Climate change and the Continuous Plankton Recorder survey

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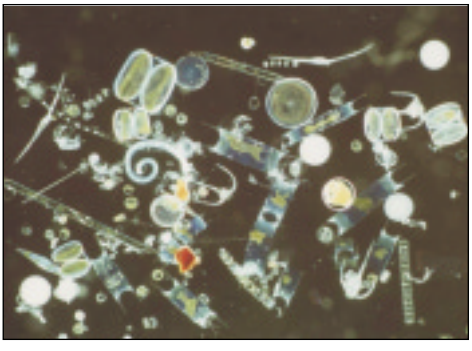
The Continuous Plankton Recorder (CPR) survey, which is operated by the Sir Alister Hardy Foundation for Ocean Science (SAHFOS) will be 70 years old in 2001 during which time close to 4 million nautical miles of the oceans have been sampled. This remarkable achievement has only been made possible through a partnership with more than 200 vessels and the voluntary assistance of many shipping companies, agents, stevedores, Masters and crew. All onboard operations including deployment and recovery are carried out in totality by the ship's crew. The survey and its products are unique as they comprise the only long-term operational monitoring programme for plankton, that extends in most ocean basins.

In contrast to the meteorological sciences there are few long-term datasets of biological information in the world, and on land those that do exist are difficult to interpret because of the development of agriculture and the effects of pollution. The oceans and shelf seas are still relatively pristine and changes in the abundance and composition of the plankton are more likely to be a response to 'natural' variability. As free floating organisms they are highly dependent on their immediate environment and can integrate effects of meteorological and hydrographic variability. Plankton has a second more direct role with respect to climate change through the export of CO_2, via what is known as the 'biological pump', to the deep ocean and in the production and export to the atmosphere of chemicals such as Dimethylsulphide (DMS) that may reinforce global warming. Clear evidence of pronounced trends and decadal change is seen in the results of the CPR survey. These changes may be acting as a 'barometer' or early warning of the effects of climate change on the oceans.

Plankton

The free floating plant life of the sea (phytoplankton), at the base of the food web, provides food for the animal plankton (zooplankton) and in turn the fish and their predators. Many of these tiny organisms exhibit spectacular patterns of shape and colour (Figure 1). For example, the dominant group in the phytoplankton, diatoms, are enclosed in two glass cups like an old fashioned pill box, often with attached spines, and under the microscope are often iridescent. Copepods are the dominant zooplankton group in the North Atlantic. They are small (typically 1 mm long) crustaceans with long antennae at the front of a muscular body that may be bright red due to oily storage products.

Light, nutrients and the degree to which the water is mixed are the main agents governing the growth of phytoplankton. Many of these factors in turn are dependent on, for example, wind strength/direction/frequency, cloudiness and precipitation which exert a strong influence on the upper 100 m of the water column. Even in clear tropical waters light only penetrates down to 100 m so most



Norman Nicholl

Figure 1: Phytoplankton

phytoplankton are found in the upper 40 m. The majority of zooplankton are also found in the upper layer of the water column although some show patterns of daily vertical migration over hundreds of metres, apparently as a predator avoidance mechanism.

The Continuous Plankton Recorder survey

The CPR towed body (Figure 2) is deployed at a depth of approximately 10 m from merchant ships, weather ships (to 1996) and more recently some naval hydrographic survey vessels on their normal routes of passage. Plankton is filtered on a band of silk that moves past an aperture at a rate that is proportional to the speed of the ship. A roll of four metres of silk is equivalent to a tow of 400 nautical miles. To enable sequential tows to be made on long routes a cassette system is used. The silks are cut into 10 nautical mile samples on which phytoplankton and zooplankton are counted and identified under a microscope into ~400 taxonomic categories.

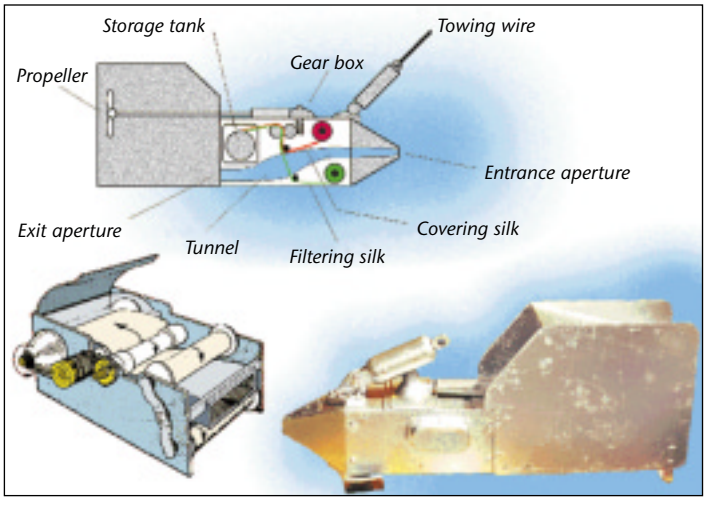


Figure 2: The Continuous Plankton Recorder and its components

Starting in the North Sea in 1931 the survey extended out into the Atlantic in 1939. Currently, the core operational area reaches from the east coast of the USA to the north west European shelf between approximately 37° N and 64° N. While most CPR samples have been obtained in this core area the database, which contains more than 2 million data points for the period from 1946 to present, includes samples from all the oceans of the northern hemisphere. In addition a small CPR survey is operated by the US National Marine Fisheries Service in the Gulf of Maine and to Bermuda. In 2000 a new synoptic survey, operated by SAHFOS, was initiated in the north-east Pacific with five tows between Alaska and California using the s.s. *Polar Alaska* and s.s *Polar Independence* and one between Canada and Kamchatka using the m.v. *Skaubryn*.

A sister survey which operates in the Southern Ocean uses the research vessels of the Australian Antarctic Division to tow CPRs between Tasmania and the Australian bases in Antarctica. Three parallel north/south CPR transects across the Southern Ocean along approximately 25° E, 110° E and 158° E were completed by this survey in collaboration with the Japanese Polar Institute within a two-week period of the winter of 1999. The CPRs towed for this unique initiative used the Australian research ship *Aurora Australis* and the Japanese vessels *Kaiyo Maru* and *Shirase* (an icebreaker). The plankton of the Southern Ocean has been little studied and the samples generated by this programme are giving a new insight into the dynamics of the major plankton group in this region of the world, crustacean euphausiids known as krill.

Logistics and operations of the CPR survey

The one-metre long, 87-kg CPR is a well-proven technology that is rugged, reliable and capable of withstanding at times harsh handling experienced during transport and deployment. Machines have even survived operation in up to force 12 storm conditions and are rarely lost at sea, which is a compliment to the seamen that deploy them and the skill of the SAHFOS workshop staff. Typically 90 per cent of tows return useable plankton samples. The length of the towing cable is adjusted according to the speed of the ship and may be up to 80 m astern. For most vessels a purpose-made davit or tow point is installed from which to deploy CPRs.

Maintaining a routine synoptic survey using ships of opportunity is a major exercise. Typically 22 routes are towed in the core region each month and more than 80,000 nautical miles are sampled each year. Dispatch of CPRs in their distinctive yellow boxes by road carrier to a UK port and return to the Laboratory in Plymouth may take anything from two weeks to many months. At present, trading patterns of ships are continually changing and it is proving increasingly difficult to maintain tows on standard routes for long periods.

By tradition the survey has employed an ex-merchant navy Captain as Marine Survey Manager, and much of the success of the current survey is down to the enthusiastic liaison of the present holder Captain Peter Pritchard. Peter regularly visits tow vessels and supervises the design and installation of davits as well as assisting with trials of new instrumentation. Our naval links were further strengthened in 2000 by the appointment of Commander Alan Johnson (RN Retd) as Assistant Director with responsibility for administration.

The North Atlantic Oscillation

Strong associations have been demonstrated between the plankton sampled by the CPR and a major mode of atmospheric variability in the northern hemisphere known as the North Atlantic Oscillation (NAO). The NAO is an alternation in the atmospheric pressure difference between the low pressure zone that is typically centred over Iceland and the subtropical high pressure zone centred over the Azores[1]. The oscillation has a pronounced effect on temperature, wind and precipitation especially in northern Europe and has been linked to changes in current strength and direction as well as the formation of deep water in the Greenland Sea and intermediate water in the Labrador Sea. Four layers of increasing density can be distinguished in the northern Atlantic from top to bottom. An upper layer equivalent to the depth of winter mixing by the wind (typically 0–600 m), an intermediate layer (normally down to 1,500 m), a deep layer down to 4,000 m) and, in the west below this layer, northerly penetration of Antarctic bottom water.

Formation of dense salty water at the surface in Nordic seas that sinks rapidly to top up the deep water layer is what pulls the warmer surface waters of the Atlantic towards the Arctic Ocean. This exchange is part of what is known as the 'Global Conveyor Belt' and ensures that Europe has a much warmer climate than its equivalent latitude (Labrador) on the other side of the Atlantic. Some copepod plankton sampled by the CPR have undergone large vertical migrations as they are normally associated with intermediate or deep water or 'hibernate' in these waters during winter months. Their patterns of occurrence reflect some of the dramatic changes that have been observed by hydrographers in the formation and distribution of intermediate and deep water over the last few decades. Since 1988 we have been in a strong positive phase of the NAO

[1] To characterise variability in the NAO, an index is calculated from the difference in sea-level pressure between the Iceland Low and Azores High (determined at standard met. stations). This index is a measure of the strength of the westerlies especially in winter months. When the index is high the westerlies are strong and vice versa.

index; in consequence, deep water formation has ceased in the Greenland Sea and, in the early 1990s, the Labrador Sea became an important site of intermediate water formation (Figure 3). Penetration of water from the North Atlantic current into Nordic seas appears to have reduced compared to a low NAO situation as found during the 1960s to 1970s, at the same time as an apparent increased northerly penetration of warmer water in the shelf edge current at the eastern margin of Europe. These patterns of physical change are backed up by biological evidence from CPR plankton.

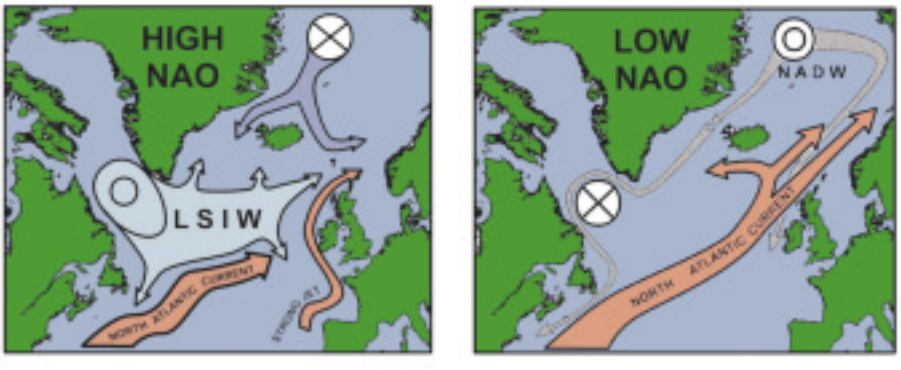
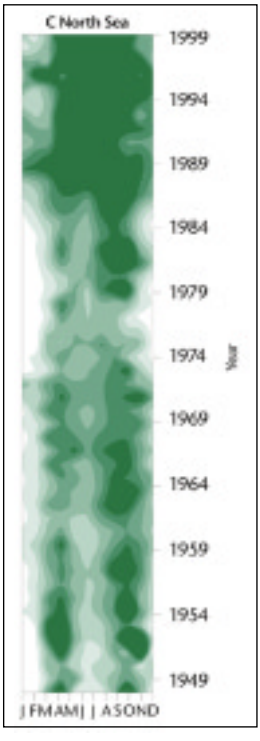


Figure 3: Phases of the North Atlantic Oscillation. (LSIW — Labrador Sea Intermediate Water formation. NADW — North Atlantic Deep Water formation)

Regime shift in the North Sea

What has been termed a regime shift occurred in the North Sea around 1987/88, approximately when the NAO changed to a strong positive phase. Regime shifts are step-wise alterations in the composition and productivity of plankton and fish, at a regional scale, that reflect major hydrographic change. The changes seen in the North Sea are clearly evident in the Phytoplankton Colour index of the CPR survey (Figure 4). When CPR silks are returned to the laboratory the colour on the surface is visually characterised (based on a standard colour card) into three levels of greenness and zero colour. While only a coarse visual index of chlorophyll, the many samples taken in the central North Sea each month of the year over the last 50 years (>20,000) clearly define progressive changes in the abundance and timing of the phytoplankton growing season. Large increases also occurred in the catches of some fish species and in the biomass of organisms living on the bottom. Associated changes in the physical characteristics of the North Sea included an increased influx of oceanic water and higher sea temperature.



Coinciding with the beginning of the regime shift a major incursion of oceanic water into the North Sea from the eastern boundary shelf edge current to the west of the British Isles appears to have occurred. This water carried with it unusual southerly plankton more characteristic of the Bay of Biscay and further south. These lusitanean species included a gelatinous tube-like plankton species that sucks and filters

Figure 4: Phytoplankton Colour Index for the North Sea, 1949–1999

very large volumes of water to derive its food known as *Doliolum nationalis*. This species had not been seen in the North Sea since 1911 and then only occurred rarely. In contrast, in the autumn of 1989 and in 1998 when a second major incursion of oceanic water appears to have occurred, this species was extremely abundant. Evidence that the eastern boundary current was stronger at these times has been derived from hydrographic sections made across the Rockall Trough. Satellite measurements of sea surface temperature along the European shelf edge suggest that pulses of warm water have extended north along the shelf over hundreds of miles. A number of fish species, some subtropical, appear to have extended their northerly range as part of these events possibly as a response to the higher temperatures found in European waters in recent years.

Plankton changes in the north-west Atlantic

The CPR routes operated by SAHFOS in the western Atlantic form an integral part of the monitoring programme of the Canadian Department of Fisheries and Oceans. The cod fishery of the North-west Atlantic was of major economic and social importance to Eastern Canada until it started to decline in the mid to late 1980s reaching a crisis in 1990/91 when the fishery was closed. Unfortunately, the CPR survey in this region was not operating during the crucial period of change in the cod fishery because of a lack of funding. It is however possible to make a comparison between sampling that was undertaken between approximately 1960 and 1980 and the new survey, which started again in 1991. Pronounced differences are evident between the two periods. Since the early 1990s in the western Labrador Sea and over the Grand Banks there has been a sharp decline in juvenile copepods and euphausiids at the same time as a marked rise in the Phytoplankton Colour index and changes in the composition of the phytoplankton. Small copepods form possibly the main food source for larval cod and the reduction in their abundance is likely to be a major factor in the decline of cod recruitment.

The Biological Pump and DMS

Phytoplankton play an important role in determining the atmospheric concentration of CO_2 by transporting CO_2 from the surface ocean to the deep ocean. They uptake CO_2 by photosynthesis in the surface waters and export a fraction of this carbon to the deep ocean in what is known as the 'biological pump'. The operation of this pump means that the atmospheric CO_2 concentration is lower than it would be if the ocean was devoid of phytoplankton. Any substantial alteration, on a global scale, of the composition or functioning of the present-day phytoplankton distribution would have significant implications for atmospheric CO_2, in addition to anthropogenic carbon release. This could act as a feedback mechanism altering the pace of climate change.

A second potential ocean biological feedback to climate is through the natural sulphur compound Dimethylsulphide (DMS). DMS is produced by many phytoplankton, and the amount of DMS produced by different groups of phytoplankton can vary greatly. A fraction of DMS passes to the atmosphere where it can form aerosols that modulate cloud properties such as cloud lifetime and albedo. Simulations by the Met Office Hadley Centre using their Global Climate Change model have indicated that climate is sensitive to ocean DMS emissions (personal communication: Steve Spall). As little is known about how ocean DMS emissions may alter in the future, this is a further potential feedback mechanism that may influence climate change.

Conclusions

Observations from the CPR survey and analyses of other long data sets have shown that pronounced changes have taken place in the shelf sea and oceanic ecosystems of the world. The extent to which these are natural events as part of long-term cycles or may be forced by global warming is still far from clear. What is evident is that these

changes have major implications for the productivity of regional seas and their harvestable living resources. Part of the reason for the collapse of the cod fishery in Canadian waters, and for the similar collapse of the herring fishery in the North Sea in the late 1970s, is now believed to be linked to associated changes in the plankton, although over-fishing is clearly also implicated. The observed changes in the plankton appear to be closely associated with alterations in the circulation and strength of major currents, which have implications for future weather patterns of adjacent land regions. If climate change is forcing these events, feedback mechanisms may reinforce or reduce the biological pump with possible major consequences for the CO_2 cycle. Developing an improved understanding of plankton abundance and distribution is thus of key importance to understanding and forecasting future climate change scenarios.

The CPR survey was incorporated in 1999 into the Initial Observing System of the Global Ocean Observing System (GOOS). The Inter-governmental Oceanographic Commission and the World Meteorological Organisation jointly co-ordinate GOOS. The survey, as a long running existing survey, fits well into the developing plans of GOOS. The Initial Observing System includes measurements from ships, buoys, coastal stations and satellites although up to the present the emphasis has been on physical measurements. In collaboration with the merchant marine SAHFOS has pointed the way to a system that could be extended to form a series of regional scale programmes to monitor the biology as well as the physics and chemistry of the oceans under the flag of GOOS.

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References

http://www.npm.ac.uk/sahfos/

Beaugrand, G., Reid, P.C., Ibanez, F. and Planque, B., 2000: Biodiversity of North Atlantic and North Sea calanoid copepods. *In* Marine Ecology Progress Series, **204**, 299–303

Hardy, A.C., 1956: The Open sea: The world of plankton. J. Fisher, J. Gilmour, Sir J. Huxley and L. Dudley Stamp, (Editors). Collins, London.

Mann, K.H. and Lazier, J.R.N., 1991: Dynamics of Marine Ecosystems: Biological-Physical Interactions in the Oceans. Blackwell Scientific Publications. Cambridge.

Reid, P.C., de Borges, M.F. and Svendsen, E., 2001: A regime shift in the North Sea circa 1988 linked to changes in the North Sea horse mackerel fishery. *In* Fisheries Research, **50**, 163–171

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

Sameoto, D., 2001: Decadal changes in the phytoplankton colour index and selected calanoid copepods in Continuous Plankton Recorder data from the Scotian Shelf. *In* Canadian Journal of Fisheries and Aquatic Sciences, **58**, 749–761.

IPCC, 2001: Working Group I Climate Change 2001: The Scientific Basis.