



Continuous Plankton Recorder sampling off the east coast of North America: history and status

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Abstract

The Continuous Plankton Recorder (CPR) survey has sampled plankton on 14 routes off the coasts of the northeast United States and Canada between 1959 and 2000. Six of these routes are still operating and are sampled on a monthly basis. Some 2047 CPR tows have been made to the end of 2000 and the resulting database represents the most extensive time series of marine plankton available anywhere in the northwest Atlantic. The location and time span of coverage of each route is presented. In addition selected information is presented on:

1. zooplankton abundance as departures from baselines for the northeast US continental shelf;
2. interannual variation in seasonality of Gulf of Maine phytoplankton;
3. zooplankton relationships to local hydrography of the Gulf of Maine and to the North Atlantic Oscillation;
4. time-space matrices of zooplankton abundance and anomalies southeast of New York City;
5. time series of phyto- and zooplankton on the Scotian Shelf;
6. seasonal cycles of Phytoplankton Colour and of zooplankton on the Scotian Shelf and Georges Bank, and in the Gulf of Maine; and
7. monthly abundance of zooplankton in Narragansett Bay, Rhode Island.

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Among the many hundreds of thousands of nautical miles towed with Continuous Plankton Recorders (CPR) (Hardy, 1939; John & Reid, 2001) on routes in the North Atlantic Ocean are 14 routes adjacent to the east coast of North America (see Fig. 1 and Table 1). Six of these routes have been sampled for several decades. They are the longest time series of marine plankton collected on the east coast of North America and are among a small number of such standardised, long-term data sets available from anywhere in the world. Although a number of institutions are now involved in the maintenance of these routes, the bulk

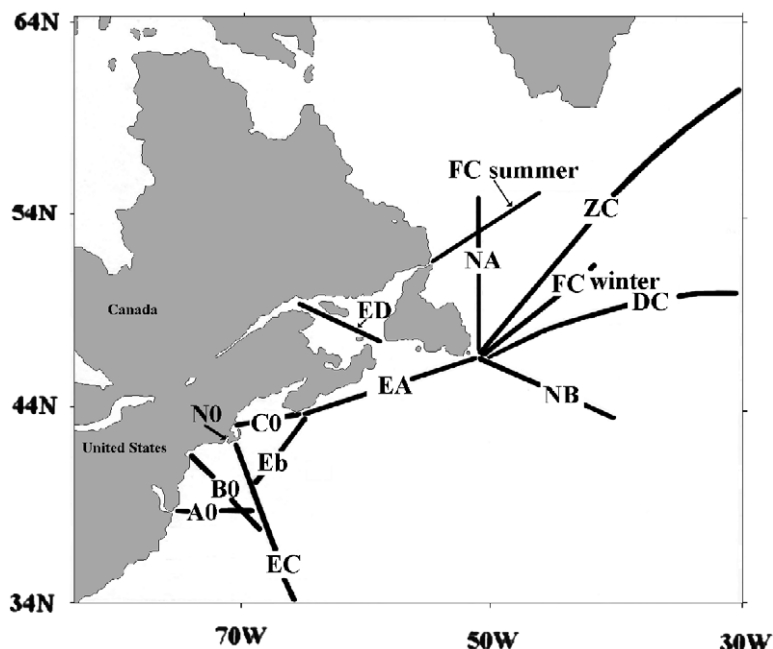


Fig. 1. Continuous Plankton Recorder routes off the east coast of North America since 1959.

Table 1

CPR and CPER routes sampled off northeast USA/Canada from 1959 through 2000

Route	Start	Finish	From	To	No. of tows on route (through 2000)	Years sampled (through 2000)	
A0	Aug 1974	Jul 1980	Chesapeake Bay	eastward	65	7	
B0	Jan 1976	Current	New York City	500 km out towards Bermuda	325	25	
C0	Jul 1961	May 1977	Boston, Massachusetts	Cape Sable, Nova Scotia	300	38	
DC	Jul 1961	Mar 1982	51°00'N 42°00'W	St John's, Newfoundland	176	22	
EA	Jul 1961	Mar 1991	Halifax, Nova Scotia	St John's, Newfoundland	247	26	
EB	Jul 1961	Mar 1991	Boston, Massachusetts	Halifax, Nova Scotia	247	24	
EC	Apr 1965	Jun 1974	Nantucket Isle	34°00'N 66°00'W	5	(4)	
ED	Jul 1966	Jul 1966	Cabot Strait	St Lawrence River mouth	1	(1)	
FC (winter—see text)	Mar 1963	Apr 1975	Oct 1968	Mar 51°20'N 42°00'W	Cape Race, Newfoundland	21	8
FC (summer—see text)	Mar 1963	Apr 1975	Oct 1968	Mar 55°20'N 46°30'W	Belle Isle Strait	21	8
FD	Apr 1975	Sep 1975	Similar to FC	Similar to FC	3	(1)	
NA	Feb 1963	Jan 1974	St John's, Newfoundland	56°30'N 51°00'W (OWS 'Bravo')	116	12	
NB	Jun 1963	Jun 1973	St John's, Newfoundland	44°00'N 41°00'W (OWS 'Delta')	100	11	
ZC	Jun 1959	Mar 1991	Cape Race, Newfoundland	51°50'N 45°00'W	387	33	
N0 (CPER)	1998	Current	Narragansett Bay	Mount Hope Bay	33	3	

of credit for their existence belongs to the staff of the Sir Alister Hardy Foundation for Ocean Science (SAHFOS) and its predecessors. Six of the 14 routes—the B0, C0, EA, EB, N0 and ZC—are currently active (see Table 1). For all routes the methods of sample collection and examination, and of data processing conform to the standards of SAHFOS (Warner & Hays, 1994). Minor differences in phytoplankton analysis and in data processing have arisen in the past, but these have now been addressed. The purpose of this paper is to present for these somewhat lesser studied routes their history and spatial extent, the concurrent measurements being made, and some of the results thus far obtained.

2. North American routes

Annual maps plotting the CPR routes towed in the northwest Atlantic from 1959 to 1993 were shown by Warner and Hays (1994). From these it can be seen that sampling was most intensive during the period 1963 to 1973. However, these maps do not show sampling that took place on the A0, B0, C0, and N0 routes after 1973. In the year 2000, CPR tows were made for a total of 22,336 nautical miles (41,339 km) along the six currently sampled routes off the northeast coast of North America.

All the CPR samples collected along the DC, EA, EB, EC, ED, FC, NA, NB and ZC routes have been processed in the UK by SAHFOS or its predecessors and are now stored in Plymouth, UK. Samples taken

along the A0, B0, C0 and N0 routes have been processed under the direction of the US National Oceanic and Atmospheric Administration-Fisheries (NOAA-Fisheries) Narragansett Laboratory. The samples for these four routes are stored at Narragansett, USA.

Quantitative standards and data comparability between routes have been assured through continuing exchange of data, software and staff between the institutions. The original plankton samples for these routes are preserved in buffered 4% formalin; they are ‘on-silk’ samples, i.e. the plankton is retained within a silk ‘sandwich’, and remains available for further examination by *bona fide* researchers. To obtain further details contact the relevant authors.

2.1. The ZC route

The initiation of CPR sampling off the northeast coast of North America took place in June 1959 when a CPR was towed along the ZC route between 56°00′N 45°00′W and the mouth of the Belle Isle Strait (Fig. 1). The ZC route is a south-westerly extension of the Z route that is towed from Reykjavik in Iceland. In 1961 the first of a series of contracts was awarded by the US Navy’s Office of Naval Research (ONR) to the Oceanographic Laboratory of the Scottish Marine Biological Association (SMBA) in Edinburgh. As a result, a major expansion in CPR sampling off the northeast coast took place in July 1961 when three new routes EA, EB and DC, were set up. Sampling along ZC halted in April 1981, but in response to renewed funding from Canada and the United States, it was re-established in March 1991 together with the EA and EB routes. The resumption of monthly sampling along these routes was at a time when the interest of the Canadian Department of Fisheries and Oceans was aroused by the collapse of the Canadian east coast ground fishery in the late 1980s and early 1990s.

The ships towing CPRs along ZC (and also along DC and FC) sail south of Cape Race, Newfoundland, in winter when the Belle Isle Strait is frequently iced up. In summer a more northerly course is followed to the mouth of the Belle Isle Strait. Temperature recorders were added to CPRs sampling along ZC in 1996 and are still in use.

2.2. The EA and EB routes

The E route (Fig. 1) was initiated in July 1961, covering the region from Cape May, New Jersey, USA (39°00′N) across the Gulf of Maine (EB route) and Scotian Shelf to St John’s, Newfoundland (54°00′N) (EA route). The EB route resulted in a major contribution of data to the C0 route described below. The route was sampled quasi-monthly until May 1976 when the sampling ceased. During this period funding for the E route was provided by the ONR and by the predecessors of SAHFOS.

The tracks of EA and EB in 1961 to 1976 went from St. John’s, Newfoundland, across the central region of the Scotian Shelf, through the Gulf of Maine, and onwards to Cape May. There were occasional ship stops in Halifax resulting in samples being collected near the coast in the Nova Scotian Current (Fig. 1). However, since 1991, stops in Halifax have been less frequent so that the route is now usually nearer to the central and southern region of the Scotian Shelf, so the central region of the Nova Scotian Current is now rarely sampled. Moreover the route followed in the 1990’s does not sample the Gulf of Maine, as previously, but crosses from the Scotian Shelf on to Georges Bank, thus providing the first monthly time series of plankton data from the Bank. Initial support for this modified route came from NOAA-Fisheries and more recently from the US National Science Foundation.

Conductivity-temperature-depth-fluorescence (CTDF) recorders have been deployed routinely along EA and EB since 1994. They performed poorly in 1994, because of problems with battery life in the cold sea temperatures, but performance was much improved in 1995 and thereafter. Temperature recorders were added to CPRs along EA and EB from June 1996 to June 1997 to act as a cross-check with the CTDF data.

2.3. The C0 route

From July 1961 until October 1974 the Oceanographic Laboratory in Edinburgh, Scotland, conducted monthly monitoring using the CPR on what is now known as the C0 route in the Gulf of Maine between Cape Sable, Nova Scotia, and the Boston, Massachusetts, area (Fig. 1). During these years this route was labelled 'EB'. In 1972 US NOAA-Fisheries and the U.K. Natural Environment Research Council developed an aide-memoire for the extension of the long-term CPR survey into additional areas of the western North Atlantic. On the U.S. side the resulting monitoring programme was designated as the Marine Resources Monitoring, Assessment and Prediction (MARMAP) Ships of Opportunity (SOOP) Program. The SOOP routes are meant to supplement the time and space coverage of their research-vessel surveys, and to allow examination of spatial and temporal variations at scales smaller than those permitted using research-vessel data. From 1972–1974 SOOP staff handled logistics for this route, preparing instruments, meeting ships, training personnel, and sending samples and data to Edinburgh for analysis. During 1974 it became impossible to find a vessel able to tow the CPR along this route, but in 1977 a new vessel had been located and the entire operation, including data processing and analysis, was moved to Narragansett.

The C0 or 'Gulf of Maine' route extends from the Massachusetts coast, to Cape Sable, Nova Scotia, for a distance of 244 nm (452 km). Because the ships of opportunity that tow the CPR follow slightly different paths from month to month, a tetragon was devised to define the route and to exclude any outlying samples during analyses. The four corners of this tetragon are defined by the following geographical positions: 43°30'N 71°00'W; 43°30'N 65°37'W; 43°00'N 65°37'W; 42°00'N 71°00'W. This tetragon includes the following geographic regions of the Gulf of Maine: Massachusetts Bay, Wilkinson Basin, the central Gulf ledges, the southern Jordan Basin, the Crowell Basin, and the western Scotian Shelf.

In addition to the SAHFOS standard processing, plankton abundance data are converted to units more easily compared with NOAA-Fisheries research-vessel results, i.e., No/100m³ for zooplankton and No/m³ for phytoplankton. Also, because of the one-dimensional spatial nature of the data, they are routinely processed into time-space matrices for the purposes of map algebra analyses.

In 1978, as part of an agreement with the United States Maritime Administration (MARAD) and NOAA's National Ocean Service (NOS), concurrent measurements of water-column temperature by means of expendable bathythermographs (XBTs), and surface salinity were added along C0. In 1991, with the assistance of NOS and NOAA's National Weather Service (NWS), continuous near-surface temperature and salinity measurements were also taken, and water-column temperature and weather observations were transmitted to shore via satellite.

2.4. The DC route

The final 450 nm (834 km) section of the route that ran westwards from Fastnet, Ireland, to St John's, Newfoundland, was designated the DC route (Fig. 1). The sampling started in July 1961 and ended in March 1982. It went from ca 51°00'N 42°00'W to St John's, Newfoundland. As with the ZC and FC routes, in summer DC followed a more northerly course into the mouth of the Belle Isle Strait in the summer months.

2.5. The NA and NB routes

Two new routes, NA and NB, were started in 1963, with the CPRs being towed by US Coast Guard cutters from St John's, Newfoundland, out to Ocean Weather Station (OWS) 'Bravo', in the Labrador Sea (NA route), and to OWS 'Delta' (NB route). These routes (Fig. 1) were funded by ONR. The sampling of these two routes finished when the two weather stations ceased operating in January 1974 (Bravo) and June 1973 (Delta), respectively.

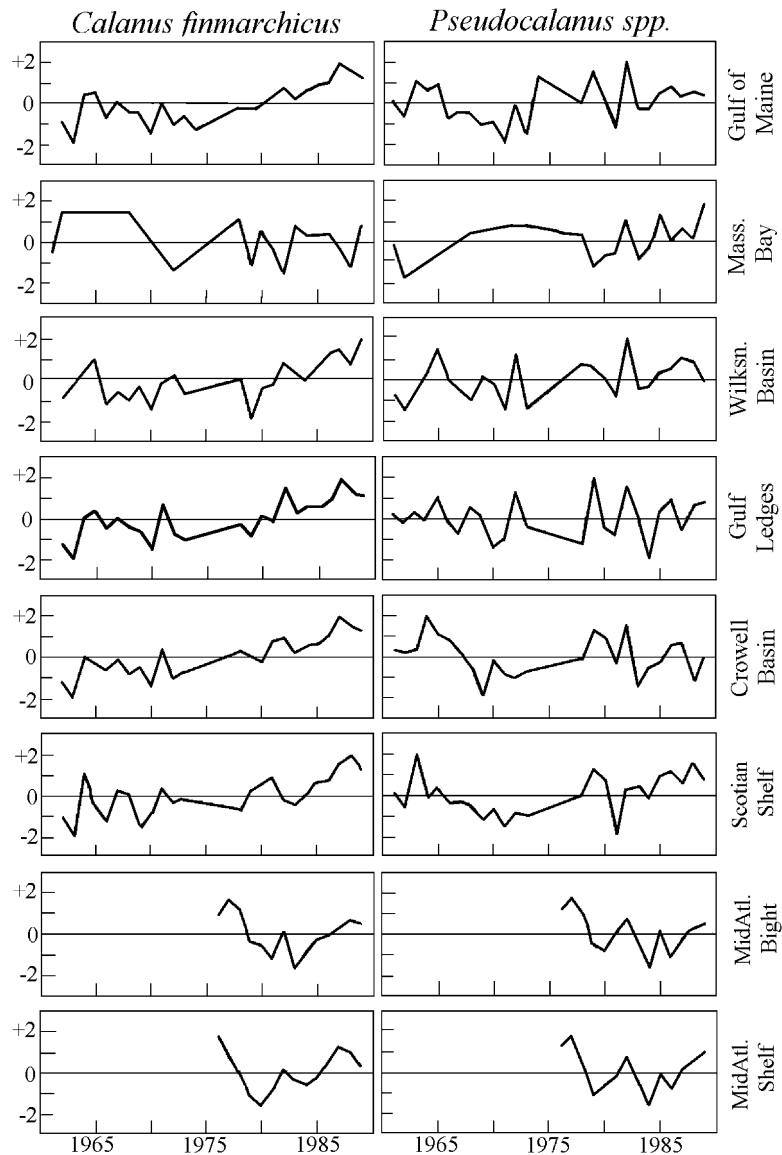


Fig. 2. Variation in the annual abundance of *Calanus finmarchicus*, and *Pseudocalanus* spp., standardised to a mean of zero and unit standard deviation, for regions of the US north-east shelf ecosystem from 1961 through 1989. From Jossi and Goulet (1993).

2.6. The FC route

The FC route (Fig. 1) was sampled from March 1963 to October 1968 and was resumed for a short time between April 1975 and March 1976. In summer it started at ca 55°20'N 46°30'W and passed into the mouth of the Belle Isle Strait, to the north of Newfoundland. However, in winter when ice occurred in Belle Isle Strait, the route passed further south around Cape Race, Newfoundland, closer to DC. Sampling along FC route came to an end in March 1976 when the ships were re-routed.

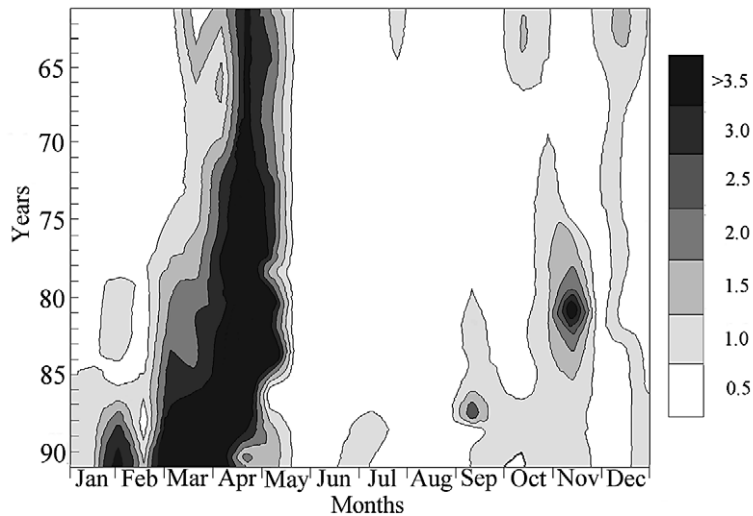


Fig. 3. Interannual variation in seasonal abundance ($\log_{10}(\text{No}/\text{m}^3+1)$) for the centric diatom *Thalassiosira* spp. across the Gulf of Maine, 1961 through 1990.

2.7. The A0 route

From August 1974 to July 1980 NOAA-Fisheries conducted CPR monitoring from the mouth of Chesapeake Bay eastward to the Gulf Stream (Fig. 1). The route was originally called 'MA', but is now designated as 'A0'. The US Coast Guard provided the majority of towing vessels and the Virginia Institute of Marine Science analysed the samples under a NOAA-Fisheries contract. Lack of vessel availability forced the termination of the route in 1980.

Data were accepted as being representative for this 'route' from anywhere in the mouth of Chesapeake Bay along a radius of 800 km, arcing from 36°00'N to 40°00'N. Such results often contributed to route B0 coverage (see below) and are included in the database for that route. A more spatially coherent subset of these data has not been produced. XBTs, surface water samples for temperature and salinity determination and weather observations were taken along this route.

2.8. The B0 route

From January 1976 to the present day NOAA-Fisheries has conducted monthly CPR monitoring along a transect running south-eastward from New York City (Fig. 1). Initially, the CPRs were towed by US Coast Guard vessels and occasionally by academic research vessels. In 1980 an agreement was established with Bermuda Container Lines, Hamilton, Bermuda, who have provided the vessel, including a NOAA stateroom, since then. The vessel has been used as a test platform for various instrumented towed bodies, and since it makes eight crossings of the transect per month it provides an exceptional contribution to the monitoring effort.

The B0 route, known initially as 'MB', starts at Ambrose Tower (40°28'N 73°50'W) and tracks offshore approximately 500 km towards Bermuda. As with the C0 route, a tetragon has been developed to exclude ship of opportunity data, which stray too far beyond the desired transect. The defined corners of this tetragon are: 40°34'N 74°00'W; 40°20'N 74°00'W; 38°30'N 69°00'W; and 36°44'N 70°30'W. Sampling generally concludes within the Gulf Stream, but since the position of the Gulf Stream varies, not every

transect traversed the entire length of the tetragon. A transect along this route typically passed through shelf, slope, and Gulf Stream water masses, and often crossed a portion of the former Deep Water Dumpsite 106.

Beginning in 1978, analog XBTs were deployed and surface water samples were taken for temperature and salinity determination. In 1992 there was a conversion to digitally recording XBTs, and to satellite equipment for the transmission of weather and water-column temperature data, resulting from funding from NOAA National Ocean Service (NOS) and National Weather Service (NWS). In 1994 NOS funds allowed the installation of a flow-through thermosalinograph for continuous near-surface monitoring. In 1995 an acoustic Doppler current profiler (ADCP) was installed in the ship using funds from the University of Rhode Island.

2.9. Occasional CPR routes

Three CPR routes have been sampled on a very few occasions—the EC, ED and FD routes (Fig. 1). The EC route passes from Nantucket Isle in a south-easterly direction out to 34°00'N 66°00'W. Five tows have been collected along this route: 1965 (1), 1966 (1), 1967 (1), and 1974 (2). The ED route from Cabot Strait at the mouth of the Gulf of St Lawrence into the River St Lawrence was sampled only once in July 1966. The FD route, a westward extension of the FC route, was sampled only in April, July and September 1975.

2.10. CPER tows on the N0 route

From 1998 to the present the NOAA-Fisheries Narragansett Laboratory, the US Environmental Protection Agency Laboratory, the Graduate School of Oceanography of the University of Rhode Island and the Rhode Island Department of Environmental Management, have been monitoring the larger phytoplankton and zooplankton of Narragansett Bay, Mount Hope Bay, Rhode Island Sound, and the Providence River with a Continuous Plankton and Environmental Recorder (CPER) (for definition of CPER see Reid et al., this volume) as part of the cooperative Narragansett Bay Project (Fig. 1). Monthly tows are taken along an

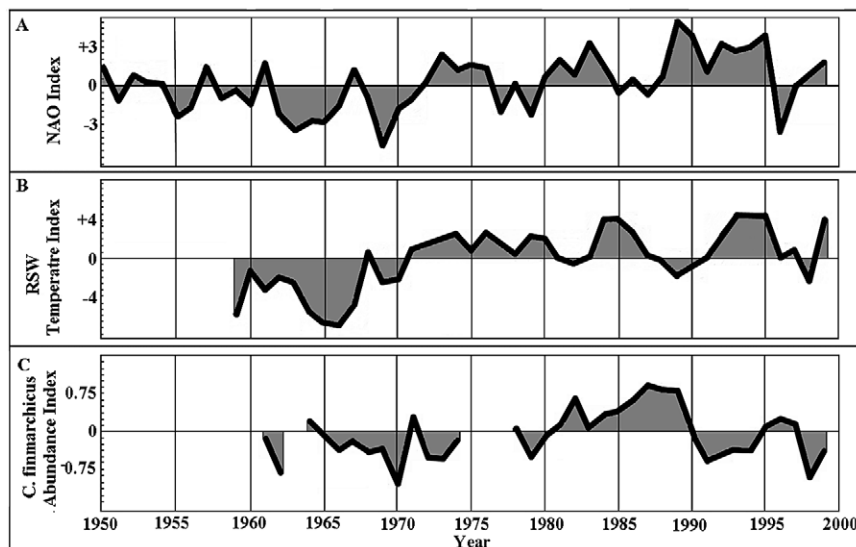


Fig. 4. Time series from the North Atlantic. (A). Annual values of the Winter NAO Index. (B). Annual values of the Regional Slope Water Temperature Index. (C). Annual values of the *Calanus finmarchicus* Abundance Index. From Pershing et al. (2001).

identical transect of 66 nm (122 km) length. For this route and until the end of 2002 a mechanical CPR plankton sampling mechanism was carried in an instrumented, undulating towed vehicle (CPR) with computer control from the towing vessel. From January 2003 the standard CPR sampling cassette was replaced by an electronically driven sampling system that takes discrete rather than continuous samples. The CPR vehicle is towed at 8 kt (15 km/hour) and it undulates from the surface to near the bottom with an undulation wavelength of 0.5–1.0 nm (0.9–1.9 km). Approximately thirteen, 5 nm (9 km) plankton samples are obtained and analysed, unlike the 10 nm samples used on standard CPR routes. Only non-contiguous samples are analysed. The Narragansett Bay Project uses the route in concert with fish population assessments; round-the-clock monitoring with buoys, sediment analysis, and satellite remotely sensed data.

The towed body also contains instruments for measuring dissolved oxygen, photosynthetically active radiation (PAR), temperature, salinity, plant biomass (fluorescence), plant production using fast repetitive rate fluorometry, flow rate through the plankton sampling mechanism, plankton counting by optical means, depth, and other towed-body control data.

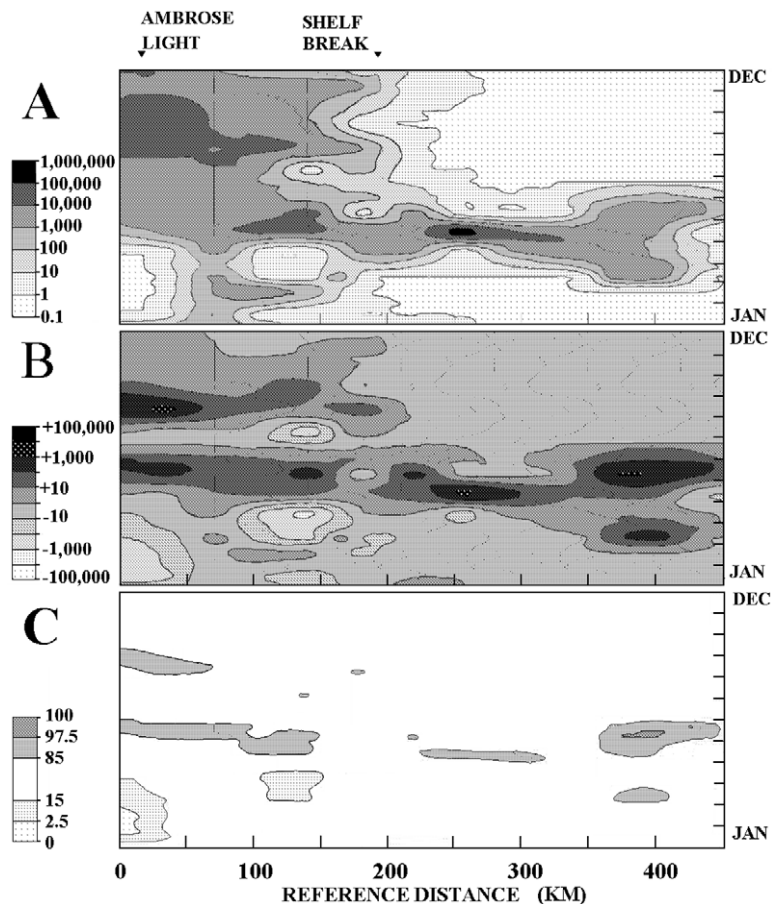


Fig. 5. Time-space conditions of copepodite stages 4–6 of *Centropages typicus*, along a Continuous Plankton Recorder transect between New York City and the Gulf Stream (route B0) during 1982. (A). Abundances (No/100m³). (B). Abundance departures from 1975–1990 medians (No/100m³). (C). Abundance departures from 1975–1990 medians (percentiles).

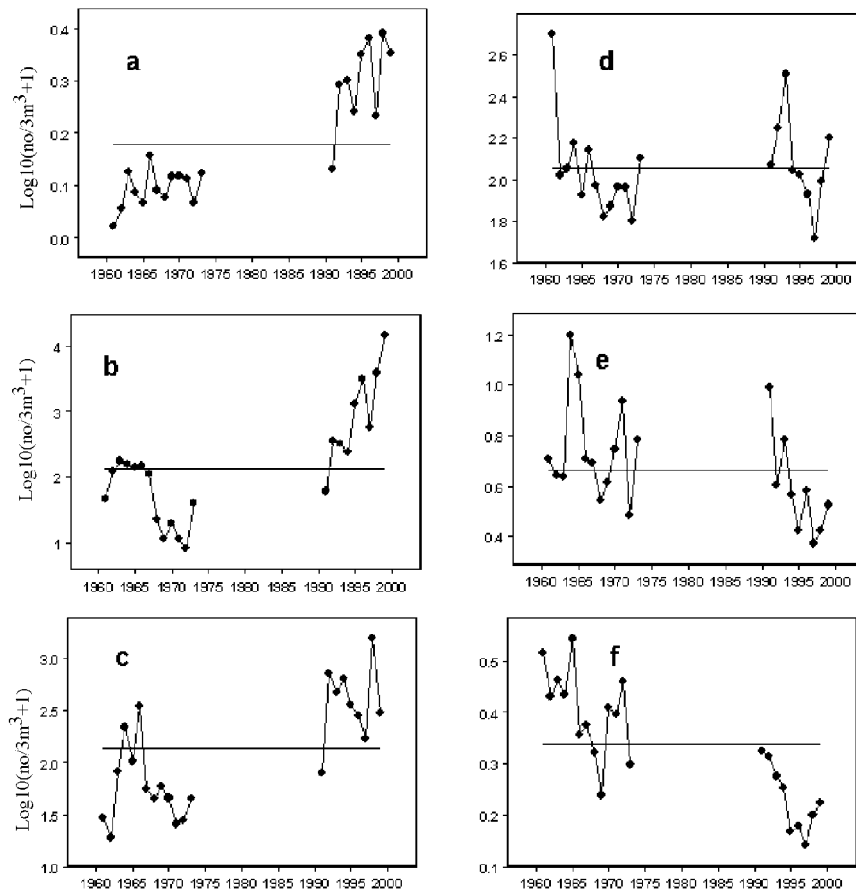


Fig. 6. Yearly means of the Phytoplankton Colour index (A), total diatoms (B), total dinoflagellates (C), copepodite stages 1–4 of *Calanus finmarchicus* (D), copepodite stages 5–6 of *Calanus finmarchicus* (E), and total euphausiids (F) on the Scotian Shelf region of the EA and EB routes. Horizontal lines represent the long-term means of the data. From Sameoto et al. (1996).

3. Selected recent results from monitoring with the CPR

3.1. Gulf of Maine

Major findings have included a significant upward trend in the copepodite stages 5–6 of *Calanus finmarchicus*, during the 1961–1990 period (Fig. 2) (Jossi & Goulet, 1993); a consistent trend toward earlier onset and longer duration of the bloom of the centric diatom *Thalassiosira* spp. between 1961 and 1990 (Fig. 3); a significant correlation between the abundance of copepodite stages 5–6 of *Calanus finmarchicus* abundance between 1961 and 1999 and both the winter North Atlantic Oscillation (NAO) and Regional Slope Water Temperature Indices (Fig. 4) (Pershing, Hannah, Greene, Sameoto, Head, Mountain et al., 2001); and a fairly stable contribution of the major taxa to the plankton biomass between 1961 and 1990, but with significant changes in some years. (Licandro, Conversi, Ibañez and Jossi (2001). An analysis of the spatial variations of plankton abundance along this and other routes has led to routine development of standardised time-space grids of these and concurrent environmental data. Fig. 5 illustrates this for *Centropages typicus*, where both temporal and spatial differences typically occur along the length of the route.

Conversi, Piontkovski and Hameed (2001) used annually averaged CPR data and found a significant positive time-lagged relationship between *C. finmarchicus* and sea surface temperature in the Gulf of Maine, with temperature preceding *C. finmarchicus* variations by about two years.

3.2. Scotian Shelf and Georges Bank

Sameoto, Kennedy and Petrie (1996) examined CPR data from EA and EB during 1961–1976 and 1991–1993. They looked at three sections: the SW Grand Banks (54°–57°W), the Scotian Shelf (57°–66°W) and the Gulf of Maine and Georges Bank (66°–71°W). The major trends seen in the EA data from the Scotian Shelf are significant increases in the Phytoplankton Colour index, the total numbers of diatoms and total

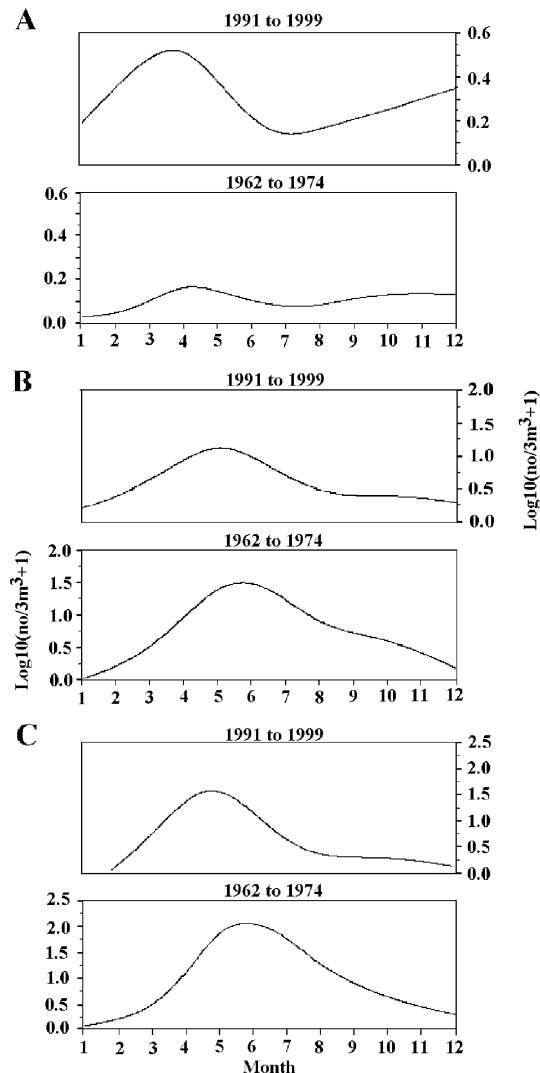


Fig. 7. Monthly mean values on the Scotian Shelf section of the EA and EB routes of (A) phytoplankton colour (relative green), (B) copepodite stages 1–4 of *Calanus finmarchicus* ($\log_{10}(\text{No}/3\text{m}^3+1)$), and (C) on the Gulf of Maine and Georges Bank sections of the EB route, copepodite stages 1–4 of *Calanus finmarchicus* ($\log_{10}(\text{No}/3\text{m}^3+1)$) for 1961–1974 and 1991–1999 data.

dinoflagellates (Fig. 6). Values of the Colour index provide a rough, estimate of total phytoplankton based on a comparison of the intensity of the green colour of the CPR samples with a set of three colour standards (Colebrook & Robinson, 1961). As these phytoplankton components increased, there was a decrease in the abundance of copepodite stages 1–4 of *C. finmarchicus* and in total Euphausiacea. The copepods *C. glacialis* and *C. hyperboreus* were more abundant on the Scotian Shelf than in the other two regions. They were found mainly between February and April and probably originated in the Gulf of St Lawrence. The timing of the phytoplankton bloom has also changed (Fig. 7(A)). From 1991 to 1998 it occurred earlier in the year and lasted longer than in the period 1961 to 1976. During the 1990s the peak abundance of copepodite stages 1–4 of *C. finmarchicus* occurred about a month earlier than in 1961 to 1969 (Figs. 7(B) and (C)) (Sameoto, 2001).

3.3. Atlantic Northeast of Newfoundland and Labrador

In the Atlantic northeast of Newfoundland the arctic-boreal copepod *C. hyperboreus* was exceptionally abundant in 1991. In 1998 it was recorded south of Georges Bank at 39° 00'N for the first time in CPR samples (Johns, Edwards, & Batten, 2001). This corresponded with a southward extension of Labrador Sea Water that brought colder conditions to the Scotian Shelf and Georges Bank area.

3.4. Narragansett Bay CPER survey

This survey is being used to establish baseline abundance indices for phytoplankton and zooplankton in the Narragansett Bay ecosystem, and to investigate functional relationships between the various components of the ecosystem. Fig. 8 shows the seasonal cycle of the copepodite stages 5–6 of *Acartia hudsonica* in different areas during 2000. Numbers of this species peaked in May in three of the five areas, reaching ca 90,000/100 m³ in Mount Hope Bay.

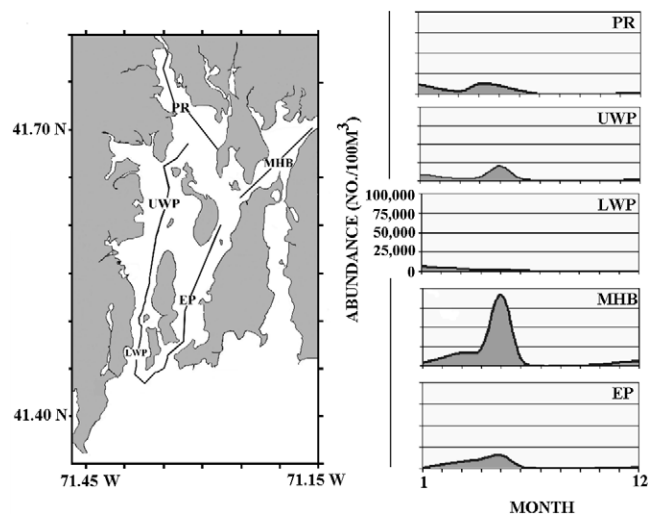


Fig. 8. Monthly abundances of copepodite stages 5–6 of *Acartia hudsonica*, for five sections of the N0 route described in the map to the left, during 2000. PR = Providence River; UWP = Upper West Passage; LWP = Lower West Passage; MHB = Mount Hope Bay; and EP = East Passage.

4. The future

In 1973 a plankton atlas giving distribution maps for 255 taxa of marine plankton recorded by the CPR survey from 1958 to 1968 was published (Oceanographic Laboratory, 1973). An updated version of this atlas, covering more than 40 years of CPR data and over 400 taxa will be published in the near future. Despite the limitations imposed by standard mesh size and sampling depth, evidence of the data value and the cost effectiveness of the Continuous Plankton Recorder survey continues to grow along with the length of the numerous plankton time series. Future plans include updated and expanded atlases; generation of additional time-space baselines; variances, and anomalies; combination of CPR and relevant ecosystem data bases for basin-wide analyses; and comparison of CPR data with tow-net data and with instrumented, undulating towed-body data for potential data efficiencies and technological advances.

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