

A3a.1 PLANKTON

A3a.1.1 Introduction

This section describes the plankton community of UK waters, and how this has changed over the past few decades. The plankton community may be broadly divided into a plant component (phytoplankton) and an animal component (zooplankton). The ecology of the plankton community is closely coupled with environmental factors. Consequently the plankton acts as an important link between the biological and physical components of the ecosystem. Members of the plankton are key producers and primary consumers in marine ecosystems and so population changes will have impacts on organisms at higher trophic levels, with important environmental and economic consequences.

Plankton across the North Atlantic has been monitored for over 70 years using the Continuous Plankton Recorder (CPR). Remote sensing by satellites such as the Coastal Zone Colour Scanner (CZCS - 1978-1986) and Sea-viewing Wide Field-of-View Sensor (SeaWiFS – 1997-current) is also used to examine phytoplankton biomass, which may be measured on the Phytoplankton Colour Index (PCI). From these data, changes in abundance and long-term trends can be distinguished. Since 2000, a number of studies commissioned by the Department of Energy and Climate Change (DECC) have been produced, describing the environment of the SEA (Strategic Environment Assessment) areas around the UK coast. Studies of the plankton communities in UK waters, relevant to the current baseline, were carried out as part of these projects.

A3a.1.2 UK context

A3a.1.2.1 Plankton community

The majority of the plankton is found within the top 20m of the water column, known as the photic zone, into which light can penetrate, allowing photosynthesis to take place. The phytoplankton community is dominated by dinoflagellates and diatoms. Diatoms are encased in a silicon shell, or test, and are predominantly autotrophic. Dinoflagellates have a pair of flagella and can produce energy both autotrophically and heterotrophically. In the northeast Atlantic, diatoms comprise a greater proportion of the phytoplankton community than dinoflagellates from November to May - see Figure A3a.1.3c (McQuatters-Gollop *et al.* 2007). The phytoplankton also includes smaller flagellates, sometimes known as the pico- or nanoplankton, which are difficult to study because of their size and consequently under-researched. Nano-plankton can be a significant component of the phytoplankton community, with abundances of *Phaeocystis pouchetti* peaking in early spring and abundances of the coccolithophore *Emiliana huxleyi* peaking in late summer and autumn (Boney 1986).

The zooplankton communities are dominated in terms of biomass and productivity by copepods, particularly *Calanus* species such as *C. finmarchicus* and *C. helgolandicus*. There is a strong geographical divide between these two species, with *C. finmarchicus* more abundant in colder, more northern waters and *C. helgolandicus* dominating warmer waters in more southerly regions, though their ranges show considerable overlap. Calanoid copepods are large crustaceans (in a planktonic context) which range in size between 0.5-6mm and are an important prey item for many species at higher trophic levels. Other important taxa include *Acartia* spp., *Temora longicornis* and *Oithona* spp.. The larger zooplankton, known as megaplankton, includes euphausiids (krill), thaliacea (salps and doliolids), siphonophores and medusae (jellyfish). The gelatinous taxa are poorly sampled as their bodies disintegrate

on contact with the CPR although they are known to be more abundant in late summer and autumn (Witt *et al.* 2007).

Krill is very abundant throughout the North Sea and is a primary food source for fish, seabirds and whales. Siphonophores (colonial hydrozoa) can reach large densities under favourable conditions. Jellyfish such as *Cyanea lamarckii*, *C. capillata* and *Aurelia aurita*, which are abundant around UK coasts (Hay *et al.* 1990), have short life-spans and high growth rates. Consequently they are able to respond to favourable conditions very rapidly (Lynam *et al.* 2004).

Meroplankton comprise the larval stages of benthic organisms and fish that spend a short period of their lifecycle in the pelagic stage before settling on the benthos. Important groups within this category include the larvae of starfish and sea urchins (echinoderms), crabs and lobsters (decapods) and some fish.

Certain species of phytoplankton and zooplankton form resting cysts which sink to the bottom sediment where they remain until they are resuspended. This feature allows them to survive unfavourable conditions, when nutrient availability may be low. Dinoflagellates (including toxic species associated with paralytic shellfish poisoning (PSP)) and the copepod genera *Acartia* and *Centropages* commonly form resting cysts. Resting cysts are usually found in silt or mud sediments (Johns & Reid 2001).

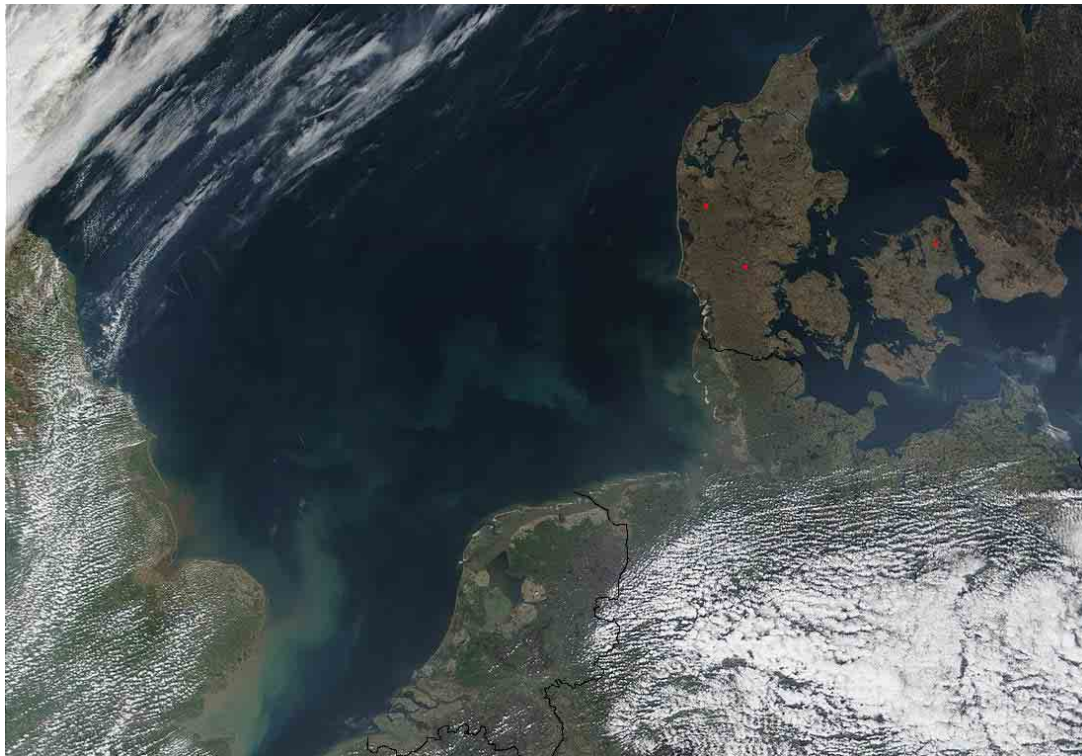
A3a.1.2.2 Plankton blooms and harmful algal events

Typically in the temperate seas a phytoplankton bloom occurs every spring, generally followed by a smaller peak in the autumn. Productivity will be determined by a combination of seasonal changes in light penetration and a cycle of nutrient introduction into the water column through mixing and turbulence caused by winds in the autumn and winter, followed by nutrient depletion as phytoplankton blooms.

The progress of the spring bloom, primarily comprising diatoms, is predominantly dependent upon episodic turbulence following short periods of stratification (see Figure A3a.1.2), which allows the resuspension of phytoplankton and the mixing of nutrients into the photic zone. The spring bloom of diatoms typically begins in shallow regions, such as the southern North Sea (see Figure A3a.1.1), where there is greater light penetration, and mixing leads to a greater quantity of re-suspended material from the seabed (McQuatters-Gollop *et al.* 2007). In spring, as the day length increases and the water column becomes more stratified, there is a bloom of diatoms (Williams & Lindley 1980). As little mixing of the water occurs silicates, which are essential for diatom growth, become depleted and other groups such as flagellates, followed later by dinoflagellates, bloom. In most regions, the diatom population peaks between April and July - see Figure A3a.1.3a, while dinoflagellates peak in the late summer, when the water tends to be more stratified - see Figure A3a.1.3b. This is typical of waters in the northeast Atlantic, as increased levels of stratification in the summer promote the growth of dinoflagellates, while opportunistic diatoms flourish in a more turbulent, nutrient-rich water column (Margalef 1973, cited in Leterme *et al.* 2006).

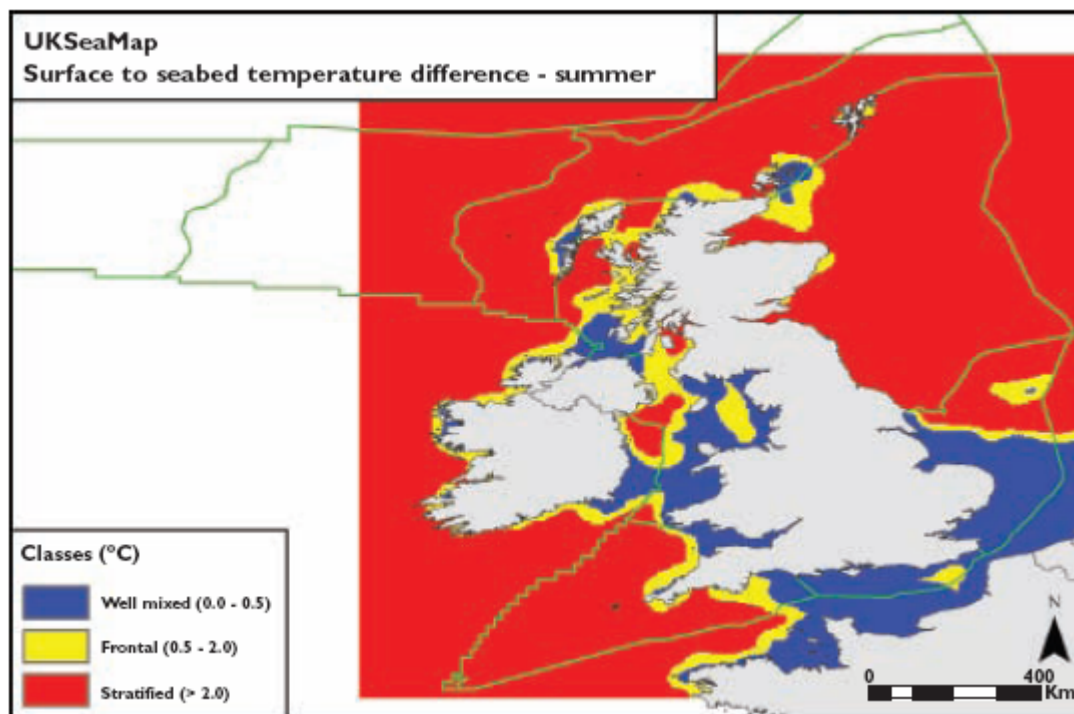
The winter distribution of phytoplankton and zooplankton around three sandbanks off the Belgian coast was investigated by M'harzi *et al.* (1998), who found significant differences in phytoplankton taxa between the banks. This was attributed to salinity, temperature and turbidity differences, and suggests that spatial heterogeneity in plankton communities during late winter may influence "starting positions" (in terms of community composition) for the spring bloom.

Figure A3a.1.1 – Satellite image of a plankton bloom in the southern North Sea



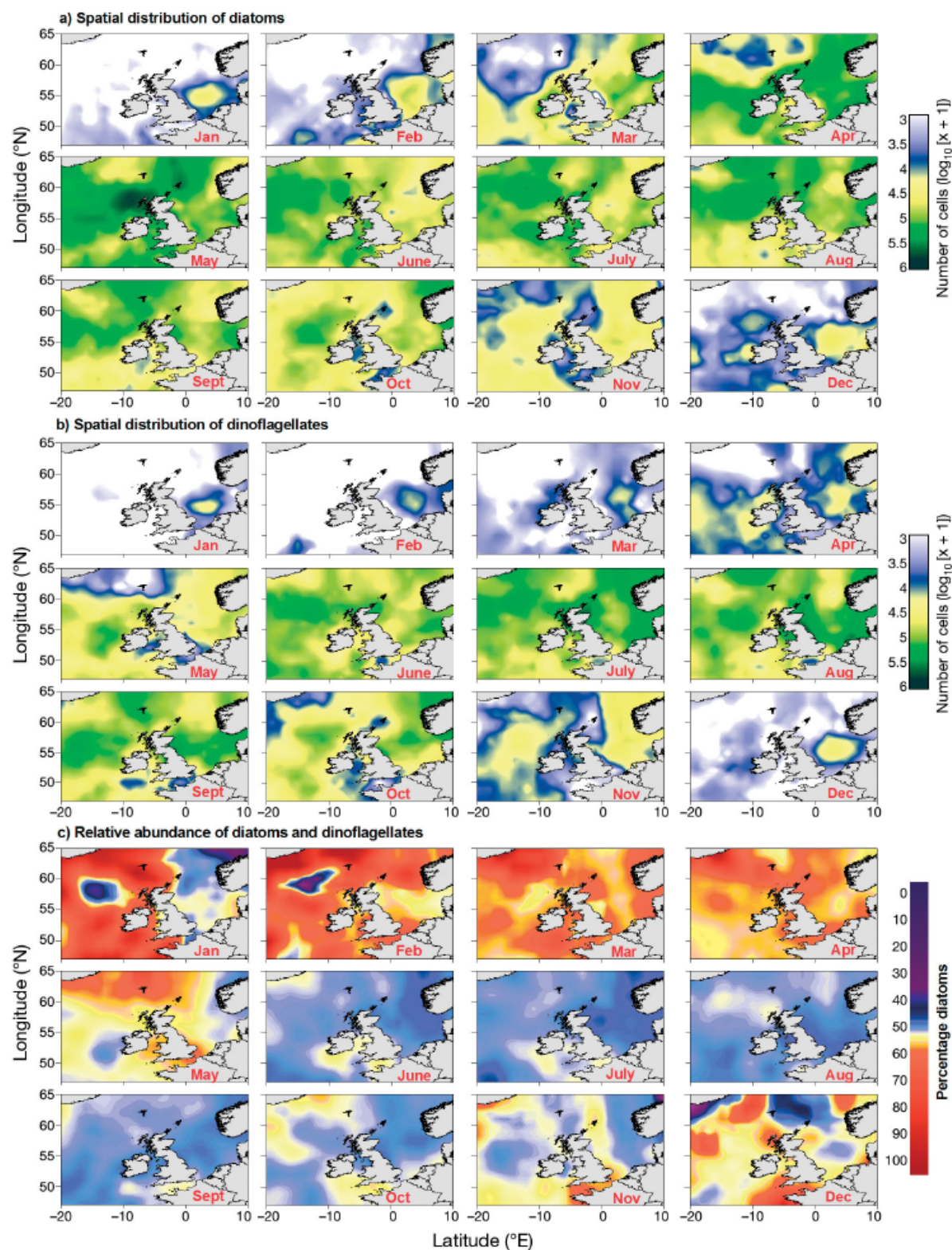
Source: NASA website.

Figure A3a.1.2 – UK summer surface to seabed temperature difference



Source: Connor et al. (2006)

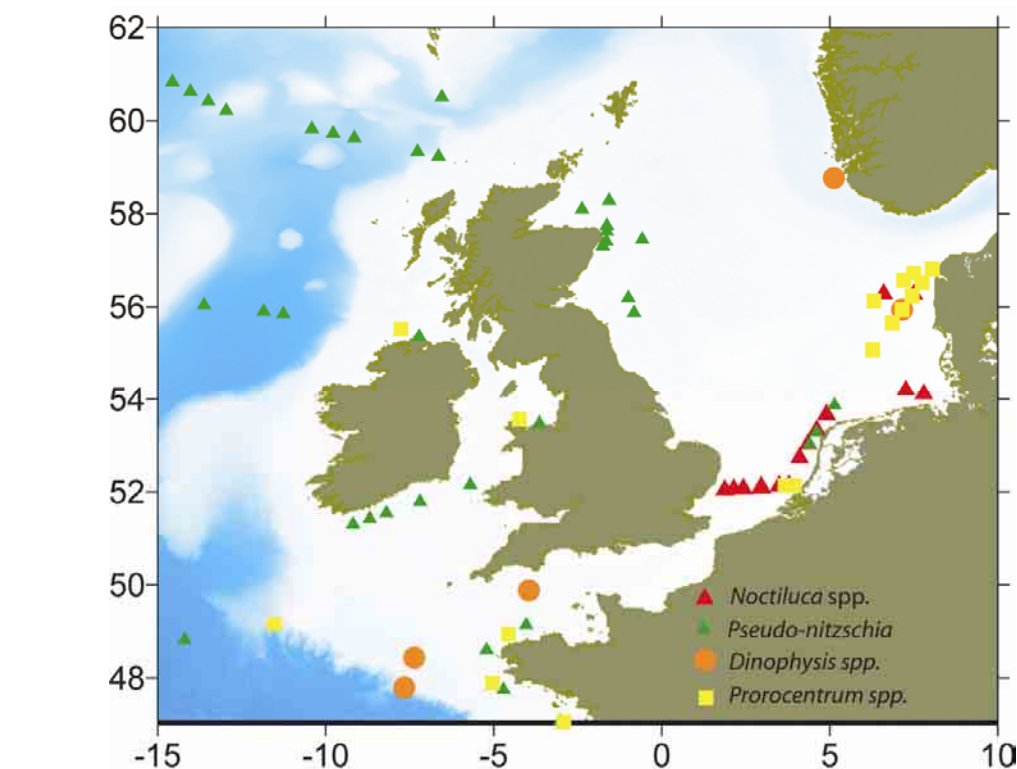
Figure A3a.1.3 – Mean monthly spatial patterns of (a) diatoms, (b) dinoflagellates and (c) their relative community abundances (as percentage diatoms) in NE Atlantic between 1958-2003.



Source: McQuatters-Gollop et al. (2007).

Under certain conditions (e.g. rapid reproduction, reduced grazing pressures, favourable environmental factors) blooms can occur at other times of the year. Many of these blooms involve nuisance or noxious species and are described as Harmful Algal Blooms (HABs). Examples include those connected with Paralytic Shellfish Poisoning (PSP), such as the dinoflagellate *Alexandrium tamarense*. Other groups known to cause HABs include *Dinophysis* spp. and *Prorocentrum* spp. (both associated with shellfish toxins), *Ceratium furca*, and *Noctiluca* spp. (both associated with nuisance blooms) (Edwards *et al.* 2006a). Analysis of long-term spatial variability in CPR data indicates that in the south and east North Sea, there have been increases in abundances of the latter two in recent decades. One of the most studied HABs is of the foam alga *Phaeocystis* spp. (DEFRA 2005), blooms of which are often tightly coupled with those of diatoms (Lancelot *et al.* 1987). *Phaeocystis* spp. can occur either as single cells or in large gelatinous colonies (Stelfox-Widdicombe *et al.* 2004), so blooms will be fed upon by a wide range of organisms and can have a rapid impact throughout the food chain, including mortality (Peperzak & Poelman 2008). HABs may be related to water surface temperatures in spring, as early seasonal stratification may favour phytoplankton growth in the water column (Joint *et al.* 1997). Along the west coast of Norway, where there has been a large increase in HABs, a strong significant correlation was evident between the increase in dinoflagellate taxa and environmental variability (including Atlantic inflow, salinity, sea surface temperature and wind speed) (Edwards *et al.* 2006a).

Figure A3a.1.4 – Occurrences of blooms in UK waters in 2004.



Source: Edwards *et al.* (2006b).

A3a.1.3 Ecological context

A number of studies have demonstrated that a change in the plankton community composition can have a significant effect on organisms at higher trophic levels. Fish populations, already under significant pressure from fishing activity, may be affected, potentially with economic and environmental consequences.

Beaugrand *et al.* (2003) suggested that cod recruitment fluctuates with changes in the plankton ecosystem. The Gadoid Outburst between 1963 and 1983 saw high rates of cod recruitment at a time of high abundances of calanoid copepods and krill, important prey items for cod larvae. Since the mid-1980s however, conditions in the plankton ecosystem have not been so favourable and this has coincided with a decrease in cod recruitment. The increasing abundance of *C. helgolandicus* at the expense of *C. finmarchicus* may also have had an effect on cod recruitment as the population of *C. helgolandicus*, unlike that of *C. finmarchicus*, peaks too late in the year for cod larvae to feed on it (Helaouet & Beaugrand 2007). Relationships between the plankton community and the abundance of salmon (Beaugrand & Reid 2003) and horse mackerel (Reid *et al.* 2001) in the North Sea have also been identified.

Sudden increases in plankton abundance may also have deleterious effects on fish populations. In 1968, a bloom of the dinoflagellate *Alexandrium tamarense* caused large scale deaths of sandeels and seabirds off the northeast coast of England (as well as hospitalising 78 people) (Coulson 1968). The zooflagellate *Noctiluca scintillans* (= *N. miliaris*) is an important predator of copepod eggs and is estimated to be responsible for the clearance of up to 50% of these eggs in the southern North Sea (Daan 1987). High abundances of jellyfish have been shown to have a deleterious effect on herring larvae through competition and predation at spawning grounds (Lynam *et al.* 2005).

A3a.1.4 Features of Regional Sea 1

The northern North Sea is characterised by deep, cool, stratified waters (JNCC 2004). The inflowing warm, nutrient rich waters from the north Atlantic are thought to be a factor promoting earlier stratification (Drinkwater *et al.* 2003), conditions suited for successful competitors such as dinoflagellates (Margalef 1973, cited in Leterme *et al.* 2006); dinoflagellates comprise a greater proportion of the phytoplankton community than diatoms from June to October, when waters will be most stratified - see Figure A3a.1.3c (McQuatters-Gollop *et al.* 2007). The spring bloom in this region is stronger, relative to the autumn bloom, than elsewhere (Longhurst 1998). The phytoplankton community is dominated by the dinoflagellate genus *Ceratium* (*C. fusus*, *C. furca*, *C. lineatum*), with diatoms such as *Thalassiosira* spp. and *Chaetoceros* spp. also abundant. HABs that have been observed in the region in recent years include the diatom *Pseudo-nitzschia*, a cause of amnesic shellfish poisoning, and the dinoflagellate *Alexandrium tamarense* – see Figure A3a.1.4.

Zooplankton species richness is higher in the northern North Sea than in the southern North Sea and the community displays greater seasonal variability (Lindley & Batten 2002). The zooplankton community is dominated by calanoid copepods, although other groups such as *Paracalanus* and *Psuedocalanus* are also abundant. There is also a high biomass of *Calanus* larval stages present in the region. Euphausiids, *Acartia*, and decapod larvae are all important components of the zooplankton assemblage.

A3a.1.5 Features of Regional Sea 2

The southern North Sea is characterised by shallow, well-mixed waters, which undergo large seasonal temperature variations (JNCC 2004). The region is largely enclosed by land and, as a result, the environment here is dynamic with considerable tidal mixing and nutrient-rich run-offs from the land (eutrophication). In these conditions, there will be relatively little stratification throughout the year and constant replenishment of nutrients, so opportunistic organisms such as diatoms are particularly successful (Margalef 1973, cited in Leterme *et al.*

2006); diatoms comprise a greater proportion of the phytoplankton community than dinoflagellates from November to May, when mixing will be at its greatest - see Figure A3a.1.3c (McQuatters-Gollop *et al.* 2007). The phytoplankton community is dominated by the dinoflagellate genus *Ceratium* (*C. fusus*, *C. furca*, *C. lineatum*), along with higher numbers of the diatom, *Chaetoceros* (subgenera *Hyalochaete* and *Phaeoceros*) than are typically found in the northern North Sea. A number of HABs caused by *Noctiluca* spp. were observed in the region in 2004 – see Figure A3a.1.4.

The zooplankton community comprises *C. helgolandicus* and *C. finmarchicus* as well as *Paracalanus* spp., *Pseudocalanus* spp., *Acartia* spp., *Temora* spp. and cladocerans such as *Evadne* spp.

A3a.1.6 Features of Regional Sea 3

Waters in the eastern English Channel are mixed and shallow, with strong tidal streams (JNCC 2004) and the plankton community is quite distinct from that seen further west. The PCI reveals lower plankton biomasses in this region than in surrounding waters, with the diatoms *Thalassiosira*, *Rhizosolenia* and *Chaetoceros* (*Hyalochaete* and *Phaeoceros*) and the dinoflagellate species *Ceratium fusus* and *C. tripos* among the most abundant (Johns 2008). Diatoms are dominant for most of the year, with dinoflagellate dominance limited to just January and August. Diatom abundance is greatest in April and May, while dinoflagellates are most abundant in July and August – see Figure A3a.1.3. HABs are not common in this region, due in part to the lower overall phytoplankton biomasses – see Figure A3a.1.4.

Key taxa in the zooplankton community include *Acartia*, *Centropages typicus* and *Temora longicornis* along with decapod and cirripede larvae and chaetognaths. The eastern English Channel is notable for the near absence of euphausiids, cladocerans and echinoderm larvae and the very low biomass of *C. helgolandicus* and *C. finmarchicus* (Johns 2008).

A3a.1.7 Features of Regional Seas 4 and 5

The waters of the western English Channel and Celtic Sea are seasonally stratified, although with greater mixing in shallower parts. There is a heavy terrestrial influence, but also an important oceanic influence from the Atlantic (JNCC 2004). The phytoplankton community in this region comprises *Thalassiosira* spp. (the most frequently recorded phytoplankton taxa), *Rhizosolenia* spp., *Chaetoceros* spp. and *Ceratium* spp. and the PCI is higher than in the eastern Channel (Johns 2008). Diatoms dominate the plankton community from September to May and are most abundant from April to July, with dinoflagellate abundances peaking between June and July – see Figure A3a.1.3. In 2004, HABs of the dinoflagellates *Dinophysis* and *Prorocentrum*, both of which can cause Diarrhetic Shellfish Poisoning (DSP), and *Pseudo-nitzschia*, a diatom associated with Amnesic Shellfish Poisoning (ASP) were recorded – see Figure A3a.1.4.

Small copepods such as *Acartia* spp., *Oithona* spp., *C. typicus*, *Paracalanus* spp. and *Pseudocalanus* spp. are abundant in the region, along with euphausiids, cladocerans and meroplankton such as echinoderm larvae. Amongst the calanoid copepods, *C. helgolandicus* is considerably more numerous than *C. finmarchicus* (Johns 2008).

A3a.1.8 Features of Regional Sea 6

The Irish Sea is strongly influenced by both coastal processes and influxes of water from the continental shelf current and the Celtic Sea. Stratification in the water column is restricted to deeper areas (JNCC 2004). The phytoplankton community within the Irish Sea is typically dominated by diatom species from December to May – see Figure A3a.1.3. Important diatom components of spring blooms in these coastal regions include *Chaetoceros* spp., *Thalassiosira* spp., *Leptocylindrus danicus* and *Leptocylindrus minimus* (Kennington & Rowlands 2007). During the summer months, dinoflagellates dominate the community, with important genera including *Ceratium*, *Gymnodinium* and *Scrippsiella*, as well as the bloom forming *Noctiluca scintillans*. Other causes of HABs in the region include *Pseudo-nitzschia*, *Prorocentrum* and *Phaeocystis* – see Figure A3a.1.4.

The zooplankton community of the region is dominated by copepods which comprise almost 70% of all zooplankton. Of these, the smaller copepods are the most important in the Irish Sea, with species such as *Pseudocalanus elongatus*, *Temora longicornis* and *Acartia clausi* among the most numerous (Kennington & Rowlands 2006). Larger calanoids are also important components of the community, with the warmer water *C. helgolandicus* more abundant than *C. finmarchicus*.

A3a.1.9 Features of Regional Sea 7

The Minch is characterised by sheltered, warm waters mainly comprising North Atlantic Water as part of the continental shelf current and heavily influenced by freshwater run-offs from sea lochs and the Clyde Estuary (JNCC 2004). High riverine inflow is typically associated with higher phytoplankton biomasses and extended seasons of growth due to nutrient inputs. However, due in part to the local geology and to the low level of anthropogenic impact in the northwest of Scotland, nutrient levels can be relatively low in and around these lochs (Kennington & Johns 2007). Tidal stirring and wind mixing will tend to keep shallow regions mixed, with the exception of short periods of fine weather in the summer when thermal stratification may become established, or periods of high freshwater loading which will stimulate haline stratification (Kennington & Johns 2007). As a result, most of the region remains well-mixed, frontal or only weakly stratified through much of the year – see Figure A3a.1.2, although deep sea loch basins are likely to remain stratified. The phytoplankton community within the Minch is typically dominated by diatom species in the first half of the year, and in adjacent sea lochs *Skeletonema costatum* can account for up to 90% of the biomass during the spring bloom (Wood *et al.* 1973). Other important diatom components of spring blooms in these coastal regions include *Rhizosolenia* spp., *Chaetoceros* spp. and *Thalassiosira* spp. (Simpson *et al.* 1979). During the summer months, dinoflagellates dominate the community, with important genera including *Ceratium*, *Protoperidinium*, *Gymnodinium* and *Scrippsiella*.

The dinoflagellate *Alexandrium tamarense*, known to cause PSP, has been reported in a number of the west coast lochs (Tett & Edwards 2002). In 1998, *Chaetoceros wighami* was responsible for the deaths of £500,000 worth of farmed salmon in the region (Treasurer *et al.* 2003). *Phaeocystis pouchetti* has been recorded in waters to the west of Scotland in recent years (Tett & Edwards 2002).

The zooplankton communities of the region are dominated in terms of biomass and productivity by large calanoid copepods. *C. helgolandicus* is present in greater numbers in the shallow, shelf waters of this region than in offshore waters at the same latitude and the population peaks in June (Kennington & Johns 2007). The *C. finmarchicus* population peaks in May and is much more evenly distributed between onshore and offshore areas to the west

of Scotland (Kennington & Johns 2007). Other important copepods include *Acartia* spp., *Oithona* spp. and *Metridia lucens*.

A3a.1.10 Features of Regional Sea 8

This region is influenced by the warm waters of the continental shelf current and the currents entering the North Sea from the northeast Atlantic and the Norwegian Sea (JNCC 2004). The phytoplankton community in these waters is dominated by the dinoflagellate genus *Ceratium* (mainly *C. fusus*, *C. furca* and *C. tripos*), with diatoms such as *Thalassiosira* spp. and *Chaetoceros* spp. also abundant. To the west of Scotland, diatoms such as *Rhizosolenia* spp. and *Fragillariopsis* spp. and coccolithophores increase in abundance towards the shelf edge, while dinoflagellates such as *Protoperdinium*, *Gymnodinium* and *Scripsiella* are also abundant in late summer. HABs caused by *Pseudo-nitzschia* occurred in the region in 2004 – see Figure A3a.1.4.

The zooplankton communities of the Scottish continental shelf region are dominated in terms of biomass and productivity by calanoid copepods, particularly *Calanus* spp. (*finmarchicus* and *helgolandicus*), *Paracalanus* spp. and *Pseudocalanus* spp. Meroplanktonic echinoderm larvae and decapod larvae are also abundant. Other important taxa in the region include *Acartia* spp., *Evadne* spp., *Oithona* spp. and *Metridia lucens*.

A3a.1.11 Features of Regional Sea 9

Regional Sea 9 is a deep, oceanic region, following the contours of the Faroe-Shetland Channel. The region is characterised by cold water inflowing from the Arctic and Norwegian Sea at depths below 600m (JNCC 2004). The Faroe-Shetland Channel will typically have lower phytoplankton biomass and a shorter productive season than waters more influenced by coastal processes (Johns & Wootton 2003). The phytoplankton community in the region is dominated by the dinoflagellate genus *Ceratium* (mainly *C. fusus*, *C. furca* and *C. tripos*), with diatoms such as *Thalassiosira* spp. and *Chaetoceros* spp. also abundant.

The zooplankton communities of the Faroe-Shetland Channel are dominated in terms of biomass and productivity by oceanic calanoid copepods, particularly *Calanus* spp. (*C. finmarchicus* and *C. helgolandicus*), *Pseudocalanus elongatus*, *Metridia lucens* and *Acartia clausii*. The Faroe-Shetland Channel is a particularly important site for *Calanus finmarchicus* as the species over-winters in dense aggregations in cold waters below the warm North Atlantic Current (Heath 1999). Spawning females migrate to surface waters in early spring and are transported to the North Sea by the Norwegian Trench Atlantic Inflow (Madden *et al.* 1999). It is thought that the channel contains the majority of this over-wintering population (Gallego *et al.* 1999). Cyclopoid copepods, such as *Oithona* spp., are also important in the region. Doliolids and salps are oceanic organisms and so are far more common in these waters than in the North Sea. Particularly high abundances of doliolids were recorded in 1989 and 1997 and are indicative of increased oceanic inflow (Edwards *et al.* 1999). The oceanic water travelling through the channel introduces warm/temperate oceanic plankton such as the copepods *Euchaeta hebes*, *Rhincalanus nasatus* and *Eucalanus elongatus*, and the doliolids *Doliolum nationalis* and *Dolioletta gegenbauri* (Edwards *et al.* 1999).

Due to the depth of this region and the vertical distribution of water masses within it, the composition of the plankton community will vary within the water column. Pipe & Coombs (1980) identified five characteristic groups of zooplankton along the northern face of the Wyville Thomson Ridge. Surface waters down to depths of about 160m are dominated by three species, with the most abundant being *Acartia clausii*. The North Atlantic Oceanic Water community is dominated by *Pseudocalanus elongatus* and *Munida* larvae and is

restricted to the upper 420m where temperatures are between 8-8.7°C. A third group of plankton is found throughout the water column and is dominated by *C. finmarchicus*, *M. lucens* and *Scolecithricella minor*. *Metridia longa*, *Calanus hyperboreus*, *Pleuromamma robusta* and *T. longicaudata* dominate the intermediate depths, between 430-510m. Finally, the Norwegian Sea Deepwater plankton community is found at peak abundance between 530-580m depth and is characterised by eight copepods and two chaetognaths, with *Spinocalanus abyssalis* and *Oncaea conifera* the most abundant species.

A3a.1.12 Features of Regional Seas 10 and 11

These deep-water regions are completely oceanic in nature with an absence of terrestrial input and little seasonal variation in primary productivity (JNCC 2004). In these offshore regions, diatoms dominate the phytoplankton assemblage in early spring, with larger taxa such as *Rhizosolenia*, *Fragillariopsis*, *Thalassionema*, *Thalassiosira* and *Nitzschia* dominating. As silicate levels decline, smaller coccolithophores such as *Emiliana huxleyi*, *Coccolithus pelagicus* and *Cyclococcolithus leptoporus* increase in abundance (Okada & McIntyre 1979). A period of dinoflagellate dominance in the phytoplankton community in January and February, as well as in late summer and autumn, is a feature of these offshore regions not seen in other UK waters – see Figure A3a.1.3.

The most frequently recorded zooplankton taxa in the offshore waters of these regions are the euphausiids, with small copepods also abundant. In these cold, oceanic waters, *C. finmarchicus* is more abundant than *C. helgolandicus* (Kennington & Johns 2007). Gelatinous organisms are also particularly abundant in these regions, with an initial increase in biomass in early summer spreading across the continental shelf by the autumn (Witt *et al.* 2007).

A3a.1.13 Evolution of the baseline

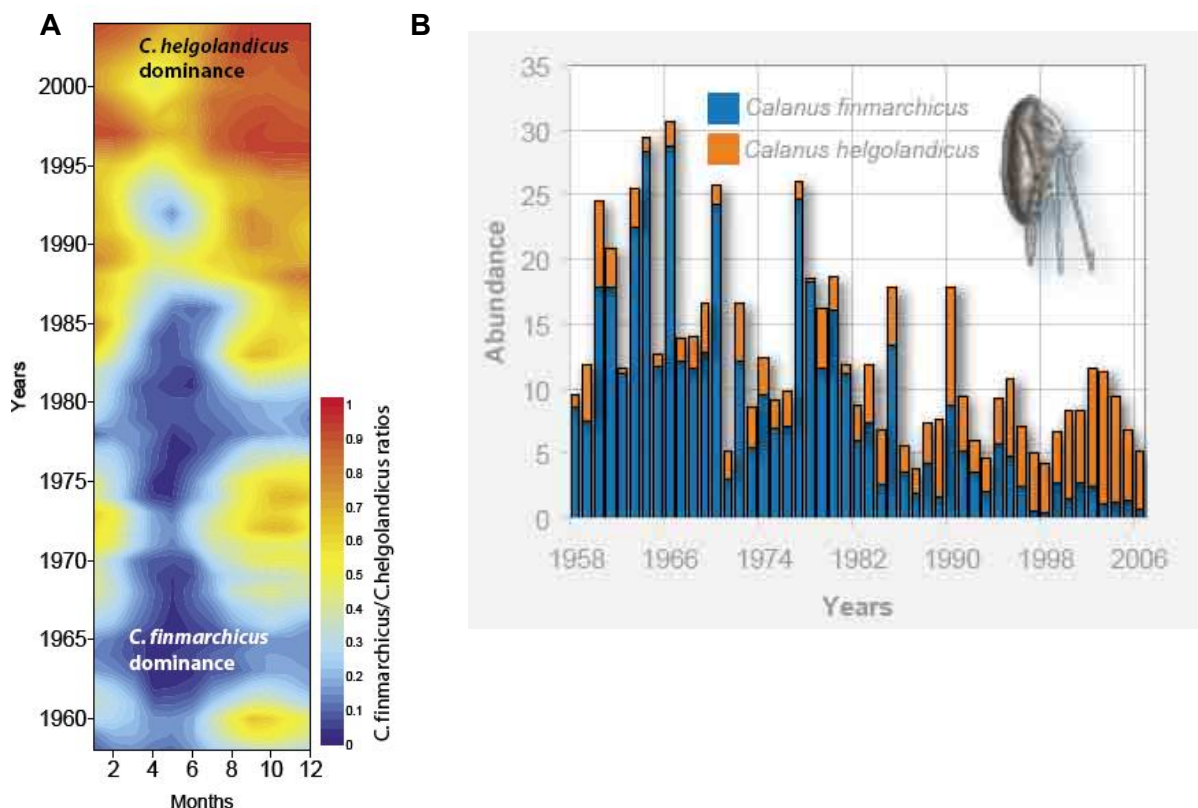
Interactions between the climate and plankton communities are complex and not fully understood and there is considerable debate over the relative importance of various driving forces on the changes that have been observed in the community over recent decades. A key influence of the North Atlantic weather patterns is the North Atlantic Oscillation (NAO). It is described using an index, typically the pressure differential between the Iceland Low and Azores High (Dickson *et al.* 1996). When the NAO is in its negative phase, westerly winds tend to be weaker, and the climate over the North Sea region colder and drier. When in a positive phase, westerly winds tend to be stronger and the climate warmer and wetter. It has been suggested that the state of the NAO is driven in part by SST in the North Atlantic (Rodwell *et al.* 1999). The NAO is also linked to eutrophication, as increased rainfall will increase nutrient inputs.

Phytoplankton biomass as measured on a Phytoplankton Colour Index has increased since the late 1980s across the northeast Atlantic (Edwards *et al.* 2001a). This trend is not fully explained by dinoflagellate and diatom abundances, suggesting that the overall increase in phytoplankton biomass may be due to taxonomic groups which are too small to be sampled by the CPR (Leterme *et al.* 2006). During the 1990s an increase in winter months by over 90% of the long-term mean was recorded (Johns & Wootton 2003). This has been linked to increases in nutrient inputs from European rivers (Richardson 1997), although evidence suggests that the effect of eutrophication on phytoplankton biomass is restricted to coastal regions (Edwards *et al.* 2002). The increase in phytoplankton biomass has recently been linked with an increase in SST and wind strength (Beaugrand 2003) and it has been suggested that dominant trends in the southern North Sea are climatically forced rather than linked with nutrient inputs (Edwards *et al.* 2002). Throughout the eastern North Atlantic

Ocean and European shelf seas, strong biogeographical shifts in all copepod assemblages have occurred, with a northward extension of more than 10° latitude of warm-water species associated with a decrease in the number of colder-water species (Beaugrand *et al.* 2002).

The North Sea is heavily influenced by inflows of water from the North Atlantic. The volume and source of these inflows can have an effect on plankton communities in the North Sea and the effect of exceptional inflows can be significant. In the late 1970s a pulse of cold, low salinity water entered the North Sea, coinciding with a negative phase of the NAO. This event, known as the Great Salinity Anomaly, was possibly associated with particularly cold winters in the southern North Sea and an observed delay in the onset, and decrease in the primary production, of the spring bloom (Edwards *et al.* 2002). At this time, one of the most abundant dinoflagellates, *Ceratium macroceros*, experienced a population crash from which it has yet to recover, perhaps as a result of losing its niche to a competitor (Edwards *et al.* 2002). Conversely, in the late 1980s, warm, more saline oceanic water entered the North Sea (Edwards *et al.* 2002). There is evidence to suggest that a regime shift took place in the North Sea following this event, due in part to hydroclimatic forcing (Beaugrand 2004, Edwards *et al.* 2006a).

Figure A3a.1.5 – ratio of *C. finmarchicus* and *C. helgolandicus* abundances in the North Sea between A: 1958-2004 (by month); B: 1958-2006.



Note: Red values indicate *C. helgolandicus* dominance, blue values indicate *C. finmarchicus* dominance.
Source: A: Edwards *et al.* (2006b); B: Edwards *et al.* (2008).

This warm anomaly is thought to have been an important factor in one of the most studied examples of regime shift in the plankton community. Typically, abundances of *C. helgolandicus* are greatest at temperatures between 13-17°C (Bonnet *et al.* 2005), and are positively correlated with the temperature of the previous year (Planque & Fromentin 1996). Consequently, increasing SST may have resulted in a northwards spread in the population of the shelf dwelling *C. helgolandicus* with a corresponding decline in the oceanic, cold-water

C. finmarchicus (Beaugrand 2003). Increasing dominance of *C. helgolandicus* since the mid 1980s can be clearly seen in Figure A3a.1.5. This figure also shows the seasonal differentiation in population peaks between the species, with *C. finmarchicus* peaking in the cooler spring months and *C. helgolandicus* in the late summer. This differentiation may be altering in the North Sea, with the peak of *C. finmarchicus* abundance arising earlier in the year, although this does not seem to be the case in more northern and western waters (Johns & Wootton 2003). Warm water inflows have also been linked to increases in euphausiid abundances around coastal regions, with consequences for animals that feed on them (Reid *et al.* 2001).

Recent research has suggested that Atlantic inflow into the North Sea is becoming more persistent, rather than episodic. These events have an effect through all trophic levels, potentially resulting in regime shift (Reid *et al.* 2001). This is notable in the phytoplankton community, with an increase in the ratio of dinoflagellates to diatoms in the southern North Sea (Hickel 1998), although it is thought that high nitrate to phosphate ratios as a result of nutrient run-off from land may also be an important factor behind this trend (Edwards *et al.* 2001a). As well as this, a number of dinoflagellates have been recorded reaching their peak abundance up to two months earlier during the 1990s than the long-term mean (Johns & Wootton 2003). This could have important ramifications for marine ecosystems, as dinoflagellates are less palatable than diatoms for copepods and fish larvae (McQuatters-Gollop *et al.* 2007) and many species are noxious to other organisms. Additionally, the growing season of phytoplankton has extended, with less distinction between seasonal blooms (Edwards *et al.* 2001a). This may result in the settling of ungrazed phytoplankton on the seabed (Reid *et al.* 2003), and potentially an increase in meroplankton from the larvae of benthic organisms, a trend that has been observed within the North Sea (Lindley & Batten 2002). The southern North Sea has shown a particular increase in abundance of decapod larvae over the last 40 years (Edwards *et al.* 1999).

It is therefore apparent that hydro-climatic events are important factors in the marine ecosystem. Organisms will respond differently and at different rates to climatic events (Beaugrand 2004), and it has been suggested that this may lead to the decoupling of biological relationships and changes at the level of the ecosystem (Edwards & Richardson 2004). Predictions of future change are difficult to make as detailed understanding of the effects of climate is limited. A recent report by the Marine Climate Change Impacts Partnership (MCCIP) (Edwards *et al.* 2007) suggests with a medium to low confidence rating, that changes in geographical distributions of centres of plankton production occurring over the next 0-5 years could affect biogeochemical cycling, oxygen production, carbon sequestration and fish, mammal and seabird populations within the next 20-50 years.

A3a.1.14 Environmental issues

A3a.1.14.1 Sensitivity to disturbance and contamination

Effects of hydrocarbon contamination on plankton have not been studied extensively, although the effects from relatively recent oil spills from tankers e.g. *Torrey Canyon*, *Exxon Valdez*, *Braer* and *Sea Empress* have been assessed.

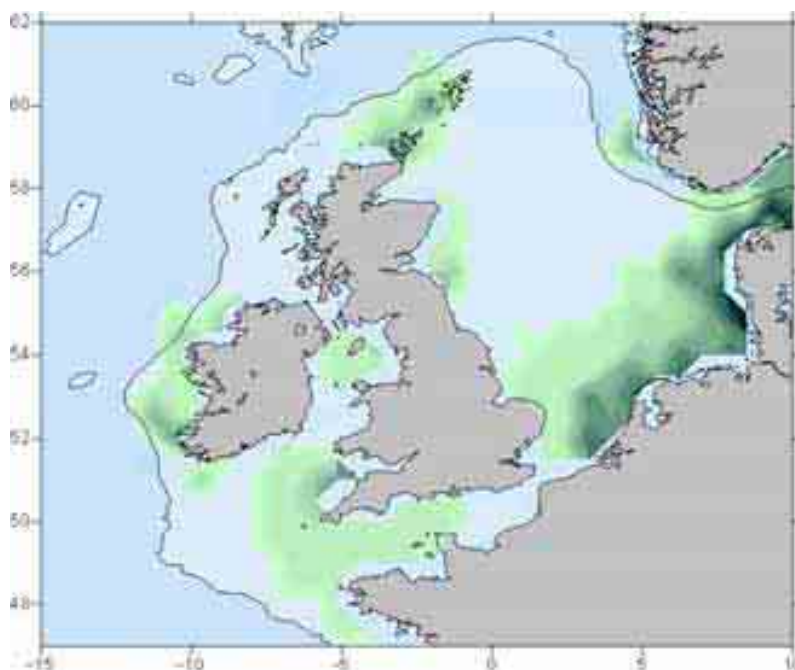
Work after the *Sea Empress* spill off the coast of southwest Wales failed to find any significant effects on the plankton (Batten *et al.* 1998), although other studies have shown lowered fecundity and offspring mortality (van Beusekom & Diel-Christiansen 1993). There is also a strong suggestion that dispersant treated oil has a more pronounced effect (van Beusekom & Diel-Christiansen 1993). Any long-term genetic changes are difficult to assess.

Oil pollution from exploration/production only forms a small percentage of entry of oil to the marine environment. In less major spills, bacteria can play an important role in removing the oil. Produced water from oil and gas extraction may include dissolved hydrocarbons, organic acids and phenols which are used in biocides, corrosion and scale inhibitors and gas treatment. Plankton may be exposed to these contaminants through passive diffusion, active uptake or through eating contaminated prey. As plankton spend most of their lives in the water column, they will be particularly exposed to those contaminants that remain in solution (Sheahan *et al.* 2001). Produced water has been shown to affect recruitment in calanoid copepods (Hay *et al.* 1988). The toxicity of produced water will decrease as it disperses away from the source. Stomgren *et al.* (1995) found that acute toxicity in the diatom *Skeletonema* spp. was only likely in individuals in the immediate vicinity of the source of produced water, while at distances greater than 2km the effects are negligible.

A3a.1.14.2 Ballast water and invasive species

Ballast water in ships has long been recognised as a source for the introduction of non-indigenous and potentially harmful organisms. A number of non-native planktonic organisms have been identified in UK waters, including diatoms such as the Indo-Pacific *Odontella sinensis* (Ostenfeld 1908) and *Coscinodiscus wailesii* (Edwards *et al.* 2001b), which is now particularly abundant in waters near to the continent - see Figure A3a.1.6.

Figure A3a.1.6 – Estimates of the mean log abundance of *C. wailesii* in the North Sea between 1985-1995.



Note: Darker colours indicate greater abundance. Source: Edwards *et al.* (2001b).

Changes in the climate are also likely to result in an incursion of non-indigenous species; rising SST is already leading to northwards incursions of warmer water species such as *C. helgolandicus*. In the northern North Sea, the diversity of zooplankton species has increased, due in part to large numbers of non-native migrants from warmer waters (Lindley & Batten 2002). There is a growing concern about the risk of invasive species and the importance of protecting native biodiversity. With raised awareness, there are a variety of operational and technical innovations being introduced (e.g. through IMO 2003) to reduce the risk of organism transfer via ballast water. The threat of invasion will be greater from

those species that can form resting stages that may remain inert in ballast water for a considerable time.