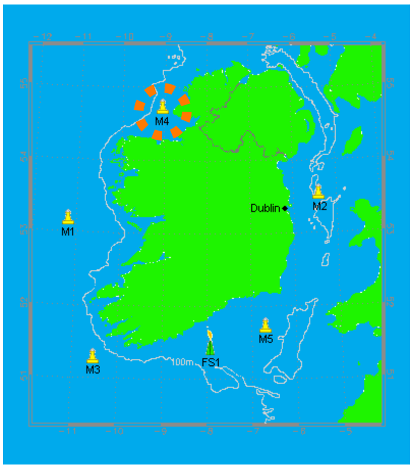


Figure 5: Wind speed from M4 Weather Buoy

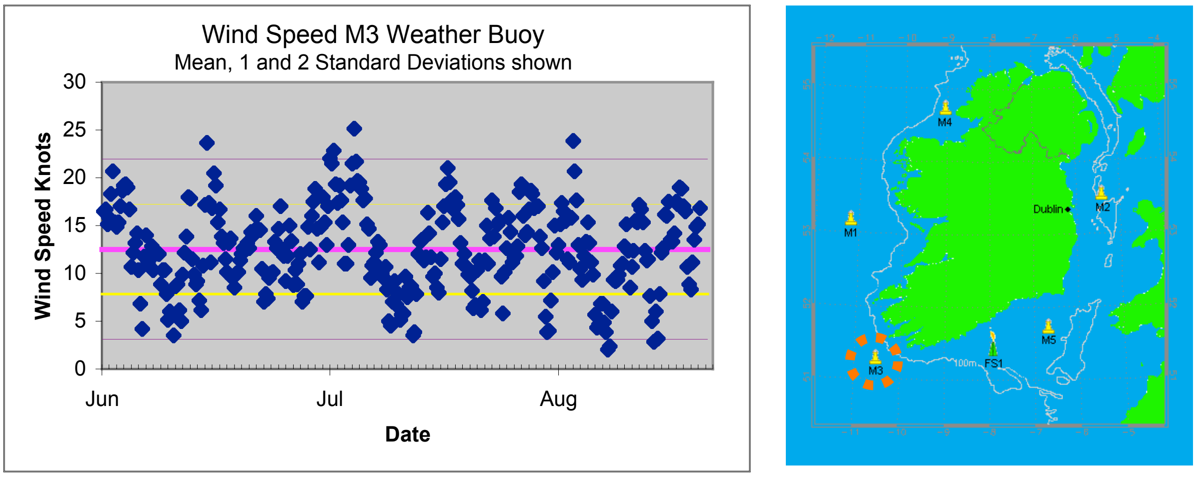


Figure 6: Wind Speed from M3 Weather Buoy

There were several periods of high winds; these were in mid June and beginning of July. These three periods exhibited a maximum 6 hourly average of less than 25 knots in each case, i.e. a strong breeze. There were no gales recorded at this buoy during this period, and the majority of wind-speed readings were between 7.8 and 17.2 knots.

The predominant wind direction, as indicated on the wind rose (Figure 7) was from the South Western quarter. During these months 67% of wind came from the North West and South West quadrants - and 41% from the South West alone. This wind direction provided ideal conditions for transporting large biomasses of this bloom into the inner parts of the western bays where it had greatest impact.

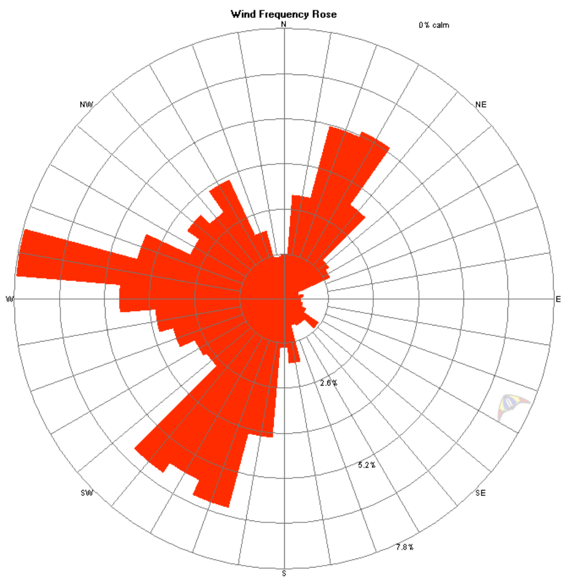


Figure 7: Wind Direction Frequency Rose from M4 Weather Buoy

In summary, the wind speeds (Figure 7) were generally low, providing low levels of turbulence and fairly calm conditions, which are ideal for the development of dinoflagellate blooms. The wind direction was predominantly onshore, which lead to the accumulation of high numbers of cells in coastal embayments and at the shores of the western seaboard.

3.2.3 Water temperature.

The Marine Institute monitors sea temperatures at 18 locations around the coast. While this service is specifically aimed at providing relevant data for the aquaculture industry, it is also useful in providing time series of water temperature for research purposes. The loggers record hourly temperatures at each site, providing comprehensive temperature records over time. Instruments are deployed from mussel lines and salmon farms. Offshore data are collected at the MI weather buoys.

In most instances there are 4 temperature sensors on each rig from near surface to near bottom in water depths ranging from 10m inshore to 100m offshore. The sensors at Killary Harbour were selected to represent general inshore seawater temperatures in summer 2005. In general, this was a warm summer with sea surface temperatures exceeding 15°C after June. In addition, some of the deeper waters in coastal embayments were also warm, as can be seen in Figure 8, which shows the temporal change in the vertical temperature profile at a site in Killary Harbour

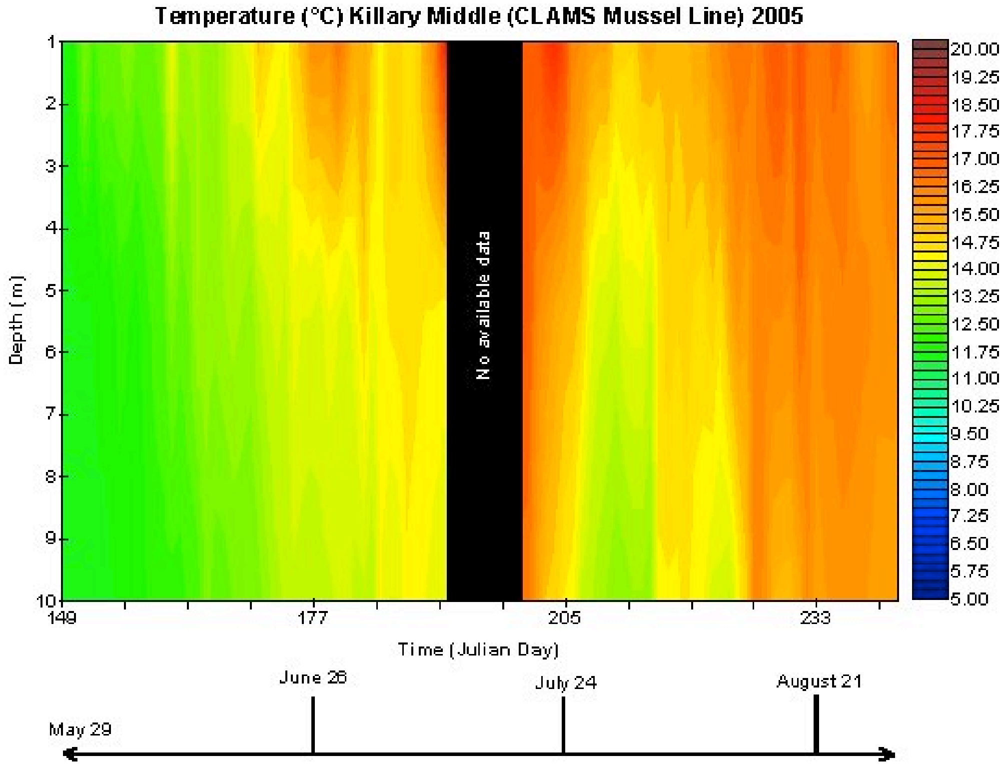


Figure 8: Temperature profile May to August 2005 Killary Harbour

3.3 Assessment of benthos

3.3.1 Grab survey

During August 2003 a survey was carried out by MI scientists along the coast of Ireland, from Clew Bay to the Boyne Estuary. This survey was carried in order to develop monitoring classification tools for benthic macro-invertebrates and phytoplankton as well as providing baseline information for monitoring under the Water Framework Directive. As part of this survey three sites within Killary Harbour were sampled for benthic macro-invertebrates (Table 3.1). As part of the investigations into the algal bloom in 2005, a post-bloom survey was carried out in August, on Killary Harbour and the three sites were re-sampled in order to assess if differences were observed in the benthic faunal constituents. The 2005 survey attempted to replicate the 2003 survey in all aspects, i.e. similar location, similar sampling device, both surveys analysed material retained on a 1mm sieve (Table 3.1; Appendix 7). However, some differences in protocols were inevitable ranging from the circumstances and individuals involved in the sorting of material to those involved in identification. However, the Marine Institute is confident that these differences did not impact materially on the results obtained and the conclusions drawn from the output of the two surveys.

The summary statistics from the two surveys are provided in Table 3.2. A number of univariate statistics, common diversity indices and a functional index were calculated from the raw data, i.e..

Univariate:	Number of taxa (S)
	Abundance (N)
Diversity:	Shannon Weiner (H')
	Margalef (d)
	(both described in Gray, 1981)
Functional:	AZTI Marine Biotic Index (AMBI) (Borja *et al*., 2000).

It is clear that while there are some similarities between the two dates there are distinct differences also. In terms of species number at each sampling location there was general consistency among the sites during 2003 (ranging from 16-18 taxa per site) while in 2005 there was a much wider range of number of taxa among the sites sampled (6-23 taxa per site). The total abundance was highly variable in both years. However, the univariate statistics were lower in 2005 when compared with 2003. For example the lower AMBI (Borja et al. 2000) values for 2003 indicate a community with a greater proportion of sensitive taxa. Both the Diversity indices (Shannon-Weiner and Margalef) both realise higher values for 2003 than 2005. Paired t-Tests were carried out on comparing individual replicates of the univariate data between the two years (Table 3.2). The statistical data realise a significant difference for the AMBI index (p=0.0002) and the Shannon-Weiner index (p=0.0251). While the Margalef index was not significant, it's value was close to significant (p= 0.0503).

The benthic infaunal communities typically observed in the benthic environment of Killary Harbour are commonly described as *Amphiura* community (*sensu* Thorsen, 1957). These communities are found in mud habitats and are typically sheltered from severe perturbations and considered stable conservative communities comprising a range of sensitive taxa. In terms of the species composition that leads to these differences it is clear that there area certain key species that were found in 2003, were not relocated at the sites during 2005. Paramount among these is the indicator species *Amphiura chiajei* (a brittlestar). Other echinoderms (*Leptosynapta inhaerens* and *Leptopentacta elongata*) were both found in the Harbour in 2003 but not in 2005. One exception to this pattern was the presence of *Magelona minuta,* a spionid polycheate, at Site 1 during 2005. Previously this species would have been considered quite sensitive (B. O'Connor, personal communication) to disturbance. However, given the large numbers observed at this site and considering the non-occurrence or reduction of other sensitive species at this site it suggests that the sensitivity of this species might have to be re-evaluated.

In summary, it is likely that the differences observed between the two years sampled are due to the removal or reduction of more sensitive taxa. In particular echinoderms, which are considered particularly sensitive megafauna, were most changed between the years.

Table 3.1: Station location, sounding depth and sampler bite depth of benthic samples from Killary Harbour during August 2003 and 2005

Location	*Device*	*Lat:*	*Long:*	*Water depth (m)*	*Sediment Description*	*Number of Reps.*
August 2003						
Killary Harbour 1	Van Veen	53 36.052	09 45.461	13.8	Mud - soft	4
Killary Harbour 2	Van Veen	53 36.108	09 47.125	14.4	Mud - soft	4
Killary Harbour 3	Van Veen	53 36.885	09 49.816	19.4	Mud - soft	4
August 2005						
Killary Harbour 1	Van Veen	53 36.087	09 45.357	7.9	Mud - soft	4
Killary Harbour 2	Van Veen	53 36.480	09 48.193	14.8	Mud - soft	4
Killary Harbour 3	Van Veen	53 36.865	09 49.608	17.2	Mud - soft	4

Table 3.2: Summary and univariate statistics of benthic infauna from Killary Harbour 2003 and 2005

Location	*No. Taxa*	*Total Abundance*	*AMBI*	*Shannon-Weiner*	*Margalef*
August 2003					
Killary Harbour 1	17	44	1.43	3.590	4.228
Killary Harbour 2	16	75	1.19	3.374	3.474
Killary Harbour 3	18	204	0.52	2.633	3.197
Mean			*1.05*	*3.199*	*3.633*
August 2005					
Killary Harbour 1	23	489	3.07	1.973	3.553
Killary Harbour 2	6	18	1.59	1.940	1.730
Killary Harbour 3	15	57	1.58	3.130	3.463
Mean			*2.08*	*2.348*	*2.915*
T-Test p value			*P=0.0002*	*P=0.0251*	*P=0.0503*

3.3.2 Dive Surveys

3.3.2.1 Kilkieran Bay Co. Galway

Dive surveys were carried out on July 5 and 6, 2005 in Kilkieran Bay, Co. Galway. Two locations were selected, representing very different habitats. The first was in the Gurraig Sound, characterised by a hard substrates (boulders) and high currents. The Second site was Rosceide Bay, which is located in northern Kilkieran Bay and comprises very fine sediments.

Gurraig Sound

A dive to 15m was carried out for 30 minutes. This site is typically characterised by a variety of large numbers of epifaunal species. It was obvious that many fauna were impacted at this site. Numerous fauna were observed, however, many were either dead or very lethargic. This was particularly true of the echinoderms *Echinus esculentus, Henricia oculata*, and *Marthasterius glacialis*). In addition, numerous anemones species were completely retracted within their column. Although it was concluded that most were still alive, this behaviour was particularly uncharacteristic and reflected some stress on the animals. There was little evidence of fish and crustaceans at the site. Along some of the boulder faces (vertical) there were large numbers of small (newly settled) *Ciona intestinalis* that appeared to be in good condition.

Rosceide Bay

A dive to 20 m was carried out for 25 minutes. This is a small embayment with a large central depression, approximately 30m deep. The site is characterised primarily by the presence of a 'population' of the Fireworks Anemone, *Pachycerianthus multiplicatus*. These animals are typically found greater than 10m. During this dive it was observed that the majority of the animals were lethargic and would not retract their tentacles or retreat into their tubes when disturbed. Some were almost completely out of their tubes. Figure 9 shows some images from Rosceide.

3.3.2.2 Killary Harbour

Dr. Rowan Holt, of Countryside Council for Wales (CCW), carried out a scuba dive in Killary Harbour, which is reported in Appendix 4. The report describes extensive mortalities of almost all benthic infaunal and epifaunal organisms. Many infaunal organisms had emerged from the sediment and were dead on the surface of the seabed. Both invertebrates and vertebrates were impacted.

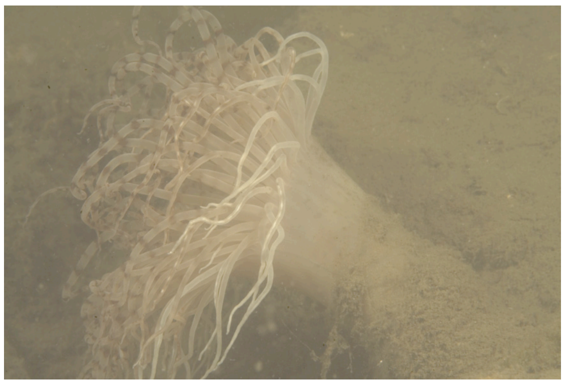


Figure 9: Images of the fireworks anemone, *Pachycerianthus multiplicatus* from Rosceide Bay, Co. Galway, indicating the lethargic nature of the specimens post-bloom (Photos courtesy of Rowan Holt).

3.3.2.3 Killary Harbour – Aqua-Fact International Services Ltd.
A report was submitted to MI by Aqua-Fact describing the results of the dive survey in Killary Harbour (Aqua-Fact, 2005). In summary, photographs taken beneath the finfish cages revealed conditions typical of such locations, i.e. scattered feed pellets with bacterial mats throughout. However, the survey also described large numbers of dead organisms (starfish and anemones) observed on the seabed in the vicinity and away from the finfish cages. Live organisms included some fish (Gobies) and crabs. At depths greater than 17m all fauna were heavily impacted, whereas at lesser depth some live fauna were observed. At six metres and shallower there were very little signs of faunal impact.

3.3.3 Sediment Profile Imaging (SPI) Survey of Killary Harbour
A report was submitted to the Marine Institute by Aqua-Fact describing the results of the SPI survey in Killary Harbour (Aqua-Fact 2005). A number of parameters were estimated using the SPI technology. Of particular interest were the depth of the Apparent Redox Potential Discontinuity (ARPD) and the Infaunal successional stage. The ARPD demonstrated apparent inverse redox potential with the surface layer of anoxic silt covering oxic sediment. This demonstrates that there had been little bioturbation at the sediment surface and that oxygen levels had been depressed at the interface. The infaunal successional stage provides an overview on the level of infaunal community development. No infaunal organisms were observed during the survey, thus indicating a highly stressed environment.

3.4. Celtic Voyager Surveys

3.4.1 Survey of Donegal Bay using underwater Video (July 10-11, 2005)
In response to reported mortalities of invertebrate and fish species throughout the Donegal Bay area in the early part of July, the MI mobilised the RV Celtic Voyager to carry out an underwater video survey of the bay on July 10 and 11, 2005. In total 11 stations were visited (Figure 11), wherein a 10 minute transect of video images of the seabed was acquired. Locations of the transects can be seen in Figure 10.The specific reports from each of the transects can be seen in Appendix 8.

Transect 1:
This transect was taken through the existing dredge spoil disposal site in Donegal Bay in the middle of Donegal Bay (Figure 11). The sediment consisted primarily of fine materials composed predominantly of silt. The site was characterised by some burrows of the prawn, *Nephrops norvegicus* and numerous feeding mounds possibly of the lugworm, *Arenicola marina*. Tracks (perhaps from the opistobranch, *Philine aperta*) were also evident. Dead cockles, *Parvicardium* sp were witnessed on the surface along with heart urchins (*Echinocardium* sp. or *Brysospis* sp.). The cockles were easily identified by the prominent food extended through the gaping shell, which was lying on the dorsal end.

Transect 2:
This site was due south of Rathlin O'Beirne Island and west of Inishmurray Island. The seabed at this location was composed of fine silt and mud. The only commentary on the seabed was that there appeared to be a light flocculent material on the surface that was easily disturbed by the action of the sled.

Transect 3:
This site was due north of transect 2. Fine silty mud characterised the seabed at this site. There were numerous small fish swimming near the bottom throughout this tow. In addition, numerous burrows were observed.

Transect 4:
This site was due south of Rathlin O'Beirne Island. The seabed at this site was composed primarily of fine silts and mud. There appeared to be heavy bioturbation throughout as witness by the extensive mounding of the sediment. There was a very heavy and dark layer of flocculent material on the sediment surface. It appeared as long mucus strings that were easily disturbed and resuspended in the water. Visibility was poor as a consequence. The fine material draped over the sediment and appeared to block off burrows and tube entrances.

Transect 5:
This site was located southwest of St. John's Point. Fine sediment dominated this site. The camera cable had scrapped away the surface layer of sediment and it was observed that hypoxic and anoxic sediments were located just below the sediment. The transect was characterised by numerous dead cockles and urchins on the surface throughout, as well as dead worms towards the end of the transect.

Transect 6:
This site was located southwest of Inver Bay and east of St. John's Point. The image quality was very good. The site was dominated by silt and muds and dead animals were observed. There were *Nephrops* sp burrows observed and mucous strings similar to transect 4 also. There were heavily decomposed starfish observed on the surface.

Transect 7:
This site was in McSwynes Bay. The bottom consisted primarily of mud. The transect was primarily characterised by a large number of decomposing urchins throughout with much flocculent material on the seabed and in the water column. Dead cockles were also observed. Some burrows (*Nephrops* and *Calianassa sp*) were observed and live prawns were observed.

Transect 8:
This site was located west of Bundoran, Co. Donegal. The seabed comprised mostly of fine sand. Distinct sand waves were evident at this station. There appeared loose material on the surface that comprised of old urchin tests. Loose organic material was gathered in the troughs of the sand waves.

Transect 9:
This site was located west of Mullaghmore Head. The seabed at this site was dominated by fine sands. There was shell debris evident throughout the tow. Numerous crabs and hermit crabs were visible throughout. There were small amounts of flocculent material on the sediment surface.

Transect 10:
This site was located east of Inismurray Island. The video tow crossed a variety of habitat types ranging from mixed sediments to cobble to finer sand towards the end of the tow. Numerous small fishes (indeterminate) were observed throughout the two. No dead animals were observed.

Transect 11:
This site was located west of Drumcliff Bay and south of Rathlin O'Beirne Island. The substrate here was mixed and described by a transition from large sand waves comprising cobbles with finer material in the troughs to fine sand to large cobble waves again. There was no evidence of dead material on the seabed during this tow.

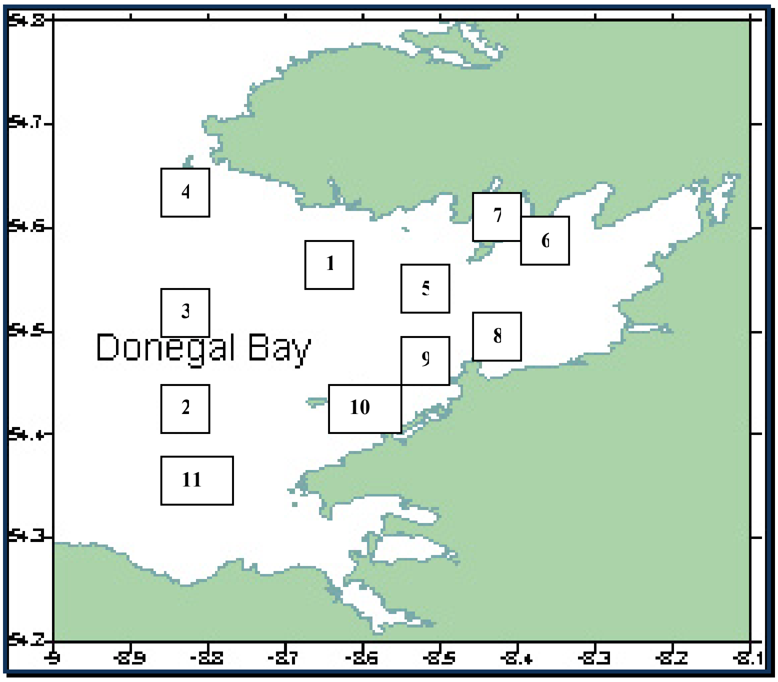


Figure 11: Locations of underwater video sample transect from Donegal Bay.

3.4.2 Celtic Voyager Survey of Galway Coast, (12- 13 July)

The Donegal Bay survey was extended on the 12th & 13th July and focused on West & South of Killary. Two transects were undertaken (Figure 12), a 15mile stretch West from the Rosroe finfish site along which 6 stations were sampled, with a 7th station in Little Killary. The second transect from North to South from Cleggan to Slyne Head was also undertaken with a series of 5 stations sampled. The objective of this survey was to establish if the bloom was dissipating, as there were still some reported mortalities of caged finfish in the area. The two transects were chosen to give coverage of the presence of blooms outside the mouth of Killary and what was to the south.

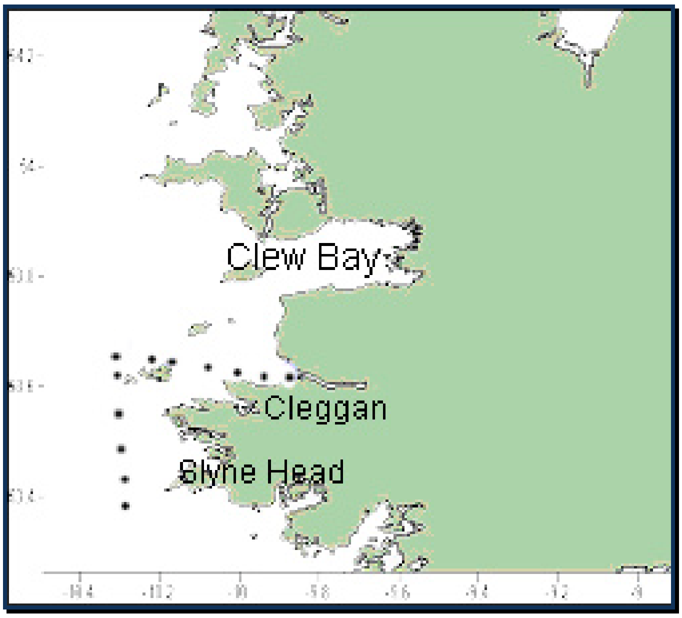


Figure 12: Locations of CTD and Phytoplankton samples

On both of these transects CTD casts were carried out. A fluorometer was added to the cage to determine the depths of chlorophyll maxima. Phytoplankton samples were taken from discrete depths using the rosette sampler. In addition, phytoplankton net hauls and Lund tube samples were taken to observe integrated qualitative and bulk phytoplankton samples. Microscopic observations of these samples showed that very low counts of *Karenia mikimotoi* were present. One of the main dominant organisms in these samples was *Dinophysis spp.* (a diarhettic shellfish toxin producer) in addition to other dinoflagellates including *Scrippsiella, Prorcentrum & Ceratium spp.* There was little evidence of any *Karenia* bloom along these transects with subsurface chlorophyll converted fluorescent maxima only reaching approx 2.5 mg.m^{-3} at depths between 5 and 10 metres.

3.5 Specific Investigations

3.5.1 Site Visits to Inner Donegal Bay (July 1, 2005)

Site visits were carried out by Marine Institute scientists in response to reports of dead invertebrate fauna being found on beaches and dredged up during fishing activities in Donegal Bay. The survey consisted of visits to intertidal location along the inner parts of Donegal Bay. In total, six locations were visited and observations were made on the sea conditions and the presence of any fauna on the shore. Site descriptions are given below.

3.5.1.1 Mullaghmore, Co. Sligo:

Dead heart urchins (*Echinocardium chordatum*) were observed in the harbour and in large numbers high on the shore of the adjoining beach (Figure 13). The line of dead animals extended for much of the beach. The majority of the dead animals consisted of just naked tests; however, a proportion (10% approx) had spines still attached. One individual near the low-water-mark was freshly dead and had both spines and animal tissue internally. In addition, to the heart urchins other dead species observed on the shoreline were crabs (*Carcinus maenus, Portunus* sp.). Some others species found were *Donax vittatus, Mya arenaria* and *Ensis* sp. However these specimens were not found in any appreciable numbers and did not appear to be recently dead.

3.5.1.2 *Rossnowlagh, Co. Donegal:*

High on the shore was a line of dead wedge shells (*Donax vittatus*). They were found in relatively high numbers in a 1-2 metre band. Of note was that 95% of the shells were articulated indicating that they were recently killed and most likely all killed at the same time.

3.5.1.3 *St-Ernans Island, Co. Donegal*:

This area is characterised by large expanses of intertidal sand flats. There were no visible mortalities on the shore. However, there were no lugworm casts visible either, as might be expected.

3.5.1.4 *Mount Charles Strand, Co. Donegal:*

The shore was characterised by the presence of large numbers, at the surface, of dead lugworms *Arenicola marina*, cockles-*Parvicardium ovale*, *Macoma balthica*, *Scrobicularia plana, Venerupis pullastra* with 2 shore crabs – *Carcinus maenus*. Lugworms and cockles were in various states of decay and mortality. Some were heavily decomposed, while others were still alive but obviously distressed.

3.5.1.5 *Bruckless Harbour, Co. Donegal:*

There was no evidence of dead animals on the seashore. There was a distinct red tinge on the water and large amount of surfactant along the shoreline.

3.5.1.6 *Killybegs Harbour, Co. Donegal:*

As with Bruckless Harbour there was no incidence of dead animals observed on the shore. However, there was some evidence of a degrading algal bloom along the shore.

Photos of the mortalities described above are shown in the following Figure 13.

Figure 13: Photomontage of the shore investigations along Donegal Bay detailing large numbers of dead heart urchins, dead cockles and lugworms and discoloured water and break-up of the bloom along the shoreline.

4. DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS:

4.1 Summary discussion

Blooms of *Karenia mikimotoi* are mostly unpredictable events, occurring intermittently in Irish coastal waters. The life cycle of *Karenia mikimotoi* is not fully elucidated and the cyst stages (if any) have not been described. It is most likely that the species over-winters as a motile cell in low numbers, awaiting a return to favourable conditions to bloom. These conditions do not occur every year and the species has variable success in achieving dominance among the phytoplankton community. On the occasions it does achieve dominance, it can form dense and extensive blooms, such as were observed to the west of Ireland in Summer 2005.

This harmful algal event was more extensive and persistent than previously reported *Karenia* blooms in Irish waters. The scale of the benthic mortalities was also more severe than in previous blooms.

Coincident with the bloom were reports of mortalities of vertebrates (fish) and invertebrate organisms along the western seaboard. Mortalities were reported from Dingle Bay (images in Appendix 3) to Loughros Beg (Co. Donegal). The habitats impacted ranged from muddy environments (McSwynes Bay, Co. Donegal and Killary Harbour Co. Galway), sandy habitats (Co. Sligo coastline) to rocky substrates (Gurraig Sound, Kilkieran Bay, Co. Galway). This broad range of habitats impacted and the geographic spread suggest a widespread water borne causative agent.

All of the mortality reports described large megafauna (> 4mm). These observations were validated by the follow-up grab survey of Killary Harbour, which included a quantitative analysis of macrofauna (>1mm). Results are reported in section 3.1, above). Given that smaller macrofauna were found alive in the Killary survey, it would appear that large macrofauna (echinoderms, cockles) were worst affected. Potential explanations for the observed mortalities include:

- That the organisms were particularly sensitive to perturbations; for example, mortalities were reported in echinoderms from Donegal to Galway. Echinoderms are generally considered sensitive to pressures in the marine environment, for example, physical disturbance and organic loading (Budd, 2002; Hill, 2000).
- Megafauna have greater oxygen demands than smaller animals due to their size. In addition, the timing of feeding activity may have coincided with periods of low oxygen in the water. (This is speculative, as information on the timing of feeding in echinoderms is scant.)
- Mortalities of cultured cod in Bertrabui Bay, Co. Galway consisted mainly of larger animals, e.g. finfish (cod). This may be due to the more aggressive feeding behaviour of the larger animals, leading to higher oxygen demands during feeding (Paul Casburn, Taidge Mara Teo, personal communication). Under normal circumstances this would not appear to pose a problem, but under the low oxygen conditions experienced during the bloom, the increased demand resulting from feeding could have resulted in mortalities.
- Aquaculture animals may have been compromised as a consequence of their culture and life stage; for example, anecdotal information suggests that substantial mortalities in oysters were in those that were being ‘hardened’ i.e. moved in to the intertidal zone to facilitate greater closing of shells and longer shelf life upon transport to market. Mortalities were also recorded in seed animals that were put out in the intertidal zone during 2005 (Appendix 9). However, it should be noted that no mortalities were noted in seed oysters in the Castlemaine Harbour where high mortalities were recorded in adult oysters.

The second bloom began to dissipate by the start of August. Although the break up of the bloom is usually associated with a change in weather conditions, it is not a definite marker to signify the end of the bloom. As recorded by Evans (1975) gales only served to intensify and extend its distribution in waters of the North coast of Wales. His paper suggests that the possibility that if heavy precipitation (with associated land drainage, low salinities and high nutrients) occurs simultaneously with gales, then the gales can actually aggravate the situation, once the organism has gained a good 'hold' on the water mass. In the case of the 2005 blooms, there were no significant changes in the weather to affect their break ups. Most likely the natural succession to a different phytoplankton community was affected by a change in nutrient and temperature conditions.

Records of long-term data sets indicate the blooms of phytoplankton are becoming more common and persistent. Continuous Plankton Recorder (CPR) data have also shown that many of the variables influencing phytoplankton standing crop are governed in by the prevailing weather. It is believed that phytoplankton changes may well be a consequence of the general deterioration, since 1940, of North Atlantic weather (Reid, 1977).

Changes in phytoplankton may be attributed to an amelioration of climate in recent decades. In several areas it has been reported that phytoplankton season length and abundance seem to have increased. In the more than 50 years that the CPRsurvey has operated in the northeast Atlantic and North Sea, large changes have been observed in the abundance and distribution of some plankton taxa (Reid, 1998). The long-term trend in the abundance of the plankton is believed to be responding to hydroclimatic variability.

4.2 Conclusions

The marine mortalities observed in coastal fauna, along the west coast in 2005 were undoubtedly associated with the presence of this exceptional bloom of *Karenia mikimotoi*. This conclusion is drawn on the basis that the specific organisms impacted were benthic megafauna and fish species previously reported as sensitive to this species. Furthermore, the patterns observed were consistent with those observed as a consequence of previous *Karenia* sp. blooms.

In addition to the susceptibility of some organisms to mortality a number of mechanisms of mortality have been suggested:

- Evidence of an ichtyotoxic compound associated with *K.mikimotoi* has recently been reported (Satake *et al.,* 2002 & 2005.). Although the mechanism of toxicity of *K.mikimotoi* is poorly understood, the toxins Gymnocin A and Gymnocin B have been suggested as a potential cause of mortality in marine vertebrates and invertebrates.
- Deoxygenation has usually been suggested as effecting mortalities of caged fish both in Ireland (Parker, 1980) and in Norway (Tangen,1977). Tangen (1977) considered two possible causes of de-oxygenation, either oxygen depletion during hours of darkness due to dinoflagellate respiration or, alternatively, aerobic bacterial breakdown during decomposition of dinoflagellate cells. (However, in previous observations by Pybus (Pybus, 1980) extremely high oxygen concentrations were recorded during a *Karenia* bloom and associated fish mortalities, therefore casting doubt on the role of oxygen depletion as the principal cause of these mortalities. It may, however, contribute as a secondary indirect cause, adding to stresses exerted by other features of the bloom.)
- Diurnal fluctuations in dissolved oxygen concentrations may induce mortalities. Oxygen super-saturation during daylight hours followed by oxygen depletion during the late hours of darkness (oxygen sag) may also result in mortalities. The EPA recorded DO supersaturation of 164% in waters along Mullaghmore Strand, Co. Sligo, on the 20th June 2005. Hundreds of dead heart urchins (*Echinocardium chordatum*) washed up on the strand were observed on the same day. The impact of oxygen fluctuation may be particularly significant if the organisms

are compromised either as a consequence of their conditions (high-density culture) or their location (high in the intertidal zone or the stage of culture (newly planted seed oysters or clams). Other possible causes including irritation and clogging of gill membranes have been suggested (Parker 1980) as inducing mortalities in caged fish.

The events described above have resulted in a substantial elimination of certain benthic communities along the western seaboard. The Marine Institute carried out a major survey of conditions and impacts associated with the event, and are committed to monitoring the recovery of the impacted areas.

4.3 Recommendations

In summary, recommendations for minimisation of future impact associated with harmful algal blooms include:

- The present state of technology therefore has not as yet provided a suitable solution to preventing red tides, and the best that can be attempted is to prevent mortalities on a small local scale. In caged fish farms it has been sometimes useful to provide aeration to the cages during periods when the depletion of oxygen is causing stress to the fish. However, this may sometimes exacerbate the situation if there is a deep layer of low oxygen water, which may be brought to the surface by aeration. It is therefore important to examine the oxygen profile of the water column before deciding to aerate fish cages.
- The toxins of *Karenia mikimotoi* in Irish water have not been studied, but it is presumed that the Irish strain may have the toxin profile identified by Satake *et al.* The severe and rapid mortality observed by *Karenia mikimotoi* in several previous events in Ireland suggest that it is not simply due to low oxygen levels. To further understand the reasons for these mortalities it is important to carry out a toxicological and characterisation of the toxins involved.
- Use of technology such as screens and bubble curtains might help protect caged fish from such high densities of algae. This technology should be further investigated in the Irish context.
- Reducing fish farm husbandry activities may limit stress to stock. For instance, reducing stocking densities of caged fish would result in less stress for the animals in low oxygen conditions, as the overall demand for oxygen would be lower. In addition, stressed fish are more susceptible to secondary infections, and this could be minimised.
- Mitigation strategies used in other countries (China, Korea, Japan) to dissipate dense blooms of red tide organisms include the dispersal of large quantities of clay into the sea to flocculate the algae, resulting in it sinking to the seabed (Hepeng, 2004). However, the method is too costly and technically difficult to prevent and terminate massive red tides. This is only suitable to break up blooms in small sheltered embayments, and usually used in these countries to prevent a bloom causing mortalities in caged fish farms. This solution however, may have other more severe and as yet unknown ecological consequences and as such, is not a suitable solution (Archambault *et al*, 2003).
- The public information strategy used appeared to function very effectively. In future the same model of public information provision should be adopted as was used on this occasion. It led to a rapid turnaround of accurate information, which is essential in the management of public interest in such events.

The occurrence of more frequent blooms such as the Karenia bloom of 2005 may be part of the effects of climate change on plankton at ocean-wide scales (Reid, 1998). Research is recommended into the area of potential effects of climate change on phytoplankton communities in order to predict, to mitigate, to minimise and potentially to prevent the harmful effects associated with such algal blooms.

REFERENCES

Archambault, M., Grant, J., & Bricelj, M. (2003). Removal efficiency of the dinoflagellate *Heterocapsa triquetra* by phosphatic clay, and implications for the mitigation of harmful algal blooms *Mar. Ecol. Prog. Ser.* Vol. **253**: 97–109, Published May 15.

Braarud, T and Heimdal, B.R. (1970). Brown Water on the Norwegian coast in Autumn (1966). *Nytt Magasin for botanik* **17**:91-97

Ballentine, D. and Smith, F.M. (1973). Observations on blooms of the dinoflagellate *Gyrodinium aureolum* Hulbert in the River Conwy and its occurrence along the North Wales Coast. *British Phycological Journal.* **8**: 233 – 238

Borja A., Franco J. and Perez V, 2000 A marine biotic index to establish the ecological quality of soft-bottom benthos within European estuarine and coastal environments. Marine Pollution Bulletin, **40**, 1100-1114

Budd, G.C., 2002. *Amphiura chiajei*. A brittlestar. *Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme* [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 25/08/2005]. Available from: <http://www.marlin.ac.uk/species/Amphiurachiajei.htm>

Chang, F.H., Chiswell, S.M. and Uddstrom, M.J. 2001. Occurrence and distribution of *Karenia brevisulcata* (Dinophycaea) during the 1998 summer toxic outbreaks on the central east coast of New Zealand. *Phycologia* **40**: 215-222

Edwards, A., Jones K., Graham J.M., Griffiths C.R., MacDougall N., Patching J., Richard M. and Raine R. (1996) Transient coastal upwelling and watercirculation in Bantry Bay, a ria on the SW coast of Ireland. *Estuarine , Coastal and Shelf Science* **42**: 213-230

Evans D. (1975) The occurrence of *Gyrodinium aureolum* in the eastern Irish Sea, 1975. *Lancashire and Western Irish Sea Fisheries Joint Committee Scientific report* 85- 89

Florida Fish and Wildlife Commission. 2005. Offshore Red Tide-Associated Mortalities and FWRI Event Response. (Updated August 17, 2005). http://www.floridamarine.org/features/view_article.asp?id=25276

Gray, J.S., 1981. The Ecology of Marine Sediments: an introduction to the structure and function of marine communities. Cambridge University Press. 187 pp.

Hepeng, J. SciDev.net Science and development Network (Updated 5 July 2004) http://www.scidev.net/News/index.cfm?fuseaction=readNews&itemid=1470&language=1

Hickel, W., Hagmeir, E., and Drebes, G. (1971). *Gymnodinium* blooms in the Helgoland Bight (North Sae) during August 1968 *Helgolander Wiss Meeresuntern.* 22, 401-416

Hill, J.M., 2000. *Echinocardium cordatum*. Sea potato. *Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme* [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 25/08/2005]. Available from: http://www.marlin.ac.uk/species/Echinocardiumcordatum.htm

Holligan PM. 1979. Dinoflagellate blooms associated with tidal fronts around the British Isles. In: Taylor, DL, Seliger, HH, Lewis, CM (eds). Toxic dinoflagellate blooms. Elsevier.

Horstman, D.A. (1980). Reported red-water outbreaks and their effects on fauna of the west and south coasts of South Africa, 1959-1980. *Fish. Bull. S. Afr.* **15**: 71-88.

Hulbert, E.M. (1957). The taxonomy of unarmoured Dinophyceae of Shallow embayments of Cape Cod, Massachusetts. *Biol. Bull., Woods Hole,* ***112**, 196-229*

Jones K. J. Gowan R.J. and Tett, P (1984) Water column structure and phytoplankton distribution in the Sound of Jura, Scotland. *Journal of experimental marine biology and ecology* **78**: 269 - 289

Ottway, B., Parker, M., McGrath, D. and Crowley M. (1979). Observations on a bloom of *Gyrodinium aureolum* Hulbert on the south coast of Ireland 1976, associated with mortalities of littoral and sub-littoral organisms. *Ir. Fish. Invest,* Series B, No.**18**; 3-9

O'Boyle S.M.B. (2002) Summer flora of shelf waters around western Ireland: Interactions between physical dynamics and phytoplankton and consequences for potentially harmful algal events. PhD Thesis; National University of Ireland, Galway.

Lu, S and Hodgkiss, I. 2004. Harmful Algal bloom causative collected from Hong Kong waters. *Hydrobiologia* **512**: 231-238.

Parker M, Dunne T., and McArdle J.(1982) exceptional blooms in Irish coastal waters. ICES CM 1982/L:44

Pybus, C. (1980). Observations on a *Gyrodinium aureolum* (Dinophyta) bloom off the south coast of Ireland. *J. mar.biol Ass. U.K.,* **60**: 661-674

Raine, R., O'Mahony, J., Mc Mahon,T., and Roden, C. (1990) Hydrography and Phytoplankton of waters off the south coast of Ireland. *Estuarine, Coastal and Shelf Sci.* **30**: 579-592

Raine, R., Joyce, B., Patching J., Jones, K. and Richard, J. (1993) Upwelling around the southwest Irish coast: Near Surface dynamics and Blooms of the dinoflagellate *Gyrodinium* cf. *aureolum* (Hulbert). *ICES CM* 1993/L:17

Raine, R. and Mc Mahon,T. (1998) Physical dynamics on the continental shelf off southwestern Ireland and their influence on coastal phytoplankton blooms. *Continental Shelf Research,* ***18**: 883 - 914*

Reid, P. C. (1977). Continuous Plankton Records: changes in the composition and abundance of the phytoplankton of the north-eastern Atlantic ocean and North Sea, 1958-1974. *Marine Biology* **40(4)**: 337-339.

Reid, P. C., B. Planque and M. Edwards (1998). Is observed variability in the long-term results of the Continuous Plankton Recorder survey a response to climate change? *Fisheries Oceanography* **7(3-4)**: 282-288.

Roden, C.M., Ryan, T, and Lennon H.J. (1980). Observations on the 1978 red tide in Roaringwater Bay, Co. Cork. *J. Sherkin Island,* **1**: 105 - 118

Roden, C.M., Lennon H.J. Mooney, E., Leahy, P. and Lart, W. (1981) Red tides, water stratification and Phytoplankton species succession around Sherkin Island, south west Ireland, in 1979. *J. Sherkin Island,* **1**: 50 - 68

Satake M., Shoji M., Oshima Y., Naoki H., Fujita T. and Yasumoto T. (2002) Gymnocin-A, a cytotoxic polyether from the notorious red tide dinoflagellate, Gymnodinium mikimotoi Tetrahedron Letters **43**: 5829–5832

Satake M., Tanaka Y., Ishikura Y., Oshima Y., Naoki H. and Yasumoto T. (2005) Gymnocin-B with the largest contiguous polyether rings from the red tide dinoflagellate, *Karenia* (formerly *Gymnodinium*) *mikimotoi* ; Tetrahedron Letters **46**; 3537–3540

Smith, G.B. 1975. The 1971 red tide and its impact on certain reef communities in the mid-eastern Gulf of Mexico. *Environmental Letters* **9(2)**:141–152.

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

Tangen K. and Bjornland T. (1981) Observationson pigments and morphology of *Gyrodinium aureolum* Hulbert, a marine dinoflagellate containing 19'-hexanoyloxyfucoxanthin as the main carotenoid. J.Plankton Res., **3**: 389-401

Thorson, G. (1957) Bottom communities (Sublittoral or Shallow shelf). *Mem. Geol. Soc. Am*. Volume **1 (67**), pp 461-534.

Vagn Hansen, Albrechtsen, and Frandsen (1969). *Danmarks Fiskeriog Havundersøgelser* Nr 29.

Appendix 1: Sequence of events

Location	*Reported Mortalities*	*Source*	*MI follow-up*
Donegal	Dead invertebrates on shoreline	DCMNR Fishery Officer	Visit to 6 shore site July 1 (MI)
	Dead invertebrates in trawls	*DCMNR Fishery Officer*	C. Voyager Survey of Donegal Bay (July 10-11; MI)
	Dead Aquaculture Species (growout)	*BIM Development officer*	Compiled mortality reports through BIM officer (MI) (Appendix 9)
Mayo	Dead birds on Shore	*EPA Castlebar*	Requested sample of liver for potential biotoxin analysis and gut for contents analysis (MI)
	Dead Aquaculture Species	*BIM Development officer*	MI
Galway	Dead Aquaculture Species (growout)	*BIM Development officer*	Compiled mortality reports through BIM officer (MI) (Appendix 9)
	Dead Aquaculture Species (hatchery/nursery)	*BIM Development officer*	Compiled mortality reports through BIM officer (Appendix 9)
	Dead invertebrates at various subtidal locations	*Recreational and Scientific Divers*	Dives in Kilkieran to verify (MI)/Grab survey in Killary Harbour to verify (MI)/ Commissioned Aqua-Fact diver and SPI survey in Killary Harbour near fish farm (MI)/ C. Voyager survey in Slyne Head to Killary Harbour area (July 13-14)
Kerry	Dead invertebrates on shoreline	*EPA*	Received images from EPA; no site visits
	Dead fish sub-tidally	*DCMNR Fishery officer*	Received verbal report and images; no site visits
	Dead Aquaculture Species	*BIM Development officer*	Compiled mortality reports through BIM officer (MI) (Appendix 9)

Appendix 2: *Karenia mikimotoi* counts summer 2005

Sample date	Location	Cell Count per litre	Sampling method	Latitude (N)	Longitude (W)
02/05/2005	Snave	40	Lund Tube	51.71806	-9.46667
03/05/2005	Cuan Baoi	80	Lund Tube	51.65131	-9.58638
05/05/2005	Dingle	1960	Integrated	52.12694	-10.26667
05/05/2005	Fraochoilean	1480	Lund Tube	53.575	-10.03503
05/05/2005	Killala Bay	80	Surface Sample	54.21083	-9.18972
05/05/2005	Sealax	480	Lund Tube		
08/05/2005	Castletownbere	120	Lund Tube	51.65556	-9.83806
09/05/2005	Newtown	440	Lund Tube	51.69278	-9.45972
09/05/2005	North Chapel	560	Lund Tube	51.69361	-9.47833
09/05/2005	Sealax	960	Lund Tube		
09/05/2005	Snave	280	Lund Tube	51.71806	-9.46667
09/05/2005	South Chapel	440	Lund Tube	51.69	-9.46972
09/05/2005	Whiddy Point	320	Lund Tube	51.70556	-9.47556
10/05/2005	Cuan Baoi	320	Lund Tube	51.65131	-9.58638
12/05/2005	Clare Island-Portlea	40	Lund Tube	53.81816	-9.95336
12/05/2005	Curraun	280	Lund Tube	53.91796	-9.79876
13/05/2005	Danoish	360	Lund Tube	53.26618	-9.74297
15/05/2005	Castletownbere	40	Lund Tube	51.65556	-9.83806
16/05/2005	Murrisk	280	Lund Tube	53.79111	-9.64611
16/05/2005	Newtown	80	Lund Tube	51.69278	-9.45972
16/05/2005	Snave	120	Lund Tube	51.71806	-9.46667
16/05/2005	Whiddy Point	280	Lund Tube	51.70556	-9.47556
17/05/2005	Gweebarra	40	Surface Sample	54.84056	-8.38139
17/05/2005	Oysterhaven	1520		51.70306	-8.46194
17/05/2005	Sealax	1160	Lund Tube		
19/05/2005	Gearhies	320	Lund Tube	51.6575	-9.54889
19/05/2005	Rosroe	40	Lund Tube	53.624	-9.86386
22/05/2005	Drumcliff Bay	40	Surface Sample	54.33583	-8.55611
24/05/2005	Clare Island-Portlea	5520	Lund Tube	53.81816	-9.95336
24/05/2005	Gweebarra	40	Surface Sample	54.84056	-8.38139
25/05/2005	Roancarraig	1320	Lund Tube	51.65612	-9.77859
26/05/2005	Castletownbere	80	Lund Tube	51.65556	-9.83806
26/05/2005	Corhaunagh	7920	Lund Tube	53.46496	-10.08594
26/05/2005	Fraochoilean	17600	Lund Tube	53.575	-10.03503
26/05/2005	Hawks Nest	6960	Lund Tube	53.48499	-10.06718
26/05/2005	Kealincha-Inishfarnard	2400	Surface Sample	51.72552	-9.99875
27/05/2005	Rosroe	5520	Lund Tube	53.624	-9.86386
29/05/2005	Drumcliff Bay	400	Surface Sample	54.33583	-8.55611
30/05/2005	Castletownbere	7480	Lund Tube	51.65556	-9.83806
30/05/2005	Danoish	5520	Lund Tube	53.26618	-9.74297
30/05/2005	Murrisk	80	Lund Tube	53.79111	-9.64611
30/05/2005	Newtown	4360	Lund Tube	51.69278	-9.45972
30/05/2005	North Channel	160		51.88056	-8.25917
30/05/2005	North Chapel	3760	Lund Tube	51.69361	-9.47833
30/05/2005	Snave	4520	Lund Tube	51.71806	-9.46667
30/05/2005	South Chapel	920	Lund Tube	51.69	-9.46972

Sample date	Location	Cell Count per litre	Sampling method	Latitude (N)	Longitude (W)
30/05/2005	Tahilla	720	Discrete Depth	51.8225	-9.82222
30/05/2005	Whiddy Point	4360	Lund Tube	51.70556	-9.47556
31/05/2005	Cuan Baoi	9440	Lund Tube	51.65131	-9.58638
31/05/2005	Dunmanus Outer	40	Integrated	51.56639	-9.71972
31/05/2005	Poulnasherry	40	Surface Sample	52.65611	-9.55389
31/05/2005	Sealax	4560	Lund Tube		
06/06/2005	Ardgroom	240	Lund Tube	51.75639	-9.87611
06/06/2005	Castletownbere	4160	Lund Tube	51.65556	-9.83806
06/06/2005	Hawks Nest	26720	Lund Tube	53.48499	-10.06718
06/06/2005	Sealax	4416	Lund Tube		
07/06/2005	Aughinish	80	Lund Tube	53.15833	-9.06667
07/06/2005	Dunmanus Inner	1240	Integrated	51.60611	-9.55528
07/06/2005	Fraochoilean	462093		53.575	-10.03503
07/06/2005	Gweebarra	760	Surface Sample	54.84056	-8.38139
07/06/2005	McSwynes Bay	680	Lund Tube	54.61333	-8.39222
07/06/2005	Murrisk	480	Lund Tube	53.79111	-9.64611
08/06/2005	Aughinish	40	Surface Sample	53.15833	-9.06667
08/06/2005	Killary Inner Mouth	80	Discrete Depth	53.627	-9.865
08/06/2005	Killary Outer Mouth	160	Discrete Depth	53.635	-9.887
09/06/2005	Castletownbere	40	Lund Tube	51.65556	-9.83806
10/06/2005	Corhaunagh	2040	Lund Tube	53.46496	-10.08594
10/06/2005	Fraochoilean	58000	Lund Tube	53.575	-10.03503
10/06/2005	Hawks Nest	720	Surface Sample	53.48499	-10.06718
10/06/2005	Rosroe	640	Lund Tube	53.624	-9.86386
12/06/2005	Castletownbere	120	Lund Tube	51.65556	-9.83806
13/06/2005	Ballylongford	120	Discrete Depth	52.57472	-9.48694
13/06/2005	Killary Harbour Middle	240	Lund Tube	53.60389	-9.80278
13/06/2005	Sealax	680	Lund Tube		
14/06/2005	Glinsk	1400	Lund Tube	55.20026	-7.78014
14/06/2005	Gweebarra	8440	Lund Tube	54.84056	-8.38139
14/06/2005	Hawks Nest	692714	Lund Tube	53.48499	-10.06718
14/06/2005	Kealincha-Inishfarnard	2760	Lund Tube	51.72552	-9.99875
14/06/2005	Killary Inner Mouth	240	Surface Sample	53.627	-9.865
14/06/2005	Killary Inner Mouth	160	Discrete Depth	53.627	-9.865
14/06/2005	Killary Outer Mouth	440	Surface Sample	53.635	-9.887
14/06/2005	Killary Outer Mouth	3760	Discrete Depth	53.635	-9.887
14/06/2005	McSwynes Bay	2040	Lund Tube	54.61333	-8.39222
14/06/2005	Millstone	240	Lund Tube	55.1916	-7.75456
15/06/2005	Aughinish	5800	Lund Tube	53.15833	-9.06667
15/06/2005	Lough Swilly (SP)	40	Lund Tube	55.15845	-7.55028
16/06/2005	Illauneragh	2012592	Surface Sample	53.27833	-9.74806
16/06/2005	Killary Inner Mouth	120	Discrete Depth	53.627	-9.865
16/06/2005	Killary Outer Mouth	80	Discrete Depth	53.635	-9.887
16/06/2005	Killary Outer Mouth	40	Discrete Depth	53.635	-9.887
16/06/2005	Tahilla	40	Discrete Depth	51.8225	-9.82222
19/06/2005	Drumcliff Bay	27040	Surface Sample	54.33583	-8.55611
20/06/2005	Aughinish	560	Lund Tube	53.15833	-9.06667
20/06/2005	Hawks Nest	475709	Lund Tube	53.48499	-10.06718
20/06/2005	Killary Harbour Middle	160	Lund Tube	53.60389	-9.80278

Sample date	Location	Cell Count per litre	Sampling method	Latitude (N)	Longitude (W)
20/06/2005	Killary Inner Mouth	960	Discrete Depth	53.627	-9.865
20/06/2005	Killary Inner Mouth	480	Discrete Depth	53.627	-9.865
20/06/2005	Killary Outer Mouth	1320	Discrete Depth	53.635	-9.887
20/06/2005	Killary Outer Mouth	3600	Discrete Depth	53.635	-9.887
20/06/2005	McSwynes Bay	8960	Lund Tube	54.61333	-8.39222
20/06/2005	Sealax	86848	Surface Sample		
20/06/2005	Sealax	104512	Lund Tube		
20/06/2005	Seastream	360	Lund Tube	53.87899	-9.64964
21/06/2005	Gweebarra	347208	Surface Sample	54.84056	-8.38139
22/06/2005	Ardmore	38760	Lund Tube	53.3003	-9.76548
23/06/2005	Belmullet	40	Surface Sample	54.18722	-9.94972
23/06/2005	Clare Island-Portlea	211899	Lund Tube	53.81816	-9.95336
23/06/2005	Cnoc	163392	Lund Tube	53.27041	-9.71382
23/06/2005	Cuigeal	124880	Lund Tube		
23/06/2005	Killala Bay	484219	Surface Sample	54.21083	-9.18972
23/06/2005	Lettercallow	38800	Lund Tube	53.29162	-9.70244
23/06/2005	Red Flag	96720	Lund Tube	53.23706	-9.78851
24/06/2005	Fraochoilean	24880		53.575	-10.03503
24/06/2005	Killary Inner Mouth	1080	Discrete Depth	53.627	-9.865
24/06/2005	Killary Outer Mouth	96163	Discrete Depth	53.635	-9.887
24/06/2005	Killary Outer Mouth	160	Discrete Depth	53.635	-9.887
25/06/2005	Greencastle	11000	Lund Tube	55.19278	-7.00056
26/06/2005	Drumcliff Bay	80		54.33583	-8.55611
27/06/2005	Banc Fluich	320	Surface Sample	52.1375	-9.91944
27/06/2005	Carrickfin	35040	Surface Sample	55.05694	-8.32167
27/06/2005	Clare Island-Portlea	80040	Lund Tube	53.81816	-9.95336
27/06/2005	Cuigeal	80			
27/06/2005	Curraun	163440	Lund Tube	53.91796	-9.79876
27/06/2005	Hawks Nest	480815	Lund Tube	53.48499	-10.06718
27/06/2005	Inishlaughill	4120	Lund Tube	53.86444	-9.635
27/06/2005	Inver Bay (Inver)	53480	Lund Tube		
27/06/2005	Killala Bay	528471	Lund Tube	54.21083	-9.18972
27/06/2005	Killary Inner Mouth	12560	Discrete Depth	53.627	-9.865
27/06/2005	Killary Outer Mouth	40	Discrete Depth	53.635	-9.887
27/06/2005	Killary Outer Mouth	560096	Discrete Depth	53.635	-9.887
27/06/2005	Kinsale Bridge	720	Surface Sample	51.69417	-8.52861
27/06/2005	Loughras Beg	178720	Surface Sample	54.76083	-8.4775
27/06/2005	McSwynes Bay	137840	Lund Tube	54.61333	-8.39222
27/06/2005	Mountcharles	3033472	Surface Sample	54.63222	-8.17528
27/06/2005	Murrisk	3440	Lund Tube	53.79111	-9.64611
27/06/2005	North Channel	40		51.88056	-8.25917
27/06/2005	Oysterhaven	80	Surface Sample	51.70306	-8.46194
27/06/2005	Sealax	500669	Lund Tube		
27/06/2005	Seastream	30280	Lund Tube	53.87899	-9.64964
27/06/2005	Tra Eanach	77040		54.88444	-8.33889
27/06/2005	Whiddy Point	80	Lund Tube	51.70556	-9.47556
28/06/2005	Aughinish	76320	Lund Tube	53.15833	-9.06667
28/06/2005	Cnoc	2362608	Lund Tube	53.27041	-9.71382
28/06/2005	Mweeloon Bay	24270		53.22889	-8.99222

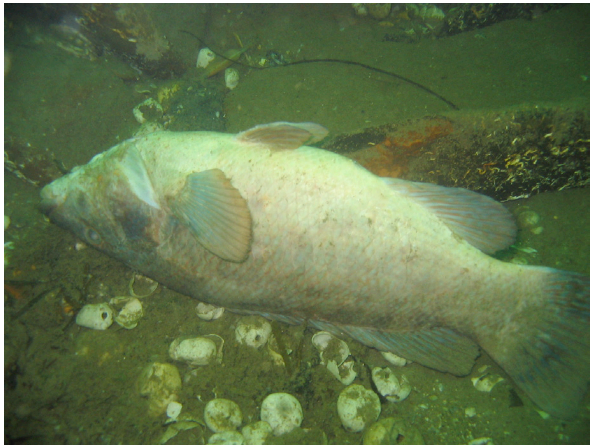
Sample date	Location	Cell Count per litre	Sampling method	Latitude (N)	Longitude (W)
29/06/2005	Cuan Baoi	80	Lund Tube	51.65131	-9.58638
29/06/2005	Eany	117520	Lund Tube	54.63394	-8.301
29/06/2005	Inver Bay (Inver)	280	Lund Tube		
29/06/2005	Inver Bay (Inver)	120	Lund Tube		
29/06/2005	Inver Bay (Inver)	520	Lund Tube		
29/06/2005	Inver Bay (Inver)	160	Lund Tube		
29/06/2005	Loughras Beg	40	Surface Sample	54.76083	-8.4775
30/06/2005	Killary Inner Mouth	3040	Discrete Depth	53.627	-9.865
30/06/2005	Killary Inner Mouth	530704	Discrete Depth	53.627	-9.865
30/06/2005	Killary Outer Mouth	594615	Discrete Depth	53.635	-9.887
30/06/2005	Killary Outer Mouth	160	Discrete Depth	53.635	-9.887
30/06/2005	Mulroy Bay	2440	Discrete Depth	55.15361	-7.68389
01/07/2005	Greencastle	5680		55.19278	-7.00056
03/07/2005	Drumcliff Bay	29640		54.33583	-8.55611
04/07/2005	Ardgroom	1040		51.75639	-9.87611
04/07/2005	Carrickfin	61800	Surface Sample	55.05694	-8.32167
04/07/2005	Cnoc	83280	Surface Sample	53.27041	-9.71382
04/07/2005	Dunmanus Inner	3960		51.60611	-9.55528
04/07/2005	Dunmanus Outer	2920		51.56639	-9.71972
04/07/2005	Fraochoilean	301024		53.575	-10.03503
04/07/2005	Greencastle	1680		55.19278	-7.00056
04/07/2005	Greenore	40	Surface Sample	54.03389	-6.14167
04/07/2005	Gweebarra	9680	Surface Sample	54.84056	-8.38139
04/07/2005	Inishlaughill	1400	Lund Tube	53.86444	-9.635
04/07/2005	Kealincha-Inishfarnard	200	Lund Tube	51.72552	-9.99875
04/07/2005	Killala Bay	200	Surface Sample	54.21083	-9.18972
04/07/2005	Killary Harbour Middle	4000	Lund Tube	53.60389	-9.80278
04/07/2005	Killary Inner Mouth	35120	Discrete Depth	53.627	-9.865
04/07/2005	Killary Inner Mouth	120	Discrete Depth	53.627	-9.865
04/07/2005	Killary Outer Mouth	58719	Discrete Depth	53.635	-9.887
04/07/2005	Killary Outer Mouth	5040	Discrete Depth	53.635	-9.887
04/07/2005	Kinsale Bridge	40	Surface Sample	51.69417	-8.52861
04/07/2005	McSwynes Bay	3320	Lund Tube	54.61333	-8.39222
04/07/2005	Mulroy Bay	26640	Lund Tube	55.15361	-7.68389
04/07/2005	Murrisk	10880	Lund Tube	53.79111	-9.64611
04/07/2005	Newtown	680	Lund Tube	51.69278	-9.45972
04/07/2005	North Channel	200		51.88056	-8.25917
04/07/2005	North Chapel	2880	Lund Tube	51.69361	-9.47833
04/07/2005	Red Flag	400	Lund Tube	53.23706	-9.78851
04/07/2005	Roancarraig	11040	Lund Tube	51.65612	-9.77859
04/07/2005	Sealax	403374	Discrete Depth		
04/07/2005	Sealax	405927	Surface Sample		
04/07/2005	Seastream	10800	Lund Tube	53.87899	-9.64964
04/07/2005	Snave	1120	Lund Tube	51.71806	-9.46667
04/07/2005	South Chapel	440	Lund Tube	51.69	-9.46972
04/07/2005	Whiddy Point	120	Lund Tube	51.70556	-9.47556
05/07/2005	Cranford A	34240	Lund Tube	55.16029	-7.69615
05/07/2005	Cuan Baoi	4160	Lund Tube	51.65131	-9.58638
05/07/2005	Fenit	520	Discrete Depth	52.27361	-9.85972

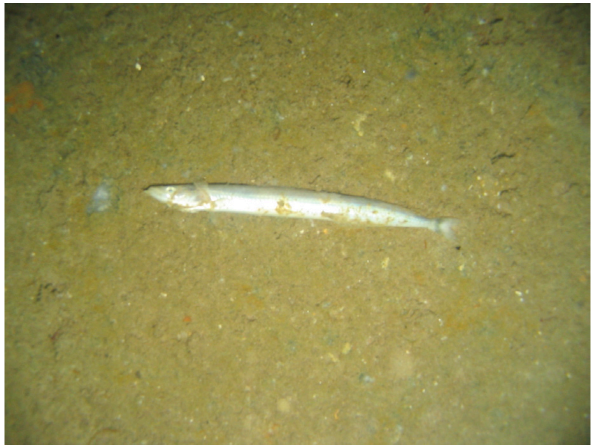
Sample date	Location	Cell Count per litre	Sampling method	Latitude (N)	Longitude (W)
05/07/2005	Fenit	40	Discrete Depth	52.27361	-9.85972
05/07/2005	Inver Bay (Inver)	120	Lund Tube		
05/07/2005	Killary Outer Mouth	360	Discrete Depth	53.635	-9.887
05/07/2005	Lough Swilly (SP)	328486	Lund Tube	55.15845	-7.55028
05/07/2005	McSwynes Bay	120	Lund Tube	54.61333	-8.39222
05/07/2005	Millford	101269	Lund Tube	55.11768	-7.69133
05/07/2005	Moross	15360	Lund Tube	55.18478	-7.70416
06/07/2005	Clare Island-Portlea	1200	Lund Tube	53.81816	-9.95336
06/07/2005	Fenit	80	Discrete Depth	52.27361	-9.85972
06/07/2005	Fenit	480	Discrete Depth	52.27361	-9.85972
06/07/2005	Glinsk	25840	Lund Tube	55.20026	-7.78014
06/07/2005	Millstone	100418	Lund Tube	55.1916	-7.75456
06/07/2005	Sealax	217856	Surface Sample		
07/07/2005	Corhaunagh	20160	Lund Tube	53.46496	-10.08594
07/07/2005	Fraochoilean	16320	Lund Tube	53.575	-10.03503
07/07/2005	Hawks Nest	120720	Lund Tube	53.48499	-10.06718
07/07/2005	Sheephaven	87653		55.14778	-7.87139
07/07/2005	Sheephaven	444222		55.14778	-7.87139
08/07/2005	Belmullet	3000	Surface Sample	54.18722	-9.94972
08/07/2005	Fenit	840	Surface Sample	52.27361	-9.85972
08/07/2005	Killala Bay	4400	Surface Sample	54.21083	-9.18972
08/07/2005	Killary Inner Mouth	5120	Discrete Depth	53.627	-9.865
08/07/2005	Killary Inner Mouth	400	Discrete Depth	53.627	-9.865
08/07/2005	Killary Outer Mouth	5600	Discrete Depth	53.635	-9.887
08/07/2005	Killary Outer Mouth	360	Discrete Depth	53.635	-9.887
08/07/2005	Seastream	184667	Integrated	53.87899	-9.64964
10/07/2005	Greencastle	217856	Lund Tube	55.19278	-7.00056
11/07/2005	Ardgroom	120	Lund Tube	51.75639	-9.87611
11/07/2005	Banc Fluich	8880	Surface Sample	52.1375	-9.91944
11/07/2005	Carrickfin	200	Surface Sample	55.05694	-8.32167
11/07/2005	Cuan Baoi	40	Lund Tube	51.65131	-9.58638
11/07/2005	Drumcliff Bay	9920	Surface Sample	54.33583	-8.55611
11/07/2005	Dunmanus Inner	40		51.60611	-9.55528
11/07/2005	Greenore	160	Surface Sample	54.03389	-6.14167
11/07/2005	Hawks Nest	720	Lund Tube	53.48499	-10.06718
11/07/2005	Inishlaughill	240	Lund Tube	53.86444	-9.635
11/07/2005	Kilbaha Pier	80	Lund Tube		
11/07/2005	Killary Harbour Middle	80	Lund Tube	53.60389	-9.80278
11/07/2005	Kinsale Bridge	80	Surface Sample	51.69417	-8.52861
11/07/2005	McSwynes Bay	400	Lund Tube	54.61333	-8.39222
11/07/2005	Murrisk	1840	Lund Tube	53.79111	-9.64611
11/07/2005	Newtown	80	Lund Tube	51.69278	-9.45972
11/07/2005	Seastream	120	Lund Tube	53.87899	-9.64964
11/07/2005	Snave	80	Lund Tube	51.71806	-9.46667
11/07/2005	Tahilla	40	Surface Sample	51.8225	-9.82222
11/07/2005	Tra Eanach	320		54.88444	-8.33889
12/07/2005	Gweebarra	440	Surface Sample	54.84056	-8.38139
12/07/2005	Kealincha-Inishfarnard	80	Lund Tube	51.72552	-9.99875
12/07/2005	Killala Bay	9160	Surface Sample	54.21083	-9.18972

Sample date	Location	Cell Count per litre	Sampling method	Latitude (N)	Longitude (W)
12/07/2005	Sealax	40	Lund Tube		
13/07/2005	Cuan Baoi	120	Lund Tube	51.65131	-9.58638
13/07/2005	Cuigeal	2440	Lund Tube		
13/07/2005	Dingle	31570		52.12694	-10.26667
13/07/2005	Eany	2400	Lund Tube	54.63394	-8.301
13/07/2005	Kealincha-Inishfarnard	5520	Lund Tube	51.72552	-9.99875
13/07/2005	Red Flag	880	Lund Tube	53.23706	-9.78851
13/07/2005	Roancarraig	4000	Lund Tube	51.65612	-9.77859
13/07/2005	Tahilla	40	Surface Sample	51.8225	-9.82222
14/07/2005	Curraun	400	Lund Tube	53.91796	-9.79876
14/07/2005	Palmer's Point	360	Lund Tube	51.64444	-9.80871
15/07/2005	Greencastle	4160	Lund Tube	55.19278	-7.00056
17/07/2005	Drumcliff Bay	3040		54.33583	-8.55611
17/07/2005	Killary Inner Mouth	80	Discrete Depth	53.627	-9.865
17/07/2005	Killary Inner Mouth	80	Discrete Depth	53.627	-9.865
17/07/2005	Killary Outer Mouth	120	Discrete Depth	53.635	-9.887
17/07/2005	North Channel	840		51.88056	-8.25917
17/07/2005	Oysterhaven	320		51.70306	-8.46194
18/07/2005	Ballylongford	120		52.57472	-9.48694
18/07/2005	Banc Fluich	560	Surface Sample	52.1375	-9.91944
18/07/2005	Brandon Bay	320	Surface Sample		
18/07/2005	Brandon Bay	560	Lund Tube		
18/07/2005	Carrickfin	40	Surface Sample	55.05694	-8.32167
18/07/2005	Cuan Baoi	40	Lund Tube	51.65131	-9.58638
18/07/2005	Dunmanus Bay	4120		51.56833	-9.67639
18/07/2005	Dunmanus Inner	2760		51.60611	-9.55528
18/07/2005	Dunmanus Outer	2800		51.56639	-9.71972
18/07/2005	Gweebarra	240	Surface Sample	54.84056	-8.38139
18/07/2005	Hawks Nest	320	Lund Tube	53.48499	-10.06718
18/07/2005	Killary Harbour Middle	40	Lund Tube	53.60389	-9.80278
18/07/2005	Lough Swilly (SP)	1240	Lund Tube	55.15845	-7.55028
18/07/2005	Murrisk	80	Lund Tube	53.79111	-9.64611
18/07/2005	North Chapel	40	Lund Tube		
18/07/2005	Poulnasherry	280	Surface Sample	52.65611	-9.55389
18/07/2005	Seastream	40	Lund Tube	53.87899	-9.64964
18/07/2005	Sheephaven	40		55.14778	-7.87139
20/07/2005	Ballydavid	162967			
20/07/2005	Cuan Baoi	120	Lund Tube	51.65131	-9.58638
20/07/2005	Dingle	20800		52.12694	-10.26667
20/07/2005	Killala Bay	480	Surface Sample	54.21083	-9.18972
20/07/2005	Ventry Harbour	15240		52.12417	-10.35972
21/07/2005	Belmullet	80	Surface Sample	54.18722	-9.94972
21/07/2005	Cnoc	40	Lund Tube	53.27041	-9.71382
21/07/2005	Killala Bay	200	Surface Sample	54.21083	-9.18972
21/07/2005	Oilean Iarthach	40	Lund Tube	53.28818	-9.73658
22/07/2005	Killary Inner Mouth	240	Discrete Depth	53.627	-9.865
22/07/2005	Killary Outer Mouth	40	Discrete Depth	53.635	-9.887
25/07/2005	Ballylongford	80		52.57472	-9.48694
25/07/2005	Carrickfin	120	Surface Sample	55.05694	-8.32167

Sample date	Location	Cell Count per litre	Sampling method	Latitude (N)	Longitude (W)
25/07/2005	Cobh	1160	Surface Sample	51.845	-8.28056
25/07/2005	Cobh	1000	Surface Sample	51.845	-8.28056
25/07/2005	Cromane East	37240	Surface Sample	52.12639	-9.87083
25/07/2005	Dingle	49566		52.12694	-10.26667
25/07/2005	Glenbeigh	3783945	Surface Sample	52.06861	-9.95306
25/07/2005	Inishlaughill	40	Lund Tube	53.86444	-9.635
25/07/2005	Lough Swilly (SP)	40	Lund Tube	55.15845	-7.55028
25/07/2005	Murrisk	40	Lund Tube	53.79111	-9.64611
25/07/2005	North Channel	1960		51.88056	-8.25917
25/07/2005	North Chapel	320	Lund Tube	51.69361	-9.47833
25/07/2005	Roaringwater Bay	640	Lund Tube	51.52306	-9.43694
25/07/2005	Sealax	160	Lund Tube		
25/07/2005	Snave	120	Lund Tube	51.71806	-9.46667
25/07/2005	South Chapel	40	Lund Tube	51.69	-9.46972
25/07/2005	Whiddy Point	80	Lund Tube	51.70556	-9.47556
26/07/2005	Cromane East	362670		52.12639	-9.87083
26/07/2005	Glenbeigh	760		52.06861	-9.95306
26/07/2005	Gweebarra	160	Surface Sample	54.84056	-8.38139
26/07/2005	Kilbaha Pier	880	Lund Tube		
26/07/2005	Poulnasherry	2600		52.65611	-9.55389
26/07/2005	Seastream	360	Lund Tube	53.87899	-9.64964
27/07/2005	Clare Island-Portlea	400	Lund Tube	53.81816	-9.95336
27/07/2005	Fenit	80		52.27361	-9.85972
27/07/2005	Glenbeigh	136682	Surface Sample	52.06861	-9.95306
27/07/2005	Glenbeigh	458660	Discrete Depth	52.06861	-9.95306
29/07/2005	Greencastle	200		55.19278	-7.00056
02/08/2005	Banc Fluich	1880	Surface Sample	52.1375	-9.91944
02/08/2005	Carrickfin	640	Surface Sample	55.05694	-8.32167
02/08/2005	Cuan Baoi	40	Lund Tube	51.65131	-9.58638
02/08/2005	Dunmanus Inner	80		51.60611	-9.55528
02/08/2005	Glenbeigh	40		52.06861	-9.95306
02/08/2005	Kinsale Bridge	40		51.69417	-8.52861
02/08/2005	Sealax	160	Lund Tube		
02/08/2005	South Chapel	40	Lund Tube	51.69	-9.46972
02/08/2005	Templenoe	80		51.86778	-9.65722
03/08/2005	Killala Bay	160	Surface Sample	54.21083	-9.18972
03/08/2005	Killary Inner Mouth	40	Discrete Depth	53.627	-9.865
03/08/2005	Killary Inner Mouth	360		53.627	-9.865
07/08/2005	Drumcliff Bay	400	Surface Sample	54.33583	-8.55611
08/08/2005	Greenore	40	Surface Sample	54.03389	-6.14167
08/08/2005	Hawks Nest	160	Lund Tube	53.48499	-10.06718
08/08/2005	Kilbaha Pier	120	Lund Tube		
08/08/2005	Poulnasherry	40	Surface Sample	52.65611	-9.55389
09/08/2005	McSwynes Bay	120	Lund Tube	54.61333	-8.39222
09/08/2005	Mulroy Bay	80	Lund Tube	55.15361	-7.68389
10/08/2005	Cuigeal	80	Lund Tube		
10/08/2005	Lough Swilly (SP)	80	Lund Tube	55.15845	-7.55028
10/08/2005	Palmer's Point	80	Lund Tube	51.64444	-9.80871
10/08/2005	Red Flag	40	Lund Tube	53.23706	-9.78851

Appendix 3: Dead Fish and Crustacea observed in Dingle Bay July 31, 2005



(Photos: Dingle Dive Centre)

Appendix 4: Report of Scuba Dives in Killary Harbour, Co. Galway

By Dr. Rowan Holt, Countryside Council for Wales.
Published in Marine Life News
(http://www.glaucus.org.uk/News2005Summer.htm)

An algal bloom of the planktonic dinoflagellate *Karenia mikimotoi* has developed in the Atlantic Ocean and been blown inshore and around the coasts and into the loughs of north-west Ireland. This microscopic organism is present in such huge numbers that underwater the sea actually looks green and the visibility is reduced to a few metres. It releases toxic substances called *gymnocins* into the sea and compounded by the deoxygenation caused by the dying plankton, the overall result has been a mass mortality of the sessile and slow moving organisms like starfish, sea urchins, benthic (bottom-dwelling) animals, scallops and other molluscs, worms and even sea anemones. In the enclosed loughs and in very shallow water, the effects are even worse, with flatfish and rock pool fish succumbing the effect of the toxins and anoxic conditions. Dead creatures litter the sea bed providing food for any crabs that have survived.

Dead Animals in Killary Harbour

The first is a priapulid (Priapulida: worm-like animals that live in the sand), *Priapulus caudatus*, and the second a sea cucumber, *Thy fusus*, that have succumbed to the effects of the algal bloom.
Fish farms have been located in some of the loughs and their stock of molluscs and fish can be killed by these naturally occurring algal blooms.
I dived Killary Harbour (a long enclosed sea lough) with Dr Joanne Porter from Aberystwyth University, only to find that all the brittlestars in what was an extensive bed; large molluscs including whelks and scallops; all starfish, all fish (everything from Blennies, Gobies, Butterfish, flatfish etc) and many of the infaunal species - (worms, priapulids, sea cucumbers), were either dead and rotting, or gaping and unresponsive. The only animals that seemed to be hanging on were the Common Hermit Crabs, *Pagurus bernhardus*, and the Organ-pipe Worm, *Serpula vermicularis,* which were still extending their tentacles from their calcareous tubes but retracting them quickly when we approached.

Appendix 5: Press Coverage (Irish Times; Saturday, 06 August 2005)

Another Life/Michael Viney: Killary Harbour is Ireland's approximation to a grand Norwegian fiord, its mountains mirrored in deep water rarely ruffled by more than work-boats visiting the blue-barrelled mussel lines, or the stately outings of the Leenane tourists' catamaran. It is intensely peaceful most of the time, while hinting at a vigorous undersea life in its 15km of Atlantic cul-de-sac.

Diving there on July 3rd, however, two marine scientists visiting from Wales found a scene of desolation on the muddy floor of the fiord. As Dr Rohan Holt described it, "all the brittlestars in what was an extensive bed, large molluscs including whelks and scallops, all starfish, all fish (blennies, gobies, butterfish, flatfish, etc) and many of the infaunal species (worms, priapulids, sea cucumbers) were either dead and rotting, or gaping and unresponsive. The only animals that seemed to be hanging on were the common hermit crabs and the organ-pipe worm . . ." It was a scene repeated in many bays and inlets from Galway to Donegal as a massive algal bloom destroyed seabed life, threatened salmon farms and killed commercial shellfish stocks. Losses of oysters, clams and scallops have run into millions of animals.

The bloom was dominated by a single phytoplankton species, Karenia mikomotoi, a microscopic, single-celled organism, named in Japan in 1935. It was first recorded in the north-east Atlantic, off Norway, in 1966, and off south-east Ireland 10 years later. Carried around the world in ballast water pumped in and out by ship it is now a common cause of "red tides" from New Zealand to Europe.

Minor blooms around Ireland's Atlantic coasts have been frequent, but Nasa satellite pictures of this June's exploding tide of cells showed an arc around the north-west that extended 100km out to sea. As lugworms began to die at western shores - a typical early sign of a Karenia bloom - its progress was updated daily by the Marine Institute's phytoplankton monitoring programme.* Not only the scale but the persistence of the bloom have been exceptional. Even late in July, when most of the cells had died and dissipated, Karenia counts were still high in Lough Swilly and Lough Foyle and reports were coming in from Kerry's Dingle Bay of dead mussels and conger eels.

Karenia is a naked dinoflagellate - that is, it lacks a tough wall to its cell. In high concentration - sometimes millions of organisms per litre of water - the cell walls rupture, and toxins harmless to humans sweep fatally through the gills of marine life. When the bloom dies its decay makes huge demands on the water's oxygen level, thus suffocating seabed life: within days of the devastation seen in Killary Harbour, the fiord's dissolved oxygen had plummeted.

Ireland's "red tides" are usually due to winds and currents that push the plankton into the island's bays. But research following a spectacular bloom of Karenia in the western English Channel in the summer of 2003 suggested that sea temperatures and ocean layering can also produce great extensions of a bloom. As the global ocean warms and plankton patterns change, the challenge is to predict the harmful blooms in time to let aquaculture take a healthy harvest.

The death of so much sea life is beginning to litter many western tidelines with the shells and carapaces of marine casualties: crabs and potato urchins have been among the first. With them have come unusual numbers of a creature that has mystified some holiday beachcombers. A Dublin reader, Nicholas Harvey, described finding dozens of them washed up along Keel Strand on Achill: "Each consisted of a soft, fleshy, cream-coloured 'body' about the size of a table-tennis ball. Attached were numerous short 'limbs' (varying in number from two to about seven depending on their size) with a greyish, almost transparent, mussel-like shell at the end which would open gently to reveal countless tiny feet or antennae slowly moving about." These were small colonies of the stalked "buoy" barnacle, otherwise *Dosima fascicularis*. This is a species of the more familiar goose barnacle that often encrusts drifting logs and crates. The buoy barnacle, while it has used tar pellets and plastics in a similar way, secretes its own float of gas-filled bubbles that looks like foam plastic. This lets it drift on the ocean surface with the shell suspended beneath the water, extending its feathery arms to capture plankton.

Dr Don Cotton, the Sligo naturalist, found hundreds of the barnacles on beaches around north Mayo and in Sligo. On my own strand, when I came to look, only a sprinkle of the animals' empty shells remained. Was Dosima, too, a victim of the Karenia bloom? And when an alien organism explodes its numbers in an ocean warmed up by human activity, do we still have to call it a "natural" event?

Appendix 6: Meterological conditions Summer 2005

		Rainfall mm			Temperature ºC			Global Solar Radiation joules per m^2		
Year		May	Jun	July	May	Jun	July	May	Jun	July
Shannon Airport	2005	90	56.6	45.9	11	15.1	16.1			
	2004	35.8	63.4	71.4	11.9	14.9	14.7			
	30 yr mean	59.5	62.8	56.8	11.3	14	15.7			
Belmullet	2005	100	74.9	32.3	10.8	14.1	15	55690	48620	49020
	2004	36.4	86.6	77.5	11.4	13.7	14.1	59774	52841	55107
	30 yr mean	67.9	67.2	67.5	10.3	12.6	14	46700	48252	48258
Malin Head	2005	77.4	83.1	24.3	9.7	13.5	14.1	54310	46570	46350
	2004	35.3	107.6	99.3	10.6	13.3	13.9	56429	51038	51213
	30 yr mean	58.9	65	71.8	9.9	12.3	13.8	50344	53919	49871
Valentia Observatory	2005	145.5	93.7	78.3	11.2	14.5	15.6	49490	52510	52930
	2004	40.9	101.4	84.8	11.5	14	14.6	56477	54769	55933
	30 yr mean	88.5	79.9	73.3	10.9	13.3	14.8	54669	52754	52047
Cork Airport	2005	89.1	58.9	107.1	10.3	14.1	15.8			
	2004	46.2	100	54.5	11.4	14.2	14.1			
	30 yr mean	84.1	67.7	65.4	10.3	13	14.9			

Appendix 7: Mean Faunal constituents (no. of taxa/0.01m^2) from 2003 and 2005 Killary Harbour benthic surveys.

	2003			2005		
Stations	1	2	3	1	2	3
NEMERTEA	0.25		0.25	0.50	0.25	
NEMATODA				0.50		
PRIAPULIDA						
Priapulus caudatus			0.25			
SIPUNCULA						
GOLFINGIIFORMES						
Phascolion strombus				0.25		
Golfingia sp	0.50	2.00	0.75			
ANNELIDA						
PHYLLODOCIDA						
Malmgrenia castanea		0.25				
Pholoe minuta	0.25					
Glycinde nordmanni				0.25		
Goniada sp.	0.25					
Nephtys incisa	1.00	1.50	3.00	1.50	1.25	0.06
EUNICIDA						
Nothria						
Lumbrineris gracilis				0.50		
ORBINIIDA						
Scoloplos armiger	0.25			0.25		
Orbinia sp.	0.50		0.25	0.00		
SPIONIDA						
Magelona minuta				28.50	0.25	
Phyllochaetopterus anglicus				0.25		
Spiochaetopterus sp.			0.75			
Chaetozone sp.	0.25	0.25		71.50	0.25	0.06
Tharyx sp.	0.25					
Diplocirrus glaucus	0.50	0.00	0.25			
CAPITELLIDA						
Capitomastus minimus						0.06
Mediomastus fragilis				0.25		
Euclymene oerstedii				0.25		
Notomastus latericeus	0.75	0.75	1.75			
OWENIIDA						
Myriochele sp.				0.25		
TEREBELLIDA						
Melinna palmata	2.00	1.25		8.50		
Pectinaria belgica			0.50			
Pectinaria sp.			0.25			
Lysilla loveni		0.25				

	2003			2005		
Stations	1	2	3	1	2	3
CHELICERATA						
Pycnogonida sp.				0.25		
CRUSTACEA						
AMPHIPODA						
Parametaphoxus fultoni						
Ampelisca sp.					0.00	0.06
Gammarus salinus					0.00	0.06
DECAPODA						
Decapoda sp.						
Callianassa subterranea			0.25			
MOLLUSCA						
MESOGASTROPODA						
Turritella communis			1.75			0.19
NUCULOIDA						
Nucula sp.		4.00	7.75	1.75		0.19
VENEROIDA						
Myrtea spinifera	1.50	1.50	3.75	1.25	2.25	0.25
Thyasira flexuosa		0.25	0.50	3.75		
Mysella bidentata			2.00	0.75		
Abra alba		1.00	1.50	0.25		
Chamelea striatula					0.25	
MYOIDA						
Corbula gibba		0.75		0.25		0.06
PHORONIDA						
PHORONIDA						
Phoronis hippocrepia				0.50		0.06
ECHINODERMATA						
OPHIURIDA						
Amphiura chiajei	2.00	4.00	25.50	0.25		
HOLOTHUROIDEA						
Leptopenctata elongata	0.25					
Leptosynapta inhaerens	0.25	0.50				
HEMICHORDATA						
Enteropneusta						
Saccoglossus sp.	0.25	0.25				

Appendix 8: Video transects, Donegal Bay

Transect	Start Time	Latitude	Longitude	End Time	Latitude	Longitude	Depth (m)
1	11:14	54 33.1955	08 38.2623	11:24	54 33.1537	08 38.4929	70
2	13:01	54 24.1730	08 50.2310	13:11	54 24.3196	08 50.1771	55
3	14:11	54 30.5531	08 50.0238	13:21	54 30.6839	08 49.9857	74
4	15:25	54 37.1445	08 49.8904	15:35	54 37.2635	08 50.0028	85
5	17:23	54 31.6208	08 30.0289	17:33	54 31.6631	08 30.1580	56
6	18:31	54 34.5062	08 21.5501	18:42	54 34.4116	08 21.5536	36
7	20:07	54 36.2404	08 25.5661	20:18	54 36.1839	08 25.7751	32
8	09:38	54 28.5191	08 25.6057	09:48	54 28.6163	08 25.4958	26
9	10:38	54 26.9810	08 31.3602	10:48	54 26.9897	08 31.5935	28
10	11:25	54 25.2998	08 36.2254	11:36	54 25.2193	08 36.4788	29
11	12:50	54 20.2969	08 49.5958	13:01	54 20.3495	08 49.9104	50

Transect 1:Specific observations: At 2:37 minutes some dead anemones were observed. At 4:10 minutes dead lugworms were seen on the surface. At 5:30 minutes extensive mats of the sulphur reducing bactreria were observed (this is expected at the spoil site given the high degree of organically enriched material that was disposed here). At 6:50 minutes a single Asterius rubens was observed At 7:10 an urchin was observed.	Transect 2: *Specific observations:* At 1:50 and 3:19 flatfish (indeter.) was observed At 8:30 *Arenicola* burrows were observed
Transect 3: *Specific observations:* At 3:17 and 6:06 flatfish were observed. The second appeared lethargic. At 5:35 an egg casing (similar to those of the bivalves Polinicinea) was observed.	Transect 4:*Specific observations:* At 2:30 crabs were visible on the sediment surface. At 4:45 there was a heart urchin on the surface At 6:10 a starfish was observed At 6:40 additional urchins were observed.
Transect 5:*Specific observations:* At 5:40 dead *Asterius rubens* decomposing on surface At 6:05 cockle with foot extended At 7:00 lethargic spider crab At 9:20 dead worms on surface.	Transect 6: *Specific observations:* At 0:05 dead crab At 7:40 gastropod *Turritella* sp shells on surface.
Transect 7:*Specific observations:* At 2:00 hermit crab *Pagurus* sp observed At 3:45 a yellow hard hat observed At 4:30 and 9:23 Sea mouse, *Amphitrite* sp was observed at surface At 7:09 Nephrops sp observed outside burrow – not moving At 8:20 and 8:37 Live Nephrops observed retreating into burrow – more normal behaviour	Transect 8: *Specific observations:* At 7:16 and razor clam (*Ensis* sp) shell was observed on the surface.
Transect 10:*Specific Observations:* At 0:58 swimming crab (*Liocarcinus sp.*) At 1:09 transition to fine sands At 2:50 depressions observed in sediment, *Echinocardium* sp. perhaps? At 3:45 live fish observed gurnard (?) At 4:15 starfish *Astropecten* sp observed.	Transect 11: *Specific Observations:* At 1:19 unidentified fish species At 6:05 Gurnard (?) At 6:12 transition to complete sand bottom At 6:30 *Astropecten* or *Luidia sarsi* visible on surface. At 8:31 Edible crab, *Cancer pagurus* visible At 9:30 coarse sand and cobbles dominate

Appendix 9: Reported aquaculture mortalities from BIM development officers along the western seaboard.

Location	*Species (% mortality or abundance)*					
	Oysters			*Clams*	*Scallops*	*Abalone*
	Spat	*Half-grown*	*Grow-out*			
Donegal[1]						
Trawbega Bay			0%			
Mulroy Bay			0%			
Sheephaven Bay			25%			
Loughrous Beg			30-40%			
McSwynes Bay			0%			
Inner-Donegal Bay			3-4%			
Inver Bay			0%			
Mayo[2]	Some mortalities observed (not quantified)					
Galway[3]						
Clarenbridge Bay	700k					
Kinvara Bay	100k					
Aughinish Bay					25,000k	
Streamstown Bay	850k		750k			20k & 20 broodstock
Ballynakill Harbour	1,000k		520k			
Kerry[4] Castlemaine Harbour [5]						
Castlemaine 1		80% (400K)	40% (4.5 tonne)			
Castlemaine 2		70-80% (275K)	60% (150k)			
Castlemaine 3		30% (40 tonne)	50% (50 tonne)			
Castlemaine 4		20% (3.2 tonne)	10% (0.4 tonne)			
Castlemaine 5				25% Seed 10% Adult		

Sources: [1] Peter McGroary; [2] Mary Hannon; [3] Tomas Burke; [4] Catherine Butler; [5] Five separate locations within Castlemaine Harbour were reported upon.