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Biological and Chemical Oceanographic Conditions on the Newfoundland and Labrador Shelf, Grand Banks, Scotian Shelf, and the Gulf of Maine During 2007

by

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Abstract

Biological and chemical variables collected in 2007 from fixed coastal stations, oceanographic transects, and ships of opportunity ranging from the southern Labrador-Newfoundland and Grand Banks Shelf (Subarea 2 and 3), extending south along the Scotian Shelf and the Bay of Fundy (Subarea 4) and into the Gulf of Maine (Subarea 5) are presented and referenced to previous information from earlier periods when available. We review the information concerning the interannual variations in inventories of nutrients (nitrate), chlorophyll *a* and indices of the spring bloom, as well as the abundance of major taxa of zooplankton collected as part of the 2007 Atlantic Zone Monitoring Program (AZMP) and the 2006 Continuous Plankton Recorder (CPR) surveys.

In general, nitrate inventories on the Newfoundland-Labrador and Grand Banks Shelf and at fixed coastal stations were above normal, while the levels along the southern transects on the Scotian Shelf were generally below the long-term average (1999-2006). A significant positive anomaly in deep nitrate inventories was noted for the southern Labrador Shelf while a large negative anomaly in shallow inventories was observed on the southwestern Scotian Shelf in 2007. The overall seasonally-adjusted annual average biomass levels of phytoplankton in 2007 were above the long-term average across all NAFO Subareas, with the exception of the northern-most transects on the Labrador-Newfoundland Shelf. The largest increase in phytoplankton biomass was observed along the central and southwestern Scotian Shelf. The magnitude and duration of the spring phytoplankton bloom at the fixed stations were near or above normal, while the timing of the spring bloom occurred slightly later in 2007.

The seasonally-adjusted annual abundance anomalies of zooplankton was near normal along the northern transects on the Labrador-Newfoundland Shelf but consistently below the long-term average in 2007 south of the Grand Banks along the Scotian Shelf and into the Bay of Fundy. The average anomalies for zooplankton abundance indicated a significant decrease for all the main transects on the Scotian Shelf. The occurrence of potential harmful algal species from the CPR survey was above normal across all NAFO Subareas in 2006. The abundance of diatoms was below normal, particularly along the Scotian Shelf, while meroplankton (summed echinodermata taxa) was above normal in 2006. The abundance of macrozooplankton (euphausiacea, hyperiidea, and decapoda) increased significantly in 2006 in the Gulf of Maine but showed negative anomalies farther north on the Scotian and Newfoundland Shelves.

From a zonal perspective, the combined indices of nutrient inventories in 2007 on the Newfoundland and Labrador and Grand Banks Shelf were above the 1999-2006 average, but below normal over much of the Scotian Shelf. In

2007, the average phytoplankton anomaly was generally above the long-term average with the exception of the two northern-most transects. The combined indices of zooplankton abundance were well below normal throughout much of the Atlantic zone in 2007. The seasonally-adjusted annual abundance anomalies for phytoplankton and zooplankton from the CPR survey during 2006 were all above the 1991-2005 average with the exception of phytoplankton on the Scotian Shelf (Subarea 4).

Introduction

We review biological and chemical oceanographic conditions on the Newfoundland and Labrador Shelf, Grand Banks, Scotian Shelf and the Bay of Fundy, and the Gulf of Maine during 2007, and reference earlier periods when data are available. More frequent directed sampling from research vessels on oceanographic transects and ships of opportunity at coastal fixed stations by the Atlantic Zone Monitoring Program (AZMP[1]) and the completion of seasonal oceanographic surveys during 2007 provided good spatial and temporal series coverage of standard variables which provides a foundation for comparison with previous years. Additional details regarding biological and chemical oceanographic conditions on the Newfoundland and Labrador Shelf, Grand Banks, Scotian Shelf, and the Gulf of Maine in 2007 and recent years can be found in Pepin *et al*. (2008) and Harrison *et al*. (2008). The continuous plankton recorder (CPR) survey[2] provides an assessment of long-term changes in abundance and geographic distribution of planktonic organisms ranging from phytoplankton cells to larger macrozooplankton (Warner and Hays 1994, Richardson et *al*. 2006). CPR collections in the northwest Atlantic began in the early 1960's and continued with some interruptions until 1986. Collections were renewed in 1991 and continue to present.

Methods

Collections of standard AZMP variables are based on sampling protocols outlined by Mitchell *et al*. (2002). Observations for 2007 and earlier years presented in this document are based on seasonal surveys conducted during the spring through the autumn months (typically March through November). The fixed coastal stations are typically sampled at bi-monthly to monthly intervals during ice-free conditions. The location of the standard oceanographic transects and fixed coastal stations are shown in Figure 1. We only used ship-based observations in the current analysis and did not utilize any remotely-sensed (i.e. satellite ocean colour imagery) data.

The CPR collects plankton at a nominal depth of 7m through an aperture and organisms are retained on a moving band of silk material and preserved. The recorder is towed by ships of opportunity along a number of standard commercial routes throughout the North Atlantic. Sections of silk representing 18.5 km tow distance and ca. $3m^3$ of water filtered are analyzed microscopically using standard methods since the inception of the program thereby allowing valid comparisons between years. Every second section is analyzed providing a horizontal scale of ca. 37 km. The nominal locations of CPR stations from 1991 through to 2006 within the NAFO Subareas are shown in Figure 1.

Annual time series of nutrient, phytoplankton, and zooplankton variables were computed from all available seasonal data along the AZMP transects and coastal fixed stations going back to 1999, and CPR stations along the commercial vessel traffic lanes going back to 1991. The annual estimates of the various indices are averages of all available data within a given year, i.e. roughly monthly for CPR, single occupations to three times a year for oceanographic transects and roughly monthly or twice monthly for the fixed stations. The CPR sampling distribution was uneven spatially and temporally because of the opportunistic nature of sampling with commercial ships, variations in shipping routes, and CPR funding. The CPR taxa included indices of phytoplankton abundance and the dominant assemblages of phytoplankton such as the Phytoplankton Colour Index [PCI], diatom [*Chaetoceros* spp.] abundance, summed dinoflagellate [*Ceratium arcticum*] and potential harmful algal bloom species [HAB]. The main HAB genera included *Dinophysis* spp., *Nitzschia* and *Pseudo-nitzschia* spp., *Gonyaulax* spp., *Gymnodinium* spp., and *Prorocentrum* spp. The mesozooplankton groups included *Calanus finmarchicus* (CV-CVI stages), other copepods [copepoda], macrozooplankton [combined euphausiacea and hyperiidea taxa], and summed invertebrate larval and post-larval stages of decapoda and echinodermata (see Richardson et *al*. 2006 for a complete description

[1] http://www.meds-sdmm.dfo-mpo.gc.ca/zmp/main_zmp_e.html

[2] See SAFHOS web site at (http://192.171.163.165/) for a description of the CPR Program collected for The Sir Alister Hardy Foundation for Ocean Science of Plymouth, England.

of the CPR taxa**)**. Time series of AZMP seasonally-adjusted (see Pepin *et al*. 2008 for a description of the analytical methods) annual means of nutrient, phytoplankton, and zooplankton variables were standardized by subtracting the long-term average and dividing by the standard deviation over the same time period to compute annual anomalies. Each series, from which the anomalies are estimated, is internally consistent to provide an equal basis for comparison. In addition, given the higher frequency of observations from the fixed coastal stations, we computed indices (magnitude, timing, and duration) to describe the extent of the spring bloom. Identical methods were applied to the CPR taxa but the availability of earlier data allowed us to extend time series of anomalies back to 1991.

Annual Variability in Nutrient, Phytoplankton, and Zooplankton Conditions in NAFO Subareas

The surface nitrate inventories in 2007 on the Newfoundland-Labrador and Grand Banks Shelf were slightly above normal, while the levels along the southern sections on the Scotian Shelf were generally below the long-term average (1999-2006), particularly on Browns Bank (Subarea 4X) which showed a significant negative anomaly (Figure 2). The trends in nitrate inventories in the upper 50m layer were reversed in 2006 with below normal levels in the Newfoundland and Labrador Shelf and Grand Banks while above average levels occurred on the Scotian Shelf (Figure 3). A significant positive anomaly in the deep nitrate inventory in 2007 was noted for the southern Labrador Shelf along the Seal Island transect (Figure 2). In contrast, deep nitrate inventories in 2007 were below normal along the southern transects of the Scotian Shelf except for the fixed coastal station in the Bay of Fundy. In general the deeper nitrate inventories were above normal to the north of the Grand Bank and negative to the south in 2007, whereas in 2006 the opposite had generally been true (Figure 3). In 2007, winter maximum inventories (0-50m) of nitrate at the fixed AZMP stations were above normal, particularly at Prince-5 in the Bay of Fundy (Figure 2). Overall, large interannual and spatial variability in nitrate levels were apparent during the earlier part of the time series (Figure 3). The shallow and deep nitrate inventories were well below normal throughout the NAFO Subareas in 2000 (0-50m only), 2001, and 2005 (Figure 3).

The time series of phytoplankton variables also demonstrated large spatial variability in recent years with significant positive anomalies in integrated chlorophyll *a* observed along the eastern and western portions of the Scotian Shelf (Halifax and Browns Bank transects) in 2007, which were not consistent with below normal biomass levels at the fixed coastal stations (Figure 4). Similar regional differences occurred north and east of the Laurentian Channel where the biomass levels on the Labrador-Newfoundland Shelf were below normal while they were above normal on the Grand Banks in 2007 (Figure 4). In general, the chlorophyll *a* biomass levels in 2006 were near normal or below the long-term average across the NAFO Subareas (Figure 5). The main variables that characterize the peak in the production cycle (only computed at the fixed stations) during the spring bloom (timing, magnitude, and duration) were near or above normal (later timing of the spring bloom) in 2007, with the exception of negative anomaly for bloom duration at the fixed Halifax-2 station (Figure 4). However, this pattern was reversed in 2006 with the production cycle well below normal except for Prince-5 that showed later timing compared to earlier spring blooms for the other fixed stations (Figure 5). Large interannual and spatial variabilities in phytoplankton indices were also apparent during the earlier time series (Figure 5). Lower than normal phytoplankton biomass and spring bloom indices occurred in 2002, 2005, and 2006 with the persistence of negative anomalies over many of the AZMP transects and fixed stations with few exceptions.

Zooplankton abundance indices showed greater spatial coherence in 2007 compared with the nutrient and phytoplankton indices. The abundance of *Calanus finmarchicus* (CV-CVI stages) was lower in 2007 throughout much of the region (Figure 6). In general, the abundance of other copepods increased on the northern sections, particularly along the Flemish Cap and Bonavista transects whereas on the Scotian Shelf abundance appears to have decreased (Figure 6). In 2007, the non-copepod taxa were below normal on all AZMP transects and at fixed stations, with the exception of Prince-5. The high spatial coherence observed in 2007 across the NAFO Subareas was not evident during earlier years (Figure 7). In 2006, the abundance of zooplankton was above normal over most of the northern transects while below normal south of the Grand Banks (Figure 7). The abundance of copepods was below average on the Scotian Shelf, in contrast to positive anomalies observed on the Newfoundland Shelf and Grand Banks in recent years (Figure 7).

The high temporal and spatial variability observed in many of the phytoplankton and zooplankton time series collected during the AZMP also characterized the pattern for the CPR taxa in recent years. In 2006, many of the phytoplankton variables (Phytoplankton Colour Index (PCI), Diatoms, *Ceratium arcticum*, and HABs) were above

normal in Subarea 3 but the anomalies diverged south of the Grand Banks (Figure 8). The occurrence of potential harmful algal species enumerated by the CPR survey was above normal across all NAFO Subareas in 2006 (Figure 8). The increase in HABs was most dramatic on the Newfoundland Shelf and Grand Banks and the Gulf of Maine relative to the Scotian Shelf. The abundance of diatoms was below normal, particularly along the Scotian Shelf, while the summed meroplankton (echinodermata taxa) was above normal in 2006 (Figure 8). The response of zooplankton varied spatially in 2006 across the Subareas. The abundance of *C. finmarchicus* was well above normal on the Scotian Shelf, part of an increasing trend that started in 2002 (Figure 9). The abundance of macrozooplankton (euphausiacea , hyperiidea, and decapoda) increased significantly in 2006 in the Gulf of Maine but showed negative anomalies further north on the Scotian and Newfoundland Shelves (Figure 8). During the early 1990's, abundances of many of the CPR zooplankton taxa were well above normal, particularly south of the Grand Banks (Figure 9). The years 1997 and 2002-2005 were characterized by below normal levels in many of the CPR phytoplankton and zooplankton taxa (Figure 9).

In order to provide a zonal perspective across the NAFO Subareas, we computed average values of anomalies for combined nutrient, phytoplankton, and zooplankton variables from different oceanographic transects and fixed stations from the Atlantic Zone Monitoring Program. The seasonal inventories of nutrients on the Newfoundland and Labrador and Grand Banks Shelf were above the 1999-2006 average, whereas below normal over much of the Scotian Shelf in 2007 (Figure 10). The average phytoplankton anomalies were above the long-term mean with the exception of the two northern transects in 2007 (Figure 10). Average zooplankton abundance was well below normal throughout much of the Atlantic zone in 2007. The only exceptions were on the Newfoundland and northern Grand Banks Shelf where zooplankton abundance was slightly above the long-term average (Figure 10). Phytoplankton and zooplankton annual average anomalies from the CPR survey during 2006 were all above the 1991-2005 average with Subarea 5 showing the greatest positive change in zooplankton abundance indices (Figure 11). The only exception occurred on the Scotian Shelf with a significant negative combined index of phytoplankton abundance.

Although the chemical and biological time series are becoming invaluable in detecting trends and changes in the lower trophic levels, there remains considerable uncertainty in the estimates of nutrient inventories and overall abundance of phytoplankton and zooplankton. This uncertainty is related to variation in water masses, and the short life histories of phytoplankton and zooplankton along with their patchy distribution, and by the limited coverage of the region by the environmental monitoring program.

Summary and Conclusions

- The surface (0-50m integral) and deep (50-150m) nitrate inventories in 2007 on the Newfoundland-Labrador and Grand Banks Shelf were near or above normal, while the levels along the southern transects across the Scotian Shelf were generally below the long-term average (1999-2006).

- In general, the winter maximum surface inventories (0-50m) of nitrate at the fixed AZMP stations were above normal, particularly at Prince-5 in the Bay of Fundy in 2007.

- The phytoplankton biomass levels on the Newfoundland Shelf and Grand Banks in 2007 were near or slightly below normal on the northern transects while biomass levels on the southern transects were significantly above the long-term average, particularly along the central and southwestern Scotian Shelf.

- The main variables that characterize the peak in the production cycle during the spring bloom (timing, magnitude, and duration) were near or above normal (later timing of blooms) in 2007 with the exception of negative anomaly for bloom duration at the fixed Halifax-2 station.

- Changes in the zooplankton abundance indices showed greater spatial coherence in 2007 in comparison to the nutrient and phytoplankton indices.

- The abundance of *Calanus finmarchicus* was lower in 2007 compared to the previous year over much of the NAFO area.

- In recent years, the abundance of copepods was above normal on the northern sections, particularly along the Flemish Cap and Bonavista transects, while abundance levels were below normal on the Scotian Shelf.

- In 2007, the abundances of non-copepod taxa were below normal on all AZMP transects and fixed stations, with the exception of Prince-5.

- The occurrence of potential harmful algal species in the CPR survey in 2006 was consistently above normal across all NAFO Subareas.

- The abundance of diatoms in the CPR survey was below normal, particularly along the Scotian Shelf (NAFO Subarea 4), while meroplankton (echinodermata) was above normal in 2006.

- The abundance of macrozooplankton in the CPR survey in 2006 increased significantly in the Gulf of Maine (Subarea 5) but showed negative anomalies further north along the Scotian and Newfoundland Shelf transects.

- From a zonal perspective, the seasonal inventories of nutrients on the Newfoundland and Labrador and Grand Banks Shelf were near or above the 1999-2006 average, whereas they were near or below normal over much of the Scotian Shelf in 2007.

- In 2007, the seasonally-adjusted annual averaged phytoplankton anomalies were above the long-term mean (1999-2006) with the exception of the two northern transects.

- Overall, the seasonally-adjusted annual averaged zooplankton anomalies in 2007 were below normal throughout much of the Atlantic zone.

- The trends for the combined phytoplankton and zooplankton anomalies from the CPR survey during 2006 were generally above the 1991-2005 average with the exception of phytoplankton on the Scotian Shelf (Subarea 4).

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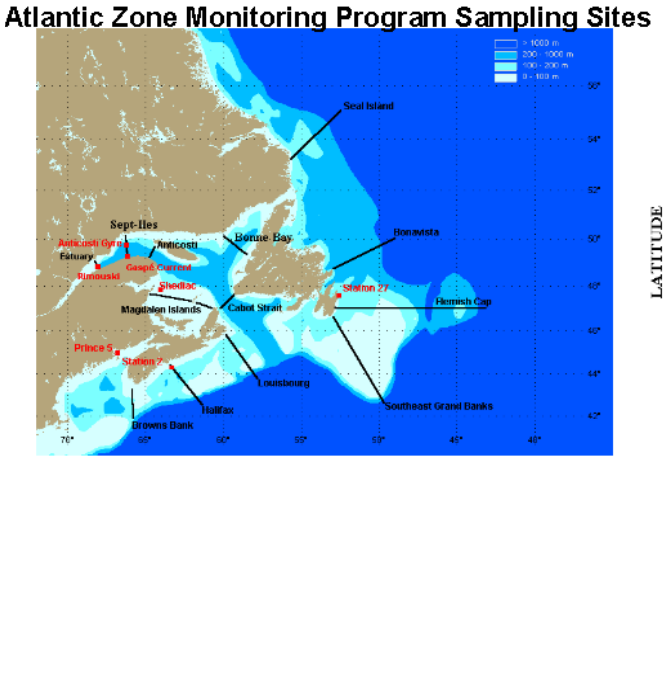
Figure 1. Location of standard Atlantic Zone Monitoring Program (left panel) fixed coastal stations (red squares) and oceanographic transects (black lines). Station locations of the Continuous Plankton Recorder (CPR) survey (right panel) during 1991-2006 in NAFO Subarea 3 (Grand Banks; white), Subarea 4 (Scotian Shelf and Bay of Fundy; yellow), Subarea 5 (Gulf of Maine; red circles).



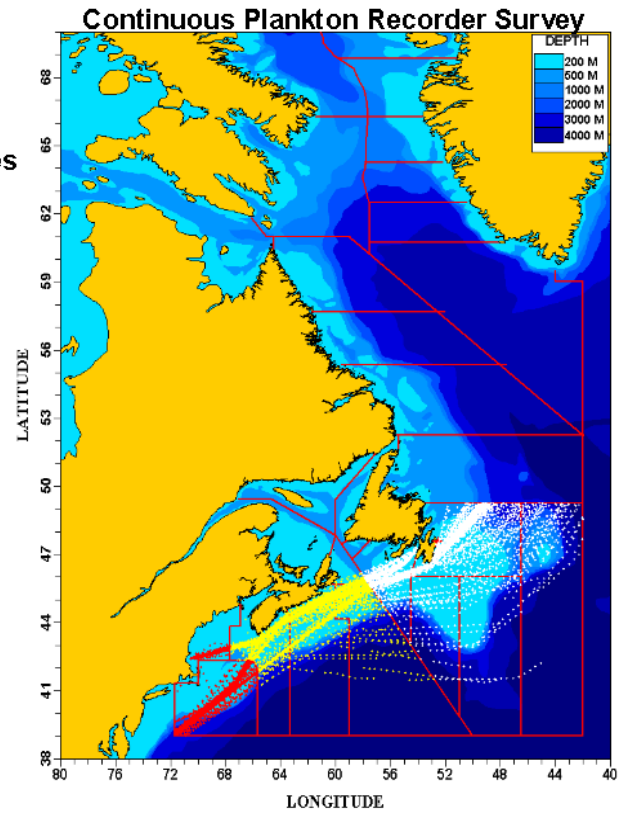


Figure 2. Summary of nutrient anomalies from different oceanographic transects and fixed stations from the Atlantic Zone Monitoring Program during 2007. The NAFO Subareas are sorted from northern (top) to southern (bottom) regions. The bottom panel shows the winter (January through March) integrated nitrate inventories (0-50m) at the fixed coastal stations.

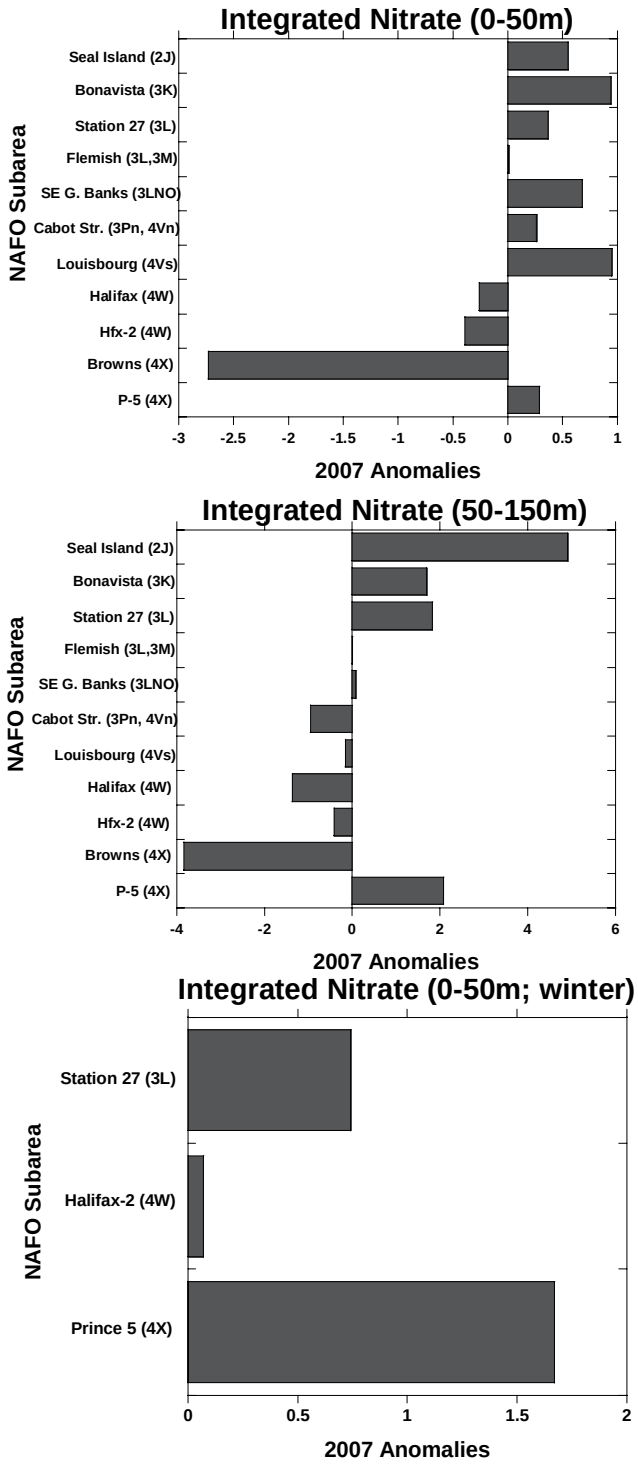


Figure 3. Time series of chemical variables from different oceanographic transects and fixed stations (highlighted in yellow) from the Atlantic Zone Monitoring Program during 1999-2007. A grey cell indicates missing data; a blue cell indicates lower than normal levels and a red cell indicates higher than normal levels. More intense colours indicate larger anomalies. The numbers in the coloured cells are the differences from the long-term mean (1999-2006) divided by the standard deviation.

NO_3_0-50m ($mmol\ m^{-2}$)		1999	2000	2001	2002	2003	2004	2005	2006	2007
	Seal Island (2J)		-0.37	-0.03	0.37		1.45	0.20	-1.61	0.55
	Bonavista Bay (3K)		-0.70	0.11	0.76	0.97	0.15	-0.20	-1.08	0.94
	Station 27 (3L)		0.26	0.13	-0.28	-0.07	0.20	0.02	-0.38	0.37
	Flemish Cap (3L, 3M)		-1.18	-0.41	0.33	1.02	0.42	-0.55	0.37	0.01
	SE Grand Banks (3LNO)		-0.58	-0.17	0.02	1.38	0.84	-0.38	-1.11	0.68
	Cabot Strait (3Pn, 4Vn)	0.46	-0.86	-0.62	2.26	-0.61	-0.37	0.00	-0.26	0.26
	Louisbourg (4Vs)	1.67	-0.35	-0.82	-1.59	0.59	-0.15	-0.07	0.71	0.95
	Halifax (4W)	2.25	-0.34	0.01	-1.08	-0.48	-0.56	-0.11	0.32	-0.26
	Hfx-2 (4W)	-1.82	1.18	1.37	-0.50	0.04	-0.05	-0.36	0.16	-0.39
	Browns Bank (4X)	0.24	0.17	-1.62	-1.25	1.25	-0.25	0.78	0.69	-2.73
	P-5 (4X)	-1.23	-0.27	-0.79	0.59	1.00	0.09	-0.96	1.58	0.29

NO_3_50-150m ($mmol\ m^{-2}$)		1999	2000	2001	2002	2003	2004	2005	2006	2007
	Seal Island (2J)		0.41	-0.89	-0.63		1.81	-0.10	-0.60	4.36
	Bonavista Bay (3K)		0.37	-1.76	-0.51	0.65	0.69	0.13	0.43	0.76
	Station 27 (3L)		0.83	-0.26	0.15	-0.46	0.02	-0.11	-0.22	0.73
	Flemish Cap (3L, 3M)		0.08	-0.63	-0.46	0.13	-0.04	-0.38	1.30	0.01
	SE Grand Banks (3LNO)		-1.29	-0.76	0.30	0.10	1.01	0.00	0.65	-0.60
	Cabot Strait (3Pn, 4Vn)	-0.35	1.12	-1.28	1.31	-0.42	-0.69	-0.73	1.03	-1.21
	Louisbourg (4Vs)	0.27	1.29	-1.54	-0.07	-0.24	-0.23	-0.90	1.41	-1.10
	Halifax (4W)	0.68	1.00	0.09	0.10	0.15	-0.65	-2.12	0.76	-1.11
	Hfx-2 (4W)	0.00	1.13	-0.71	0.64	1.07	-0.92	-1.63	0.42	-0.09
	Browns Bank (4X)	-2.00	-0.33	0.02	0.48	1.16	1.03	-0.49	0.13	-1.11
	P-5 (4X)	-1.07	-0.33	-1.09	1.08	1.16	-0.28	-0.68	1.23	0.12

	January - March	1999	2000	2001	2002	2003	2004	2005	2006	2007
NO_3-Win(J-M)_0-50m ($mmol\ m^{-2}$)	*Station 27 (3L)*		1.31	-0.24	-0.21	0.41	-0.53	-0.68	-1.03	0.74
	Hfx-2 (4W)	-0.94	0.56	1.01	-1.78	0.54	1.00	0.16	-0.55	0.07
	P-5 (4X)	-0.67	0.41	-1.20	-0.62	0.30	1.71	-0.84	0.92	1.67

Anomaly
<-2.5
-2.5 to -2.0
-2 to -1.5
-1.5 to -1.0
-1.0 to -0.5
-0.5 to 0.0
0.0 to 0.5
0.5 to 1.0
1.0 to 1.5
1.5 to 2
2.0 to 2.5
>2.5

Figure 4. Summary of phytoplankton anomalies from different oceanographic transects and fixed stations from the Atlantic Zone Monitoring Program during 2007. The NAFO Subareas are sorted from northern (top) to southern (bottom) regions. The magnitude, timing, and duration measures are only available from the AZMP fixed stations because of the frequency of sample collection at these sites. Positive anomalies for bloom timing refer to later blooms while negative values indicate earlier blooms.

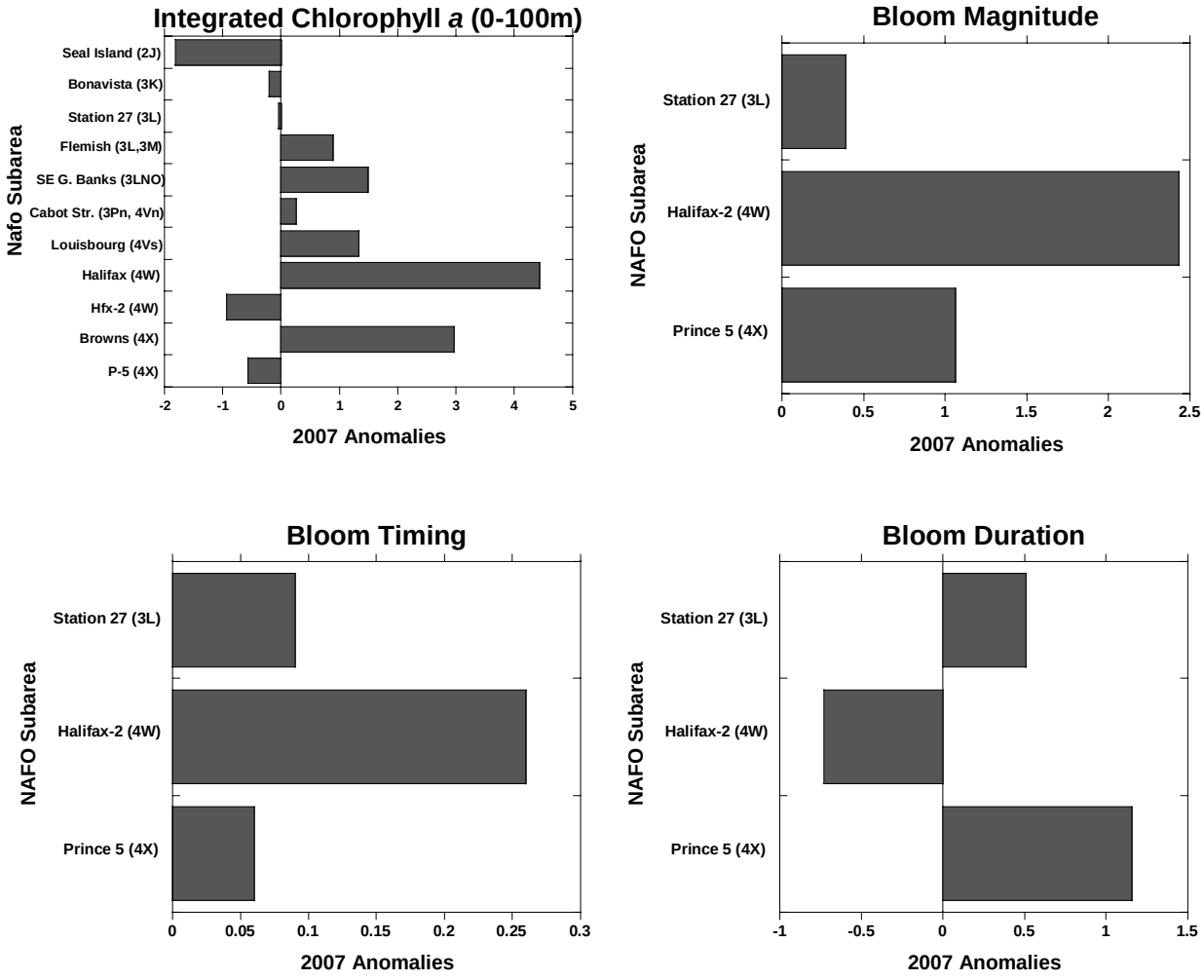


Figure 5. Time series of phytoplankton variables from different oceanographic transects and fixed stations (highlighted in yellow) from the Atlantic Zone Monitoring Program during 1999-2007. A grey cell indicates missing data; a blue cell indicates lower than normal levels and a red cell indicates higher than normal levels. For bloom timing, blue cells indicate earlier blooms while red cells refer to later blooms than normal. More intense colours indicate larger anomalies. The numbers in the coloured cells are the differences from the long-term mean (1999-2006) divided by the standard deviation.

	Location	1999	2000	2001	2002	2003	2004	2005	2006	2007
CHL_0-100m (mg m-2)	*Seal Island (2J)*		0.27	1.62	0.34	-1.53	-0.84	-0.17	0.32	-1.82
	Bonavista Bay (3K)		0.97	0.11	-0.84	-1.21	0.14	-0.08	0.90	-0.21
	Station 27 (3L)		0.76	0.63	1.09	-0.64	-0.01	-1.85	0.01	-0.04
	Flemish Cap (3L, 3M)		0.28	-0.02	-1.15	-0.43	0.07	1.01	0.24	0.89
	SE Grand Banks (3LNO)		-0.88	0.93	-0.31	-0.34	0.81	-0.13	-0.08	1.49
	Cabot Strait (3Pn, 4Vn)	1.07	1.73	-0.62	-0.82	-1.17	0.40	-0.52	-0.06	0.26
	Louisbourg (4Vs)	-0.51	0.37	-0.69	-1.21	1.93	0.45	0.41	-0.75	1.33
	Halifax (4W)	-0.66	0.28	-0.13	-0.96	1.33	-0.48	1.60	-0.99	4.43
	Hfx-2 (4W)	2.06	0.43	0.25	-0.32	0.20	-0.75	-0.75	-1.11	-0.93
	Browns Bank (4X)	-0.45	-0.11	-0.25	-0.87	2.32	0.17	-0.08	-0.73	2.97
	P-5 (4X)	1.24	0.72	0.65	0.44	-0.58	0.27	-1.11	-1.64	-0.57
		1999	2000	2001	2002	2003	2004	2005	2006	2007
Bloom-Timing (Year-Day)	*Station 27 (3L)*		-1.47	1.59	-0.48	0.52	-0.55	0.66	-0.26	0.09
	Hfx-2 (4W)	-0.77	0.41	0.70	-1.07	1.88	0.26	-0.63	-0.77	0.26
	P-5 (4X)		-0.23	-0.96	0.08	0.06	-1.35	0.84	1.57	0.06
		1999	2000	2001	2002	2003	2004	2005	2006	2007
Bloom-Magnitude (mg m^{-2})	*Station 27 (3L)*		-0.12	1.59	0.48	0.28	0.19	-0.90	-1.52	0.39
	Hfx-2 (4W)	-1.14	-0.74	-0.61	-0.19	1.33	1.14	1.01	-0.81	2.43
	P-5 (4X)		2.00	-0.92	-0.46	0.25	-0.26	-0.87	0.27	1.06
		1999	2000	2001	2002	2003	2004	2005	2006	2007
Bloom-Duration (Days)	*Station 27 (3L)*		1.63	0.64	0.34	0.10	-0.44	-1.02	-1.26	0.51
	Hfx-2 (4W)	1.32	0.42	0.42	0.61	-0.02	0.23	-1.36	-1.62	-0.73
	P-5 (4X)		-0.98	1.52	-1.03	-0.52	1.01	0.44	-0.42	1.16

Anomaly	
<-2.5	
-2.5 to -2.0	
-2 to -1.5	
-1.5 to -1.0	
-1.0 to -0.5	
-0.5 to 0.0	
0.0 to 0.5	
0.5 to 1.0	
1.0 to 1.5	
1.5 to 2	
2.0 to 2.5	
>2.5	

Figure 6. Summary of zooplankton anomalies from different oceanographic transects and fixed stations from the Atlantic Zone Monitoring Program during 2007. The NAFO Subareas are sorted from northern (top) to southern (bottom) regions.

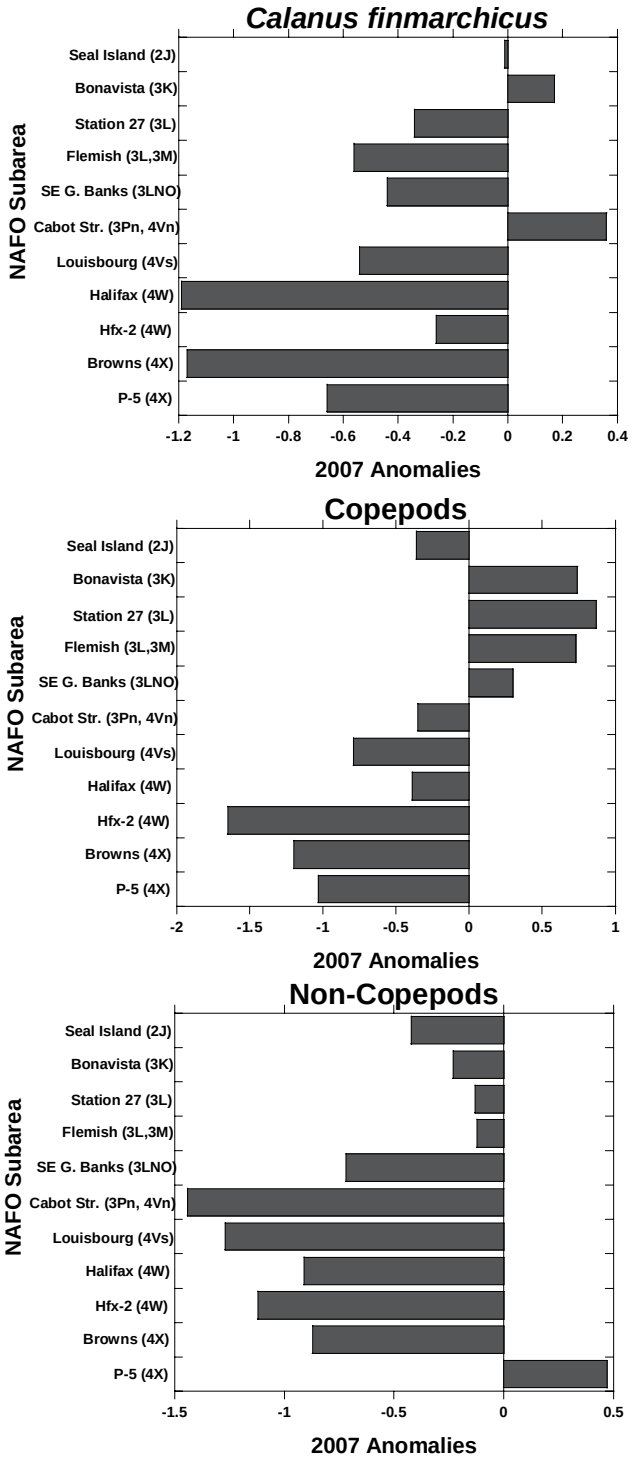


Figure 7. Time series of zooplankton variables from different oceanographic transects and fixed stations (highlighted in yellow) from the Atlantic Zone Monitoring Program during 1999-2007. A grey cell indicates missing data; a blue cell indicates lower than normal levels and a red cell indicates higher than normal levels. More intense colours indicate larger anomalies. The numbers in the coloured cells are the differences from the long-term mean (1999-2006) divided by the standard deviation.

Calanus finmarchicus		1999	2000	2001	2002	2003	2004	2005	2006	2007
	Seal Island (2J)		-1.15	-0.80	-0.38	-0.31	1.64	1.04	-0.04	-0.01
	Bonavista Bay (3K)	-1.64	-1.05	-0.18	0.12	0.21	0.96	0.11	1.48	0.17
	Station 27 (3L)	0.87	-0.22	0.93	0.15	0.15	-1.31	-1.59	1.02	-0.34
	Flemish Cap (3L, 3M)	-1.53	-1.34	0.69	0.75	-0.05	-0.21	0.43	1.26	-0.56
	SE Grand Banks (3LNO)	-1.24	-1.15	-0.08	0.89	0.64	-0.32	1.64	-0.39	-0.44
	Cabot Strait (3Pn, 4Vn)	0.51	-0.76	-0.77	-2.95	2.05	-0.25	-0.40	-0.39	0.36
	Louisbourg (4Vs)	2.02	-0.65	-0.70	1.01	-0.85	-0.30	-0.42	-0.10	-0.54
	Halifax (4W)	1.25	0.16	0.40	-1.96	0.55	-0.56	0.70	-0.53	-1.19
	Hfx-2 (4W)	0.86	0.85	1.48	-0.33	0.22	-0.89	-1.18	-1.01	-0.26
	Browns Bank (4X)	0.82	-0.88	0.86	-0.89	1.09	-1.11	-0.83	0.95	-1.17
	P-5 (4X)	-0.87	-1.01	1.53	-1.15	0.28	-0.11	0.11	1.20	-0.66

Copepods		1999	2000	2001	2002	2003	2004	2005	2006	2007
	Seal Island (2J)		-1.32	-0.98	-0.48	-0.18	1.26	0.81	0.89	-0.36
	Bonavista Bay (3K)	-1.68	-0.78	-0.07	-0.29	0.68	0.57	-0.06	1.63	0.74
	Station 27 (3L)	-0.75	0.96	-0.67	1.85	0.45	-1.05	-0.27	-0.51	0.87
	Flemish Cap (3L, 3M)	-1.43	-0.75	0.33	-0.07	-0.48	-0.23	0.78	1.84	0.73
	SE Grand Banks (3LNO)	-1.82	0.62	-0.84	0.16	0.16	0.43	1.52	-0.22	0.30
	Cabot Strait (3Pn, 4Vn)	1.28	-1.08	-0.92	-3.19	1.23	0.19	0.18	-0.89	-0.35
	Louisbourg (4Vs)	2.31	-0.66	-0.03	-0.88	0.16	-0.61	-0.18	-0.12	-0.79
	Halifax (4W)	1.91	0.42	-0.04	-1.17	-0.33	-0.87	0.72	-0.63	-0.39
	Hfx-2 (4W)	1.61	0.72	0.37	-1.43	-0.30	-0.04	0.30	-1.23	-1.65
	Browns Bank (4X)	1.16	0.98	0.17	-0.54	0.97	-1.68	-0.68	-0.39	-1.20
	P-5 (4X)	-0.11	0.94	1.69	-0.92	0.19	-0.57	-1.42	0.21	-1.03

Non-copepods		1999	2000	2001	2002	2003	2004	2005	2006	2007
	Seal Island (2J)		-0.83	-0.57	-0.81	-0.54	0.55	0.30	1.91	-0.42
	Bonavista Bay (3K)	-1.59	-0.96	0.36	0.25	0.32	-0.16	-0.02	1.79	-0.23
	Station 27 (3L)	-1.07	1.08	1.41	0.24	0.05	0.24	-0.39	-1.55	-0.13
	Flemish Cap (3L, 3M)	-1.84	0.38	0.70	1.22	-0.58	-0.75	0.10	0.76	-0.12
	SE Grand Banks (3LNO)	-1.55	1.99	0.12	-0.08	-0.19	-0.50	0.49	-0.29	-0.72
	Cabot Strait (3Pn, 4Vn)	1.00	-1.17	-0.81	-2.51	0.20	1.53	-0.78	0.03	-1.44
	Louisbourg (4Vs)	0.91	-1.04	0.65	-0.50	-1.26	-0.21	-0.20	1.65	-1.27
	Halifax (4W)	1.59	0.10	-0.70	-1.04	0.22	-0.33	1.24	-1.08	-0.91
	Hfx-2 (4W)	2.14	0.09	-0.58	-0.98	-0.54	0.01	0.56	-0.70	-1.12
	Browns Bank (4X)	1.49	0.48	-0.37	-1.04	0.24	-1.04	1.15	-0.92	-0.87
	P-5 (4X)	1.51	0.97	0.38	0.17	-1.21	-0.43	-1.40	0.01	0.47

Anomaly
<-2.5
-2.5 to -2.0
-2 to -1.5
-1.5 to -1.0
-1.0 to -0.5
-0.5 to 0.0
0.0 to 0.5
0.5 to 1.0
1.0 to 1.5
1.5 to 2
2.0 to 2.5
>2.5

Figure 8. Summary of phytoplankton and zooplankton anomalies from the Continuous Plankton Recorder (CPR) survey during 2006. The NAFO Subareas are sorted from north (NAFO Subarea 3 – Newfoundland Shelf and Grand Banks) to south (NAFO Subarea 5 - Gulf of Maine).

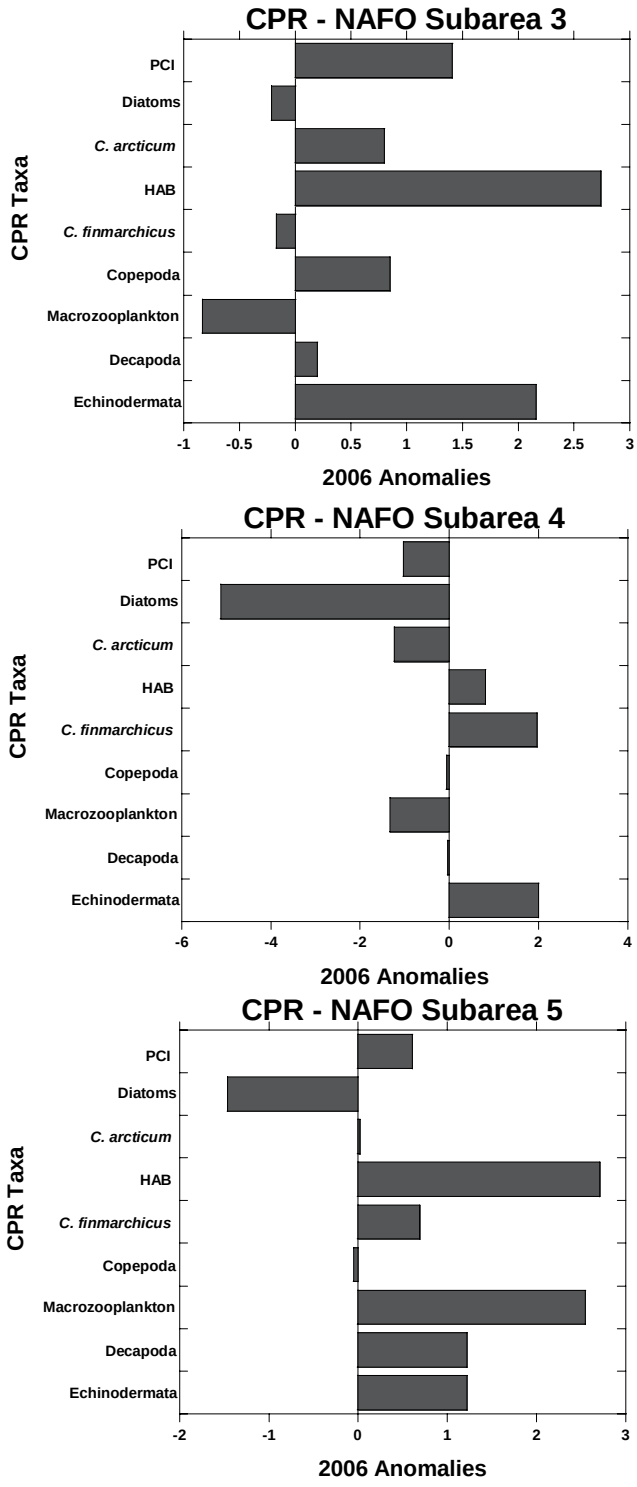


Figure 9. Time series of CPR taxa from different NAFO Subareas during 1991-2006. A grey cell indicates missing data; a blue cell indicates lower than normal levels and a red cell indicates higher than normal levels. More intense colours indicate larger anomalies. The number in the coloured cells are the differences from the long-term mean (1991-2005) divided by the standard deviation. All relative abundance values were log(10) transformed prior to computing standardized anomalies. The Phytoplankton Colour Index [PCI] and Diatoms which are represented by all *Chaetoceros* spp. represent biomass levels. Harmful algal bloom species [HAB], decapoda and echinodermata (larval and post-larval stages) were summed within a given year as indicator taxa and response of the benthos. The abundance of *Calanus finmarchicus* (CV-CVI stages), copepoda (all non-calanoid and calanoid copepods) and macrozooplankton which consist of both euphausiacea and hyperiidea represent important prey field for fish, invertebrates, and marine seabirds.

	Year	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
NAFO3	PCI		1.41	1.05	-0.53	-0.30	-0.83	-1.36	0.63	-0.55	-0.86	-1.58		0.46	0.93	0.15	1.41
	Diatoms	2.20	1.07	-0.24	-0.24	0.52	-1.46	-1.58	-0.15	-0.34	-0.08	0.87	0.47	0.64	-0.98	-0.72	-0.21
	C. arcticum	-2.05	0.10	-0.07	0.30	0.40	0.78	0.60	-0.12	-0.23	0.65	1.01	-0.16	-0.21	0.78	-2.59	0.80
	HAB	-1.23	1.91	-1.15	1.43	0.30	0.71	-0.89	-0.63	0.21	-0.42	-0.19	-1.24	-0.13	-0.04	1.37	2.77
	C. finmarchicus	0.08	-1.89	0.11	-0.65	-0.34	0.14	-0.70	0.78	2.25	-0.50	1.12	0.88	-0.13	-1.47	0.48	-0.17
	Copepoda	-1.40	1.39	0.63	-0.15	0.13	0.05	-0.39	1.35	1.15	0.05	-0.20	1.10	-1.79	-1.11	-0.83	0.85
	Macrozooplankton	1.35	-1.56	0.55	1.85	0.70	-0.28	0.90	-0.11	-0.21	0.90	-0.55	-0.42	-1.62	-0.96	0.29	-0.83
	Decapoda	-0.35	-0.41	1.65	-0.33	1.13	1.38	-1.13	0.39	0.28	-0.08	1.42	-1.04	-0.79	-0.73	-1.39	0.20
	Echinodermata	-0.33	-0.48	1.56	0.84	-1.43	-0.40	-0.56	0.56	-0.18	0.50	0.31	-0.96	-0.75	0.51	-1.37	2.16
NAFO4	PCI		0.68		-0.23	1.33	1.30	-0.34	0.36	-1.06	-1.24	0.17		0.99	-0.20	-1.76	-1.02
	Diatoms	-0.94	0.34	-0.11	-0.42	0.76	0.86	-0.04	0.59	1.14	-0.14	0.49	0.09	0.10	0.38	-3.07	-5.12
	C. arcticum	-1.53	-0.28	-0.08	-1.10	-0.23	1.17	-0.57	1.45	0.18	0.01	2.21	0.42	-0.13	-0.40	-1.11	-1.23
	HAB	-1.34	-0.28	-1.13	-0.29	1.84	1.42	-0.36	0.88	1.56	-0.44	0.05	-0.78	-0.79	-0.70	0.34	0.82
	C. finmarchicus	2.07	-0.50	-0.21	-1.69	-0.82	-0.28	0.20	-1.26	-0.61	0.33	-0.07	-0.35	0.73	1.26	1.21	1.97
	Copepoda	1.91	0.64	1.52	-0.23	-0.48	-0.59	-0.89	-0.78	0.82	1.06	-0.91	-1.55	-0.72	0.20	-0.01	-0.06
	Macrozooplankton	1.39	1.08	0.40	0.61	0.01	0.85	-0.34	0.59	0.47	-0.74	-0.51	-2.64	-0.02	-0.06	-1.09	-1.33
	Decapoda	-0.42	0.16	1.68	-0.36	0.17	-1.27	-0.98	-1.08	1.58	0.64	1.55	-1.31	0.00	-0.21	-0.14	-0.03
	Echinodermata	-0.59	-0.53	0.91	0.48	-0.78	-1.01	-1.67	-0.07	1.73	-0.36	-0.78	-0.05	-0.10	1.20	1.63	2.00
NAFO5	PCI		0.17			1.92		-1.54	0.47	-1.05	-1.02	-0.05		0.49	0.54	0.06	0.61
	Diatoms	0.11	-0.43	1.10	-1.22	-1.58	-0.21	1.35	1.31	0.16	0.21	-0.75	0.16	0.30	-1.70	1.18	-1.46
	C. arcticum	0.01	0.14	0.16	-0.87	0.50	-0.42	-0.41	3.27	-0.15	0.31	-0.42	-0.72	-0.87	0.04	-0.58	0.02
	HAB	-1.31	-0.15	-0.36	-0.77	0.68	0.13	-0.41	2.77	0.57	-0.30	0.38	-0.83	-1.19	0.07	0.73	2.70
	C. finmarchicus	2.07	-0.14	-0.55	-0.84	1.03	-0.20	0.74	-1.68	-0.45	-0.30	0.07	-1.06	0.33	1.55	-0.58	0.69
	Copepoda	1.52	0.80	1.63	-0.39	-0.69	-0.56	-0.91	-0.80	0.89	1.29	-0.94	-1.43	-0.73	0.23	0.09	-0.05
	Macrozooplankton	1.43	-0.83	-0.10	-1.47	1.47	-0.45	-0.63	1.33	0.20	0.00	-1.09	-1.34	1.01	-0.20	0.69	2.55
	Decapoda	1.23	0.49	1.82	0.10	-0.63	-1.50	-0.12	-0.15	0.35	1.14	0.92	-0.60	-0.44	-1.21	-1.40	1.22
	Echinodermata	1.23	0.49	1.82	0.10	-0.63	-1.50	-0.12	-0.15	0.35	1.14	0.92	-0.60	-0.44	-1.21	-1.40	1.22

Anomaly
<-2.5
-2.5 to -2.0
-2 to -1.5
-1.5 to -1.0
-1.0 to -0.5
-0.5 to 0.0
0.0 to 0.5
0.5 to 1.0
1.0 to 1.5
1.5 to 2
2.0 to 2.5
>2.5

Figure 10. Summary of average nutrient, phytoplankton, and zooplankton anomalies from different oceanographic transects and fixed stations from the Atlantic Zone Monitoring Program during 2007. The NAFO Subareas are sorted from northern (top) to southern (bottom) regions.

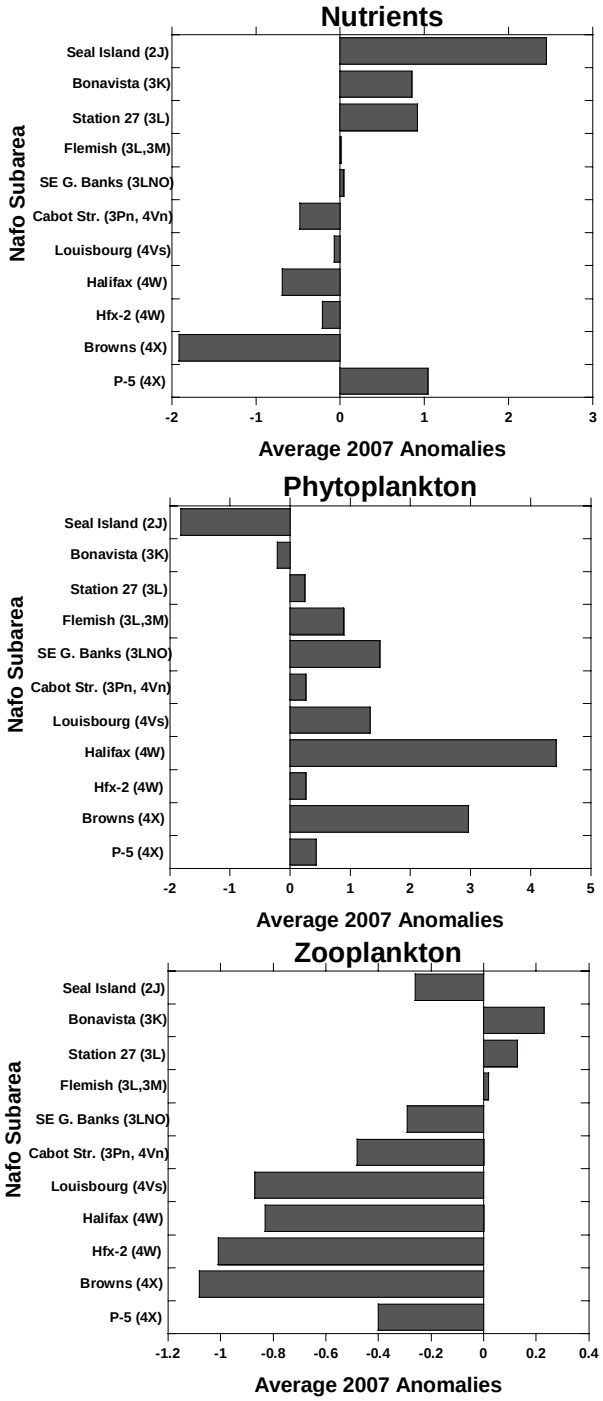


Figure 11. Summary of average phytoplankton and zooplankton anomalies from the CPR survey for different NAFO Subareas during 2006. The NAFO Subareas are sorted from northern (top) to southern (bottom) regions.