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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 2010

by

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Abstract

Biological and chemical variables collected in 2010 from fixed coastal stations, oceanographic transects, and ships of opportunity ranging from the 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 inferred from satellite imagery, as well as the abundance of major taxa of zooplankton collected as part of the 2010 Atlantic Zone Monitoring Program (AZMP). In general, nitrate inventories in NAFO Subareas 2 and 3 were below normal, consistent with available data further south in Subareas 4 in 2010. The nutrient anomaly time series for Subareas shows large interannual and spatial variability throughout the 12-year record. Lower than normal surface phytoplankton blooms were detected with satellite imagery in northern Subareas across the Labrador Shelf, Labrador Sea, and Greenland Shelf in 2010. Enhanced blooms were detected along the central and southern Subareas extending across the Gulf of St. Lawrence, Newfoundland Shelf and Grand Banks to the eastern Scotian Shelf in 2010. The timing of the production cycle occurred significantly earlier across the entire Northwest Atlantic in 2010. Enhanced abundance of large and total copepods as well as non-copepod zooplankton were observed for the northern Subareas in 2010 with some of the highest standardized anomalies observed in the 12-year time series. The composite indices summing each of the zooplankton groups across the NAFO Subareas indicated a general declining trend over the 12-year time series until the abrupt increase in 2010. Overall, the combined composite indices of inventories and abundances across trophic levels (nutrients, phytoplankton and zooplankton) generally exhibit weak associations (i.e. correlations) between adjacent trophic levels and high interannual variability.

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 2010, and reference earlier periods when data were 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 2010 provided good spatial and temporal series coverage of standard

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

variables which affords 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 2010 and recent years can be found in Pepin *et al*. (2011) and Johnson *et al*. (2011).

Methods

Collections of standard AZMP variables are based on sampling protocols outlined by Mitchell *et al*. (2002). Observations for 2010 and earlier years presented in this document are based on seasonal surveys conducted during the spring through the autumn (typically March through December). The fixed coastal stations are typically sampled at twice monthly to monthly intervals during ice-free conditions. The location of the standard oceanographic transects and fixed coastal stations are shown in Figure 1.

Phytoplankton biomass was estimated from ocean colour data collected by the Moderate Resolution Imaging Spectroradiometer (MODIS) "Aqua" sensor (http://modis.gsfc.nasa.gov/). The MODIS data stream began in July, 2002. Satellite data do not provide information on the vertical structure of phytoplankton in the water column but do provide highly resolved (~1.5 km) data on their geographical distribution in surface waters at the large scale. Two week composite images of surface chlorophyll for the entire NW Atlantic (39-62.5° N Latitude 42-71° W Longitude) are routinely produced from SeaWiFS/MODIS data[2]. Basic statistics (mean, range, standard deviation, etc.) are extracted from the composites for selected sub-regions as shown in Figure 1.

Scorecard indices were developed as a method of summarizing the many variables used to represent the state of lower trophic levels. To simplify the information, the time-series of the annual estimate of inventory or abundance for each summary variable was standardized to a mean of zero (for the period 1999 – 2010) and unit standard deviation ([observation – mean]/SD). The standard deviation provides a measure of the variability of an index. The result of this standardization yields a series of anomalies. The scorecard serves to illustrate departures from the long term mean across the range of variables by colour coding anomalies as either being above-later (red) or below-earlier (blue) the long term average, with darkening shades serving to represent the increasing magnitude of that departure. For the chemical-biological observations, the key variables selected were: (1) near surface (0-50 m) and deep (50-150 m) nitrate inventories, and (2) chlorophyll *a* concentration and peak intensity, initiation, peak timing and duration of the spring bloom, and zooplankton abundance (*Calanus finmarchicus, Pseudocalanus spp*., total copepods, and total non-copepod zooplankton) and biomass (dry weight) for the AZMP fixed stations and seasonal section surveys.

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

Based on the available data, the upper water-column nitrate inventories were below normal across the Newfoundland-Labrador Shelf and Grand Banks and extended further south to the Scotian Shelf in 2010 (Figure 2). Similar negative anomalies were observed in the deep nitrate inventories across the NAFO Subareas in 2010 although observations across several sections were not available. The annual trends in nitrate inventories in the upper 50m layer have remained below normal on the Newfoundland and Labrador Shelf and Grand Banks while near-normal and above average levels occurred on the Scotian Shelf during recent years (Figure 3). Overall, large interannual and spatial variability in nitrate levels are apparent throughout the time series (Figure 3). The combined indices for shallow and deep inventories of nitrate across all NAFO Subareas indicated minima in 2010 and maxima in 2003, with no apparent trends in either of the nutrient indices over the 12-year time series (Figure 4). In general, the composite trends in both shallow and deep nitrate inventories were near-synchronous over the time series.

The standardized anomalies in 2010 indicate below-normal levels in phytoplankton biomass and peak intensity of the spring bloom in northern subareas extending from the Hudson Strait (Subarea 0B), across the Labrador Shelf (2H) and Sea (1F-2H) to the Greenland Shelf (1F) (Figure 5). Generally, near-normal levels were observed across the southern Labrador Shelf (2J) in 2010. Phytoplankton biomass and bloom intensity were significantly greater in the southern and central sub-regions across the Gulf of St. Lawrence (4S-4R), northeast Newfoundland Shelf (3K) and Grand Banks (3LNOM) down to the eastern Scotian Shelf (4Vs) in 2010. The anomalies indicated near-normal

[2] (http://www.mar.dfo.mpo.gc.ca/science/ocean/ias/seawifs/seawifs_1.html)

conditions across the southern Scotian Shelf (4W) down to Subarea 5-Georges Bank (Figure 5). Significant changes in the timing of the production cycle were observed over the NAFO Subareas in 2010. The initiation and timing of the peak spring bloom revealed a coherent shift to earlier timing across the entire zone with only a few exceptions (Figure 5). The standardized anomalies ranged from 1 to 2 standard deviation units indicating a highly significant change in the timing of the production cycle across the North Atlantic. Although the timing indices indicated a substantial shift to earlier timing, the duration of the production cycle in the northern Subareas increased while the northern Grand Banks and Scotian Shelf tended to decline.

The standardized time series anomalies showed large interannual variability in average chlorophyll *a* concentration with some regional coherence across the NAFO Subareas (Figure 6). Low levels of phytoplankton biomass were observed during 2005 and 2007-2008 in contrast to significantly higher levels in 2006 and 2009-2010. In terms of peak intensity of the spring bloom, 2005 again stands out as a weak year while 2003 and 2006 ranks at the highest levels observed in the short time series (Figure 7). Dramatic changes noted to earlier timing for initiation and peak bloom indices in 2010 were not apparent in previous years, although the timing of the production cycle was clearly delayed during 2003-2005 (Figure 8-9). The duration of the production cycle also showed a large degree of variability during the short time series (Figure 10). The minimum duration was detected in 2003 across the entire zone while the longest spring blooms were observed during 2005-2006, largely confined to the Subareas south of the Labrador Shelf (2J). We developed a simple composite index by summing the annual MODIS anomalies across the NAFO Subareas within a given year. The first composite index for chlorophyll *a* concentration and peak intensity reached a maximum in 2006 while the minima was detected in 2005 (Figure 11). We detected a slight downward trend in the second composite index (timing indices) during 2003 through 2009 followed by a sudden change to earlier timing in 2010 as noted above (Figure 11).

The principal zooplankton indices indicated that abundance was generally higher than average, with densities of large calanoid and small copepods reaching their highest levels in 2010 on the Grand Banks and northeast Newfoundland Shelf (3LNO) and the southern Labrador Shelf (2J-3K) respectively (Figure 12). There was evidence of a north-to-south gradient in the anomalies in zooplankton abundance in 2010, with conditions near or below the long-term average on the oceanographic sections south of the Grand Banks. Substantial increase in the abundance of large and total copepods as well as non-copepods were observed for the northern Grand Banks (3L) in 2010 with some of the highest standardized anomalies observed in the 12-year time series (Figure 12). The only exception to this general pattern was for small copepods which were substantially elevated further north along the Labrador Shelf (2J) and northeast Newfoundland Shelf (3K).

Although many of the zooplankton abundance indices reached their highest levels in 2010 in the northern Subareas, the time series of anomalies indicated relatively weak secondary production during 2000 through 2009 (Figure 13). We observed near-record levels of all zooplankton indices in 1999 along the southern Subareas (Scotian Shelf) while the conditions in the northern Subareas (Grand Banks and northeast Newfoundland Shelf) were substantially below normal (Figure 13). We detected a gradient in zooplankton dry weight anomalies across the Subareas in 2010 with above normal levels in the north (3K, 3M) and declining southwards across the Scotian Shelf (Figure 14). The time series of zooplankton dry weight anomalies indicated reduced biomass in the early period (1999-2000) followed by a peak in secondary production during 2002-2005 and near-normal levels during the latter period (Figure 15). The composite indices summing each of the zooplankton abundance indices across the NAFO Subareas indicated a general declining trend over the 12-year time series until the abrupt change in 2010 which is principally attributed to the increased abundance in the northern regions (Figure 16). The composite index for zooplankton dry weight was relatively invariant over the 12-year time series except for the early period which was consistently below normal across the Subareas. The combined indices of inventories of nitrate across the NAFO Subareas were at the lowest levels in the 12-year time series in 2010 (Figure 17). This is in contrast to above average nutrient inventories in previous years. The combined indices for the magnitude of the spring phytoplankton bloom indicated above normal levels in recent years but reduced from the maximum observed in 2006. The combined composite index for zooplankton indicated a minima in 2000, followed by above average levels from 2001-2003, after which they remained near or below normal until an abrupt increase in 2010. The combined indices of inventories and abundances across trophic levels (nutrients, phytoplankton and zooplankton) generally exhibit weak associations (i.e. correlations) between adjacent trophic levels and high interannual variability across the NAFO Subareas.

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 NAFO Subareas by the environmental monitoring program.

Biological and Chemical Highlights

- Based on available data, the upper and deep water-column nitrate inventories were below normal across the Newfoundland-Labrador and Grand Banks Shelf and extending further south to the Scotian Shelf in 2010.
- Overall, large interannual and spatial variability in nutrient levels are apparent during 1999-2010.
- Substantial reductions in surface phytoplankton blooms were detected with satellite imagery in northern Subareas across the Labrador Shelf, Labrador Sea, and Greenland Shelf in 2010.
- Elevated phytoplankton biomass was observed along the central and southern Subareas extending across the GSL, Newfoundland Shelf and Grand Banks to the eastern Scotian Shelf in 2010.
- A dramatic shift to earlier initiation and timing of the spring bloom was observed across the entire North Atlantic in 2010.
- Substantial increases in the abundance of large and total copepods as well as non-copepod zooplankton were observed for the northern Subareas in 2010 with some of the highest standardized anomalies observed in the 12-year time series.
- The composite indices summing each of the zooplankton groups across the NAFO Subareas indicated a general declining trend over the 12-year time series until the abrupt increase in 2010.
- Overall, the combined composite indices of inventories and abundances across trophic levels (nutrients, phytoplankton and zooplankton) generally exhibit weak associations (i.e. correlations) between adjacent trophic levels and high interannual variability.

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References

C. Johnson, G. Harrison, E. Head, J. Spry, K. Pauley, H. Maass, M. Kennedy, C. Porter, I. Yashayaeva, and B. Casault. 2011. Optical, chemical and biological oceanographic conditions in the Maritimes region in 2010. Canadian Science Advisory Secretariat, Research Document 2011/XXX, (in press).

Mitchell, M.R., G. Harrison, K. Pauley, A. Gagné, G. Maillet and P. Strain 2002. Atlantic Zone Monitoring Program Sampling Protocol. Canadian Technical Report of Hydrography and Ocean Sciences 223, 23 pp.

P. Pepin, G.L. Maillet, S. Fraser, T. Shears, and G. Redmond. 2011. Biological and Chemical Oceanographic conditions on the Newfoundland and Labrador Shelf during 2010. Canadian Science Advisory Secretariat, Research Document 2011/XXX, (in press).

Figure 1. Location of the NAFO Regulatory Areas (white boxes) and standard Atlantic Zone Monitoring Program fixed coastal stations (closed red squares) and oceanographic transects (red lines) . Moderate Resolution Imaging Spectroradiometer (MODIS) "Aqua" sensor statistical sub-regions shown by the open red boxes (HS=Hudson Strait, GS=Greenland Shelf, CLS=central Labrador Sea, BRA=Bravo, NLS=northern Labrador Shelf, HB=Hamilton Bank (Seal Island), SAB=St. Anthony Basin, NENS=northeast Newfoundland Shelf, NEGSL=northeast Gulf of St. Lawrence, AC=Avalon Channel, MS=Magdallon Shallows, CS=Cabot Strait, FP=Flemish Pass, HIB=Hibernia, SPB=St. Pierre Bank, SES=southeast Shoal, ESS=eastern Scotian Shelf, WB=Western Bank, CSS=central Scotian Shelf, WSS=western Scotian Shelf, LS=Lurcher Shoal, GB=Georges Bank.

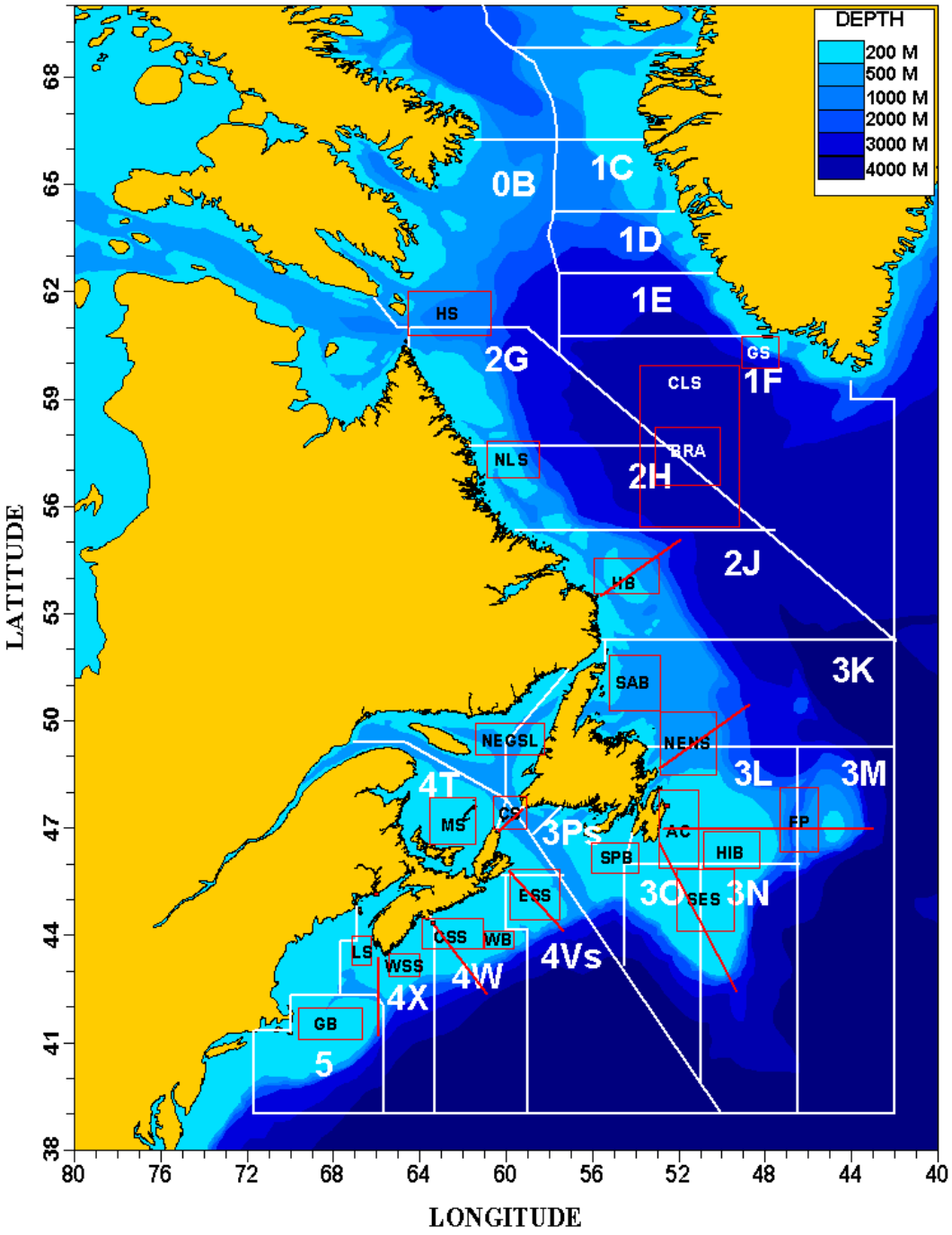

Figure 2. Summary of nitrate (combined nitrate and nitrite which represents the principal limiting nutrient in the system) anomalies from different oceanographic transects and fixed stations from the Atlantic Zone Monitoring Program during 2010. The standardized anomalies are the differences between the annual average for a given year and the long-term mean (1999-2010) divided by the standard deviation. The NAFO Subareas are sorted by latitude from north (top) to south (bottom) regions.

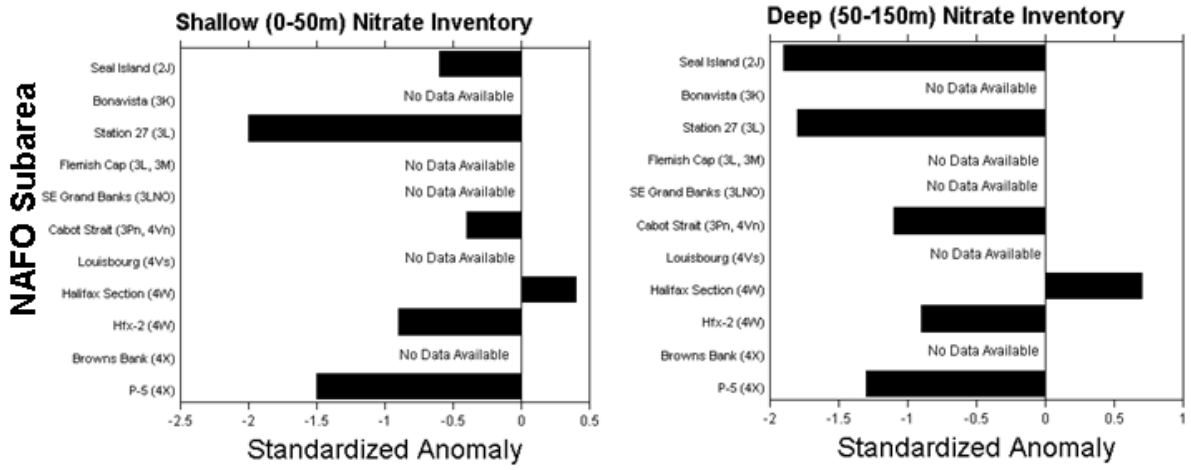

Figure 3. Time series of chemical variables from different oceanographic transects and fixed stations (highlighted in yellow) from the Atlantic Zone Monitoring Program during 1999-2010. A grey cell indicates missing data; a blue cell indicates lower than normal levels and a red cell indicates higher than normal levels. More intense colours indicate larger anomalies. The numbers in the coloured cells are the differences in the annual average value from the long-term mean (1999-2010) divided by the standard deviation. The NAFO Subareas are sorted by latitude from north (top) to south (bottom) regions.

Index
Nitrate Inventory
0-50 m (mmol m^{-2})

Section	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Seal Island (2J)		-0.2	0.2	0.6		1.7	0.4	-1.4	0.8	-1.7	0.3	-0.6
Bonavista (3K)		-0.6	-0.5	1.2	1.5	0.3	-1.0	-1.3	1.3	-0.3	-0.5	
Station 27 (3L)		0.0	1.9	-0.5	0.7	0.3	0.0	-0.8	0.8	0.3	-0.6	-2.0
Flemish Cap (3L, 3M)		-0.8	-0.1	1.0	2.1	0.5	-0.7	-0.6	0.4	-0.8	-0.9	
SE Grand Banks (3LNO)		-0.8	-0.3	0.0	2.4	0.6	0.1	-1.3	0.3	-0.6	-0.3	
Cabot Strait (3Pn, 4Vn)	1.5	-1.6	-0.9	0.0	-1.1	-0.4	0.4	-0.1	1.0	1.3	0.2	-0.4
Louisbourg (4Vs)	1.8	-0.7	-1.2	-2.0	0.5	-0.4	-0.3	0.7	0.9	0.6	0.0	
Halifax Section (4W)	2.0	-0.8	0.1	-1.2	-0.7	-0.7	-0.3	0.1	-0.4	1.8	-0.3	0.4
Hfx-2 (4W)	-2.2	1.2	1.3	-0.7	-0.2	0.1	-0.6	0.3	0.2	1.2	0.4	-0.9
Browns Bank (4X)	0.1	-0.6	-0.8	-0.9	0.7	-0.3	0.1	0.3	-1.8	2.0	1.2	
P-5 (4X)	-1.0	-0.5	-0.6	0.7	1.1	0.1	-0.9	1.4	-0.4	0.1	1.5	-1.5

Nitrate Inventory
50-150 m (mmol m^{-2})

Seal Island (2J)		0.4	0.2	0.3		0.6	0.3	0.3	1.0	-1.8	0.6	-1.9
Bonavista (3K)		0.1	-1.2	-0.3	1.1	0.9	-0.9	0.5	1.6	-0.6	-1.1	
Station 27 (3L)		1.4	0.2	0.2	-0.7	-0.6	-0.1	-0.1	1.0	1.5	-0.9	-1.8
Flemish Cap (3L, 3M)		0.8	-0.8	-0.7	1.0	0.4	-1.2	1.2	1.2	-0.6	-1.3	
SE Grand Banks (3LNO)		-1.9	-1.4	0.2	0.2	1.0	-0.3	0.2	0.8	1.3	0.0	
Cabot Strait (3Pn, 4Vn)	0.0	1.7	-0.9	-0.7	-0.1	1.2	-0.7	0.1	-1.3	0.6	1.2	-1.1
Louisbourg (4Vs)	0.5	1.6	-1.3	-0.9	0.7	-0.6	0.4	0.4	-1.9	-0.1	0.4	
Halifax Section (4W)	0.4	0.6	-0.1	-0.7	-0.1	-0.8	-2.0	0.5	-1.1	1.1	1.5	0.7
Hfx-2 (4W)	-0.7	0.8	-0.8	0.1	1.5	-0.8	-1.1	1.7	-0.7	-0.3	1.0	-0.9
Browns Bank (4X)	-2.0	-0.2	0.1	-1.0	1.2	1.1	-0.4	0.2	-1.0	-0.1	0.9	
P-5 (4X)	-0.8	-0.5	-1.3	0.9	1.1	-0.3	-0.6	1.1	-0.4	0.4	1.7	-1.3

Figure 4. Composite sums across all NAFO Subareas for shallow and deep nitrate inventories during 1999-2010 and total sum combining both indices.

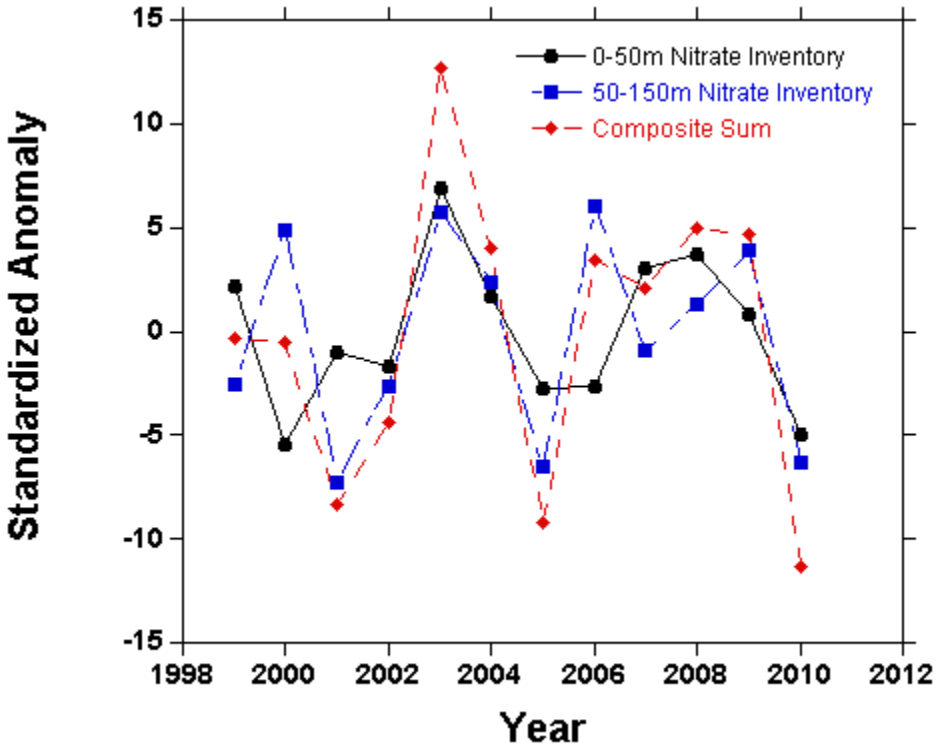

Figure 5. Summary of phytoplankton anomalies from Moderate Resolution Imaging Spectroradiometer (MODIS) "Aqua" sensor imagery across the different statistical sub-regions during 2010. The standardized anomalies are the differences between the annual average for a given year and the long-term mean (2003-2010) divided by the standard deviation. The NAFO Subareas are sorted from northern (top) to southern (bottom) regions. Negative anomalies for the timing indices (initiation, peak timing, and duration) indicate earlier/shorter blooms while positive anomalies indicate the reverse.

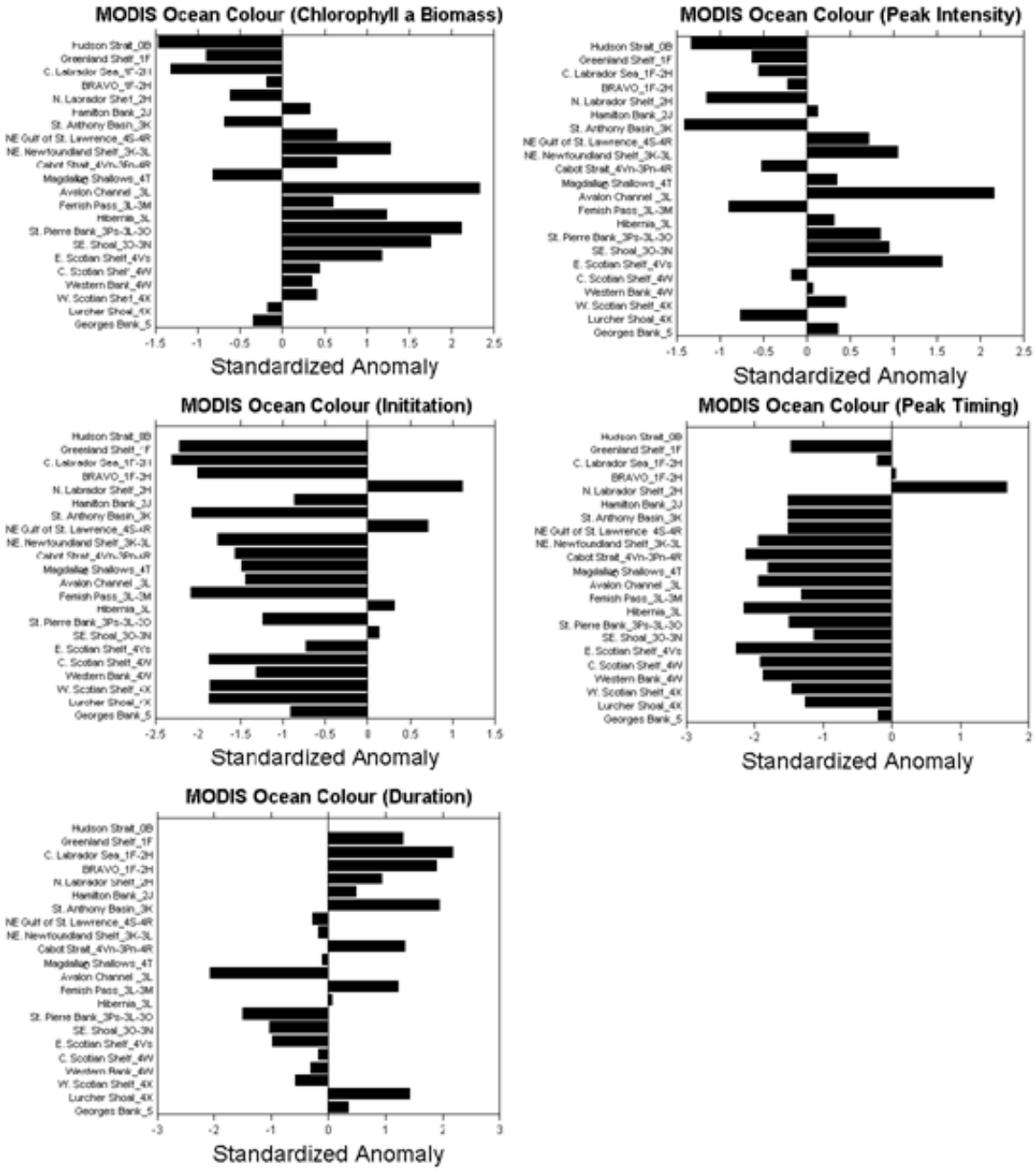

Figure 6. Annual anomalies of mean phytoplankton biomass derived from Moderate Resolution Imaging Spectroradiometer (MODIS) “Aqua” sensor imagery across the different NAFO Subareas extending from Georges Bank to the Hudson Strait during 2003-2010. A grey cell indicates missing data; a blue cell indicates lower than normal levels and a red cell indicates higher than normal levels. More intense colours indicate larger standardized anomalies. The numbers in the coloured cells are the differences from the long-term mean (2003-2010) divided by the standard deviation.

NAFO Subarea	2003	2004	2005	2006	2007	2008	2009	2010
Hudson Strait_0B	-0.48	-1.45	0.98	0.42	0.53	0.86	0.60	-1.47
Greenland Shelf_1F	1.01	0.87	-1.37	0.37	0.95	-1.19	0.27	-0.90
C. Labrador Sea_1F-2H	0.13	-1.17	0.11	1.46	0.68	0.85	-0.73	-1.32
BRAVO_1F-2H	-0.23	-0.79	0.50	2.08	-0.15	0.08	-1.30	-0.19
N. Labrador Shelf_2H	0.99	-0.44	-0.42	1.43	0.21	-1.70	0.54	-0.61
Hamilton Bank_2J	-0.27	-0.36	-1.21	2.02	-0.80	-0.32	0.62	0.32
St. Anthony Basin_3K	-0.51	0.34	-1.29	-0.28	0.62	-0.19	1.99	-0.69
NE Gulf of St. Lawrence_4S-4R	-0.12	-0.08	-0.83	2.01	-0.38	-1.30	0.06	0.64
NE. Newfoundland Shelf_3K-3L	-0.85	-0.36	-1.38	0.68	-0.07	-0.62	1.32	1.28
Cabot Strait_4Vn-3Pn-4R	0.45	-0.41	-1.58	1.49	0.44	-1.14	0.10	0.65
Magdallon Shallows_4T	-0.60	1.34	-0.91	1.74	-0.20	-0.52	-0.02	-0.82
Avalon Channel _3L	-0.37	-0.42	-0.75	0.45	-0.47	-0.46	-0.31	2.32
Femish Pass_3L-3M	-0.31	-1.17	1.45	0.25	-0.71	-1.17	1.06	0.60
Hibernia_3L	-1.32	0.89	-1.48	-0.45	0.08	0.50	0.54	1.23
St. Pierre Bank_3Ps-3L-3O	-0.45	0.21	0.31	0.33	-0.78	-0.97	-0.76	2.11
SE. Shoal_3O-3N	0.82	-0.44	-1.11	-0.50	-1.14	0.55	0.08	1.74
E. Scotian Shelf_4Vs	-0.36	-0.23	-1.98	0.69	0.98	-0.26	-0.01	1.18
C. Scotian Shelf_4W	0.21	-1.39	-1.30	0.35	-0.27	0.29	1.69	0.43
Western Bank_4W	-1.18	-0.65	-1.35	0.30	1.60	0.19	0.74	0.34
W. Scotian Shelf_4X	0.54	-1.51	-1.23	1.06	0.05	-0.49	1.18	0.40
Lurcher Shoal_4X	-0.36	-0.39	-0.82	2.32	-0.64	-0.27	0.36	-0.18
Georges Bank_5	1.11	0.27	-1.28	-0.66	-0.39	-0.47	1.77	-0.34

Figure 7. Annual anomalies of peak spring bloom intensity derived from Moderate Resolution Imaging Spectroradiometer (MODIS) “Aqua” sensor imagery across the different NAFO Subareas extending from Georges Bank to the Hudson Strait during 2003-2010. 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 standardized anomalies. The numbers in the coloured cells are the differences from the long-term mean (2003-2010) divided by the standard deviation.

NAFO Subarea	2003	2004	2005	2006	2007	2008	2009	2010
Hudson Strait_0B	0.15	-0.70	1.58	0.82	-0.99	0.71	-0.24	-1.33
Greenland Shelf_1F	1.20	1.09	-1.20	0.49	0.64	-1.36	-0.23	-0.63
C. Labrador Sea_1F-2H	0.15	-0.10	-0.51	0.22	-0.08	2.16	-1.30	-0.55
BRAVO_1F-2H	-0.10	-0.54	-0.68	1.05	0.16	1.75	-1.42	-0.22
N. Labrador Shelf_2H	1.14	-1.24	0.14	0.66	0.32	-0.99	1.13	-1.16
Hamilton Bank_2J	0.18	-0.52	-1.09	0.34	-1.13	0.07	2.02	0.12
St. Anthony Basin_3K	1.21	-0.38	-0.54	1.21	-0.04	-0.93	0.88	-1.41
NE Gulf of St. Lawrence_4S-4R	-0.36	-0.16	-0.56	2.20	-0.46	-0.76	-0.63	0.71
NE. Newfoundland Shelf_3K-3L	-0.56	-0.01	-0.85	0.76	-0.91	-1.03	1.55	1.05
Cabot Strait_4Vn-3Pn-4R	1.07	0.29	-1.20	0.49	1.42	-1.33	-0.21	-0.52
Magdallon Shallows_4T	-0.57	1.35	-0.75	1.63	-0.41	-0.95	-0.66	0.34
Avalon Channel _3L	-0.14	-0.69	-0.76	0.78	-0.33	-0.37	-0.64	2.16
Femish Pass_3L-3M	0.27	-0.94	0.93	-0.64	0.47	-0.89	1.71	-0.90
Hibernia_3L	-1.15	0.19	-1.11	-0.71	1.03	1.64	-0.21	0.31
St. Pierre Bank_3Ps-3L-3O	0.31	-0.03	1.84	-0.14	-0.93	-1.20	-0.69	0.85
SE. Shoal_3O-3N	1.30	-0.52	-1.12	-0.36	-0.35	1.20	-1.09	0.94
E. Scotian Shelf_4Vs	0.75	0.48	-1.43	-0.31	0.29	-0.12	-1.23	1.56
C. Scotian Shelf_4W	2.23	-0.64	-0.96	-0.64	0.03	-0.29	0.44	-0.18
Western Bank_4W	0.06	0.09	-1.01	-1.01	2.21	-0.15	-0.26	0.07
W. Scotian Shelf_4X	2.02	-0.54	-1.10	-0.38	-0.36	-0.73	0.66	0.44
Lurcher Shoal_4X	0.54	-0.56	-0.64	0.29	-1.04	0.13	2.05	-0.77
Georges Bank_5	1.81	0.45	-1.07	-0.69	-1.01	-0.54	0.68	0.36

Figure 8. Annual anomalies of initiation timing of the spring bloom derived from Moderate Resolution Imaging Spectroradiometer (MODIS) "Aqua" sensor imagery across the different NAFO Subareas extending from Georges Bank to the Hudson Strait during 2003-2010. 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 standardized anomalies. The numbers in the coloured cells are the differences from the long-term mean (2003-2010) divided by the standard deviation.

NAFO Subarea	2003	2004	2005	2006	2007	2008	2009	2010
Hudson Strait_0B								
Greenland Shelf_1F	0.19	0.46	-0.68	0.49	0.46	0.47	0.82	-2.22
C. Labrador Sea_1F-2H	0.51	0.43	0.66	0.31	0.13	0.70	-0.43	-2.31
BRAVO_1F-2H	1.02	0.21	0.72	0.13	0.39	0.51	-0.97	-2.01
N. Labrador Shelf_2H	-1.67	0.09	-0.62	-0.58	0.74	-0.33	1.26	1.11
Hamilton Bank_2J	0.57	-0.06	-1.89	0.91	-0.16	0.36	1.16	-0.87
St. Anthony Basin_3K	1.17	0.76	0.39	-0.26	0.54	-0.06	-0.45	-2.08
NE Gulf of St. Lawrence_4S-4R	-0.36	-0.16	-0.56	2.20	-0.46	-0.76	-0.63	0.71
NE. Newfoundland Shelf_3K-3L	1.36	0.32	0.23	1.11	-0.66	-0.19	-0.40	-1.77
Cabot Strait_4Vn-3Pn-4R	0.74	1.11	-0.43	0.35	1.19	-0.50	-0.89	-1.57
Magdallon Shallows_4T	0.05	1.76	-0.78	-0.44	0.02	-0.04	0.93	-1.49
Avalon Channel _3L	0.88	0.64	-0.69	1.63	-0.02	-0.28	-0.73	-1.44
Femish Pass_3L-3M	1.45	0.18	0.34	-0.07	0.25	-0.41	0.35	-2.09
Hibernia_3L	-1.15	0.19	-1.11	-0.71	1.03	1.64	-0.21	0.31
St. Pierre Bank_3Ps-3L-3O	-0.02	1.18	1.59	-0.27	-0.23	-1.19	0.17	-1.23
SE. Shoal_3O-3N	0.09	0.35	-0.77	-0.21	-0.57	2.13	-1.16	0.13
E. Scotian Shelf_4Vs	0.67	1.01	-0.72	0.20	0.70	0.73	-1.85	-0.73
C. Scotian Shelf_4W	1.56	-0.02	0.01	0.25	-0.12	0.80	-0.61	-1.87
Western Bank_4W	1.80	0.17	-0.70	-1.04	0.21	0.46	0.41	-1.31
W. Scotian Shelf_4X	1.61	0.25	-0.37	0.38	0.62	-0.21	-0.41	-1.86
Lurcher Shoal_4X	0.48	0.01	-0.03	1.34	-0.95	0.30	0.70	-1.87
Georges Bank_5	1.76	0.99	-0.90	-0.50	-0.51	-0.59	0.66	-0.91

Figure 9. Annual anomalies of peak timing of the spring bloom derived from Moderate Resolution Imaging Spectroradiometer (MODIS) "Aqua" sensor imagery across the different NAFO Subareas extending from Georges Bank to the Hudson Strait during 2003-2010. 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 standardized anomalies. The numbers in the coloured cells are the differences from the long-term mean (2003-2010) divided by the standard deviation.

NAFO Subarea	2003	2004	2005	2006	2007	2008	2009	2010
Hudson Strait_0B								
Greenland Shelf_1F	-0.05	-0.63	0.30	-0.52	-0.07	1.95	0.50	-1.47
C. Labrador Sea_1F-2H	-0.18	1.54	1.34	-0.35	-0.74	-1.43	0.02	-0.21
BRAVO_1F-2H	0.47	0.43	1.17	0.12	-0.46	-2.20	0.40	0.06
N. Labrador Shelf_2H	-1.42	0.98	-0.92	-0.51	-0.11	0.09	0.21	1.68
Hamilton Bank_2J	0.22	-0.67	-0.60	1.45	0.91	-0.57	0.77	-1.51
St. Anthony Basin_3K	1.27	0.33	-0.41	-1.17	0.75	-0.18	0.93	-1.51
NE Gulf of St. Lawrence_4S-4R	0.89	-0.22	0.19	1.83	-0.43	-0.32	-0.41	-1.52
NE. Newfoundland Shelf_3K-3L	1.31	0.66	-0.56	-0.41	0.70	0.32	-0.09	-1.94
Cabot Strait_4Vn-3Pn-4R	0.23	0.50	0.55	-0.40	0.13	1.30	-0.19	-2.12
Magdallon Shallows_4T	-0.24	0.27	0.52	1.48	-0.88	0.58	0.07	-1.81
Avalon Channel _3L	1.50	0.57	0.28	0.07	-0.14	0.31	-0.64	-1.95
Femish Pass_3L-3M	2.10	0.57	-0.50	-0.47	-0.06	-0.13	-0.20	-1.32
Hibernia_3L	0.40	0.38	0.42	0.03	0.62	1.01	-0.71	-2.15
St. Pierre Bank_3Ps-3L-3O	-0.25	-0.48	-1.02	1.38	0.23	1.04	0.60	-1.50
SE. Shoal_3O-3N	1.73	0.48	-0.05	-0.30	0.32	0.42	-1.46	-1.14
E. Scotian Shelf_4Vs	0.77	0.93	0.39	-0.06	-0.17	0.49	-0.08	-2.26
C. Scotian Shelf_4W	-0.08	0.23	1.43	0.07	-0.35	0.97	-0.35	-1.92
Western Bank_4W	0.45	-0.40	1.46	0.22	-0.63	0.74	0.01	-1.87
W. Scotian Shelf_4X	-1.10	0.38	1.49	0.92	-0.03	0.36	-0.55	-1.46
Lurcher Shoal_4X	-0.11	-0.47	-0.31	2.08	0.35	-0.68	0.39	-1.26
Georges Bank_5	-0.30	-0.07	1.03	-1.01	1.84	-0.12	-1.18	-0.19

Figure 10. Annual anomalies of duration of the production cycle derived from Moderate Resolution Imaging Spectroradiometer (MODIS) "Aqua" sensor imagery across the different NAFO Subareas extending from Georges Bank to the Hudson Strait during 2003-2010. A grey cell indicates missing data; a blue cell indicates shorter duration and a red cell indicates longer duration of the production cycle. More intense colours indicate larger standardized anomalies. The numbers in the coloured cells are the differences from the long-term mean (2003-2010) divided by the standard deviation.

NAFO Subarea	2003	2004	2005	2006	2007	2008	2009	2010
Hudson Strait_0B								
Greenland Shelf_1F	-0.30	0.40	0.97	-1.19	-1.01	0.83	-1.00	1.30
C. Labrador Sea_1F-2H	-0.57	-0.28	-0.40	-0.04	-0.14	-1.20	0.46	2.18
BRAVO_1F-2H	-0.96	-0.28	-0.49	0.19	-0.24	-1.07	0.98	1.88
N. Labrador Shelf_2H	0.37	1.18	-1.21	0.51	-1.06	0.50	-1.22	0.94
Hamilton Bank_2J	-1.01	0.18	1.53	-0.46	1.01	-0.29	-1.44	0.48
St. Anthony Basin_3K	-1.46	-0.01	0.48	-0.02	-0.93	0.05	-0.05	1.94
NE Gulf of St. Lawrence_4S-4R	-0.92	0.32	0.48	-1.94	0.85	0.46	1.03	-0.29
NE. Newfoundland Shelf_3K-3L	-0.62	-0.16	1.10	0.79	-0.47	1.24	-1.73	-0.16
Cabot Strait_4Vn-3Pn-4R	-1.27	-0.86	0.75	-0.21	-1.13	0.76	0.64	1.33
Magdallon Shallows_4T	-0.06	-1.17	1.27	1.19	-0.62	0.77	-1.28	-0.10
Avalon Channel _3L	-0.62	0.08	1.18	0.01	0.35	0.19	0.87	-2.07
Femish Pass_3L-3M	-0.85	0.09	-0.78	0.82	-0.29	1.21	-1.41	1.21
Hibernia_3L	1.38	-0.78	1.05	0.88	-1.12	-1.10	-0.39	0.07
St. Pierre Bank_3Ps-3L-3O	-0.25	-0.48	-1.02	1.38	0.23	1.04	0.60	-1.50
SE. Shoal_3O-3N	-0.14	0.43	1.52	0.57	0.02	-1.72	0.35	-1.03
E. Scotian Shelf_4Vs	-1.12	-0.28	1.26	1.07	-0.93	-0.09	1.06	-0.98
C. Scotian Shelf_4W	-2.16	0.32	1.00	0.64	0.41	0.54	-0.59	-0.17
Western Bank_4W	-1.42	-0.01	1.18	1.44	-0.76	0.59	-0.70	-0.32
W. Scotian Shelf_4X	-2.24	0.44	0.92	0.56	0.41	0.18	0.31	-0.58
Lurcher Shoal_4X	-0.76	0.30	0.04	-0.83	1.51	-0.88	-0.79	1.41
Georges Bank_5	-1.72	-0.58	1.04	0.82	0.64	0.53	-1.07	0.35

Figure 11. Composite sums across all NAFO Subareas for each MODIS satellite ocean colour index during 2003-2010 and total sum of chlorophyll a concentration and peak intensity (composite sum 1) and timing indices; initiation, peak timing, and duration (composite sum 2).

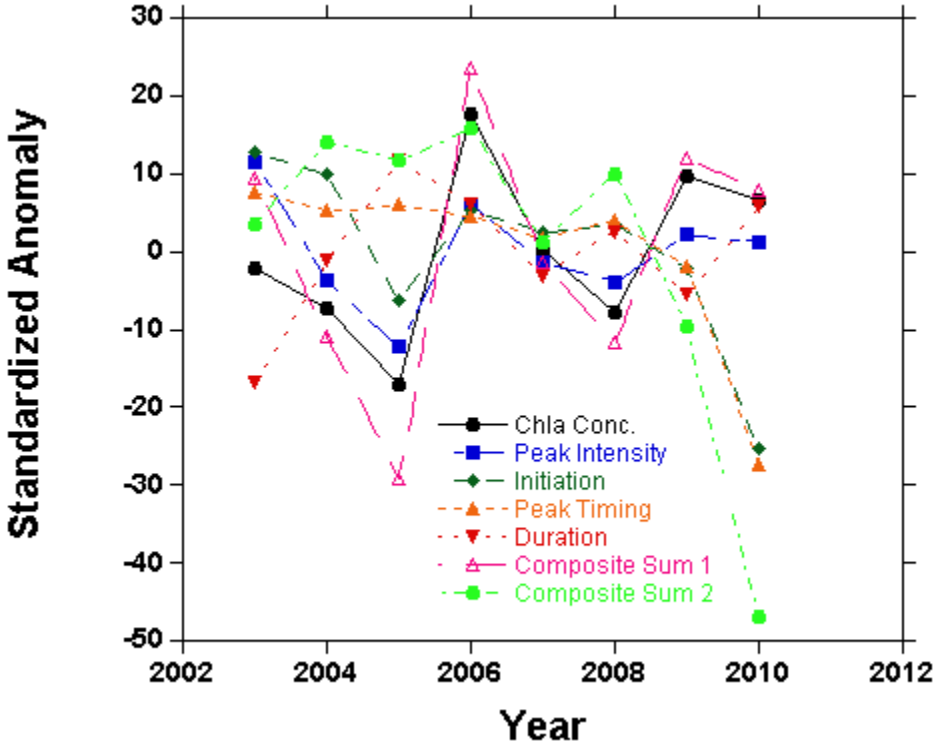

Figure 12. Summary of zooplankton abundance anomalies from different oceanographic transects and fixed stations from the Atlantic Zone Monitoring Program during 2010. The NAFO Subareas are sorted from the southern Labrador Shelf - 2J (top) to southern Scotian Shelf - 4X (bottom).

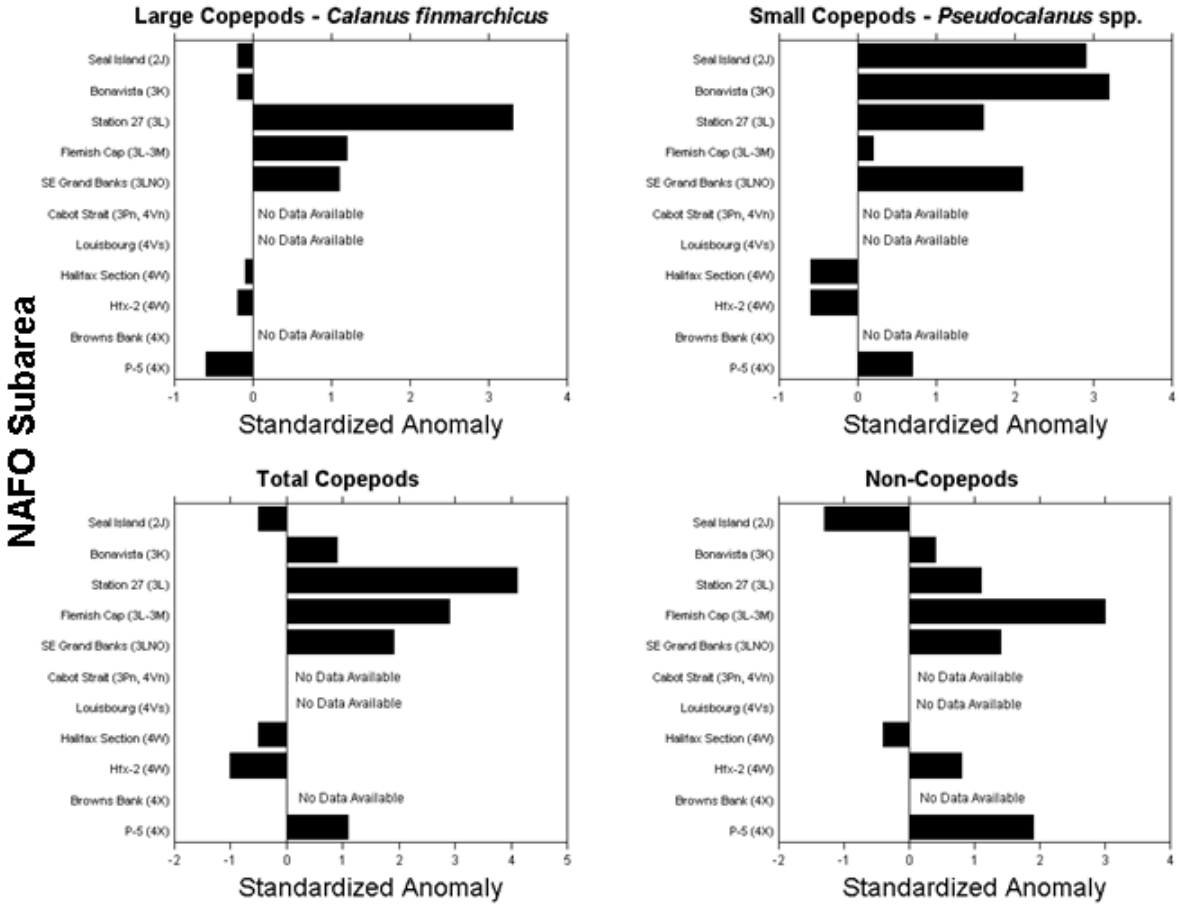

Figure 13. Time series of zooplankton abundance anomalies from different oceanographic transects and fixed stations from the Atlantic Zone Monitoring Program during 1999-2010. A grey cell indicates missing data; a blue cell indicates lower than normal levels and a red cell indicates higher than normal levels. More intense colours indicate larger anomalies. The numbers in the coloured cells are the differences from the long-term mean (1999-2010) divided by the standard deviation. The NAFO Subareas are sorted by latitude from north (top) to south (bottom) regions.

Index	Section-Subarea	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Large Copepods	Seal Island (2J)		-1.8	-0.7	0.0	0.0	1.2	0.9	0.3	0.3	-0.4	-1.2	-0.2
Calanus finmarchicus	Bonavista (3K)	-1.9	-1.0	0.1	0.3	0.4	0.8	0.3	1.1	0.7	0.2	0.2	-0.2
	Station 27 (3L)	1.6	0.5	0.5	0.6	-0.2	-1.6	-0.4	-0.9	-0.5	-4.3	-0.4	3.3
	Flemish Cap (3L-3M)	-1.9	-1.2	0.6	0.7	0.2	0.1	0.5	0.9	0.1	0.3	0.2	1.2
	SE Grand Banks (3LNO)	-1.9	-1.1	0.4	0.8	0.6	0.2	0.9	0.2	0.3	0.1	0.7	1.1
	Cabot Strait (3Pn, 4Vn)	1.2	-1.0	-1.0		1.5	-0.1	-0.3	-0.3	0.9	-0.7	-1.2	
	Louisbourg (4Vs)	0.9	-0.8	-0.6	2.0	-0.8	0.1	-0.5	-0.3	-0.3	1.0	-0.3	
	Halifax Section (4W)	1.6	-0.3	-0.2	-1.7	0.2	-1.0	0.7	0.5	-1.3	0.2	1.5	-0.1
	Hfx-2 (4W)	1.1	0.9	1.3	-0.2	0.6	-0.7	-1.4	-0.7	-0.1	1.2	-1.7	-0.2
	Browns Bank (4X)	0.1	-1.1	0.7	0.5	1.5	-1.3	-1.0	0.6	-1.2	1.1	0.9	
	P-5 (4X)	-1.2	-1.1	1.4	-1.2	0.5	0.1	0.6	1.9	-0.7	0.0	0.2	-0.6
		1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Small Copepods	Seal Island (2J)		-0.5	0.7	-0.9	0.6	-0.3	-1.1	1.6	3.3	0.4	-1.0	2.9
Pseudocalanus	Bonavista (3K)	-1.6	-1.2	1.2	0.3	0.7	0.3	-0.6	0.8	-0.1	0.2	1.0	3.2
	Station 27 (3L)	-0.5	1.1	0.6	0.8	0.6	-2.0	0.0	-0.6	0.8	-1.6	2.2	1.6
	Flemish Cap (3L-3M)	2.2	0.4	-0.5	0.4	-0.5	-0.6	-1.0	-0.3	-0.7	-0.6	-0.3	0.2
	SE Grand Banks (3LNO)	-2.1	1.0	0.5	0.7	-0.4	0.1	0.6	-0.4	0.5	-0.4	0.1	2.1
	Cabot Strait (3Pn, 4Vn)	1.0	-1.3	-0.4		1.6	-0.2	-0.2	-0.6	0.0	0.8	-0.9	
	Louisbourg (4Vs)	1.5	-1.1	0.1	1.5	-0.2	-0.7	-0.9	-0.3	-0.6	-0.1	-0.8	
	Halifax Section (4W)	2.2	-0.7	-0.3	2.1	-0.2	-0.7	-0.5	-0.2	-0.4	-0.3	-0.4	-0.6
	Hfx-2 (4W)	1.6	0.5	0.0	-0.3	0.9	1.0	0.3	-1.9	-1.4	0.5	-0.6	-0.6
	Browns Bank (4X)	0.8	-0.2	1.5	-0.4	1.1	-1.3	-0.8	-0.7	-0.9	-0.4	-1.0	
	P-5 (4X)	0.4	0.5	2.0	0.4	0.0	-0.7	-0.9	-1.1	-0.5	0.8	-1.5	0.7
		1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Total Copepods	Seal Island (2J)		-1.7	-0.9	-0.2	0.1	1.0	0.8	0.8	0.0	-0.6	-0.8	-0.5
	Bonavista (3K)	-1.9	-0.8	0.1	-0.1	0.7	0.6	0.1	1.3	0.8	0.7	1.0	0.9
	Station 27 (3L)	-0.7	1.0	-0.7	1.7	0.5	-1.2	-0.2	-0.4	1.0	-1.4	3.5	4.1
	Flemish Cap (3L-3M)	-1.9	-0.6	0.4	0.1	-0.3	0.0	0.8	1.4	0.7	0.8	1.0	2.9
	SE Grand Banks (3LNO)	-2.1	0.6	-0.6	0.3	0.2	0.5	1.2	0.0	0.9	0.4	1.0	1.9
	Cabot Strait (3Pn, 4Vn)	1.6	-1.2	-1.0		1.0	0.3	0.3	-1.0	-0.3	0.0	-0.7	
	Louisbourg (4Vs)	2.4	-0.7	-0.1	-0.4	0.2	-0.7	-0.3	-0.3	-0.9	0.7	-0.9	
	Halifax Section (4W)	2.5	0.6	0.0	-0.7	-0.3	-1.1	1.1	-0.8	-0.4	-0.6	0.2	-0.5
	Hfx-2 (4W)	1.9	1.0	0.6	-1.3	-0.1	0.2	0.7	-0.9	-1.3	-0.2	0.4	-1.0
	Browns Bank (4X)	1.1	0.9	0.1	-0.2	1.0	-1.8	-0.8	-0.4	-1.3	0.2	-1.0	
	P-5 (4X)	-0.1	1.2	1.6	-0.8	0.4	-0.2	-1.3	0.7	-1.0	-0.4	-1.3	1.1
		1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Non-Copepods	Seal Island (2J)		-1.0	-0.5	-1.0	-0.4	0.8	0.6	1.6	-0.3	-1.4	-0.5	-1.3
	Bonavista (3K)	-2.0	-0.9	0.5	0.4	0.5	0.1	0.2	1.3	0.2	0.0	1.0	0.4
	Station 27 (3L)	-1.0	1.0	1.3	0.3	0.1	0.3	-0.3	-1.7	-0.2	-2.9	-1.3	1.1
	Flemish Cap (3L-3M)	-2.2	0.5	0.6	0.9	-0.3	-0.4	0.3	0.6	0.0	0.5	0.4	3.0
	SE Grand Banks (3LNO)	-2.2	1.2	0.3	0.2	0.1	-0.2	0.5	0.0	-0.3	0.0	0.1	1.4
	Cabot Strait (3Pn, 4Vn)	1.1	-1.2	-0.9		0.3	1.4	-0.8	0.1	-1.5	-0.6	-0.7	
	Louisbourg (4Vs)	0.3	-1.2	1.1	1.3	-1.2	-0.7	-0.3	0.7	-1.2	0.1	-1.0	
	Halifax Section (4W)	2.6	0.4	-0.7	-0.1	0.2	-0.4	1.0	-1.0	-0.9	0.1	-0.7	-0.4
	Hfx-2 (4W)	2.4	0.1	-0.4	-1.0	-0.5	0.3	0.9	-0.7	-1.2	-0.2	-0.6	0.8
	Browns Bank (4X)	1.5	0.5	-0.4	-0.3	1.0	-1.4	0.2	-1.0	-1.0	0.0	-1.1	
	P-5 (4X)	1.5	0.8	0.3	0.1	-1.0	-0.2	-1.5	-0.2	-0.3	-0.4	-1.0	1.9

Figure 14. Summary of zooplankton dry weight anomalies from different oceanographic transects and fixed stations from the Atlantic Zone Monitoring Program during 2010. The NAFO Subareas are sorted from the southern Labrador Shelf - 2J (top) to southern Scotian Shelf - 4X (bottom).

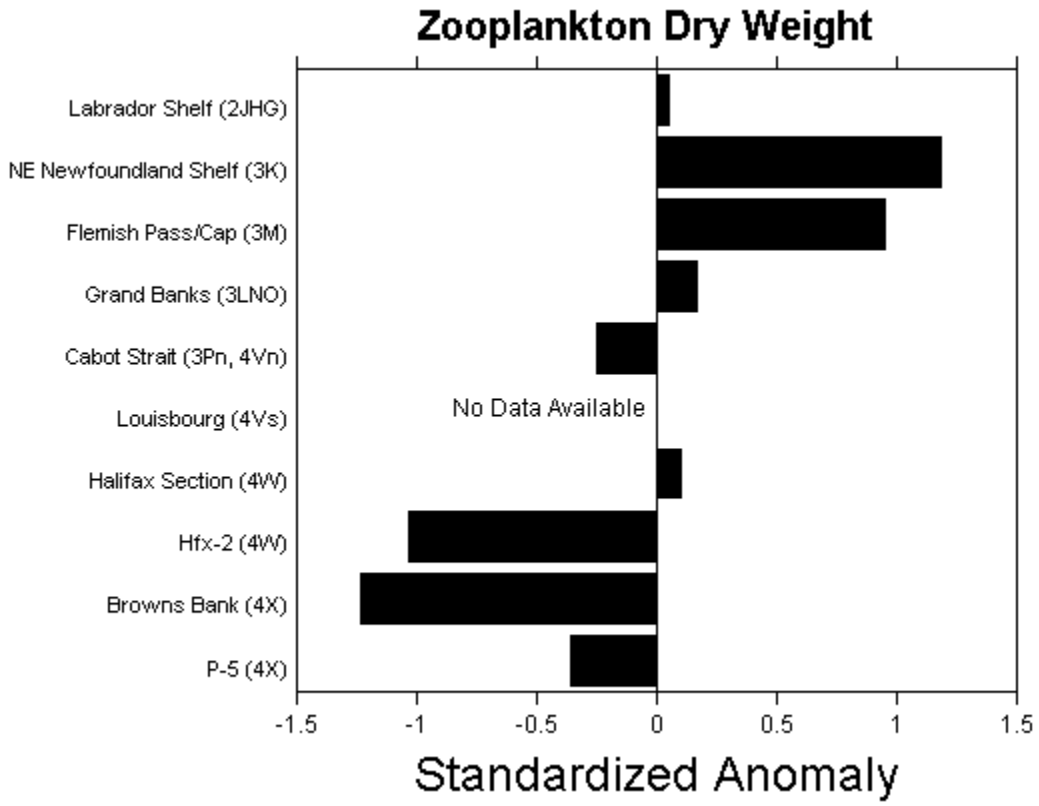

Figure 15. Time series of zooplankton dry weight anomalies from different oceanographic transects and fixed stations from the Atlantic Zone Monitoring Program during 1999-2010. A grey cell indicates missing data; a blue cell indicates lower than normal levels and a red cell indicates higher than normal levels. More intense colours indicate larger anomalies. The numbers in the coloured cells are the differences from the long-term mean (1999-2010) divided by the standard deviation. The NAFO Subareas are sorted by latitude from north (top) to south (bottom) regions.

NAFO Subarea	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Labrador Shelf (2JHG)	-0.56	-2.04	-0.39	0.58	0.71	-0.40	0.50	0.59	2.04	-0.42	-0.66	0.05
NE Newfoundland Shelf (3K)	-0.77	-1.52	0.26	-0.48	0.96	1.84	0.66	0.03	-0.46	-1.01	-0.68	1.18
Flemish Pass/Cap (3M)	-1.16	-1.67	-0.20	0.85	-0.62	-1.17	1.06	0.54	0.01	-0.01	1.43	0.95
Grand Banks (3LNO)	-0.53	-0.80	-0.52	2.35	0.20	1.19	0.16	0.12	0.18	-1.27	0.17	0.17
Cabot Strait (3Pn, 4Vn)			1.26		0.90	1.61	-0.77	-0.40	-0.91	-1.12	-0.32	-0.25
Louisbourg (4Vs)												
Halifax Section (4W)	-0.60	2.95	0.14		0.47	-0.28	-0.24	-0.52	-0.39		-0.28	0.10
Hfx-2 (4W)	-2.24	-0.08	1.07	-0.90	0.00	1.10	1.12	0.09	0.68	0.06	0.14	-1.03
Browns Bank (4X)			-0.54	2.12	1.06	-0.50	-0.22		0.00	-0.45	-0.24	-1.23
P-5 (4X)	-1.18	-0.24	2.17	-0.63	-0.03	-0.72	1.17	0.56	-1.14	-0.39	0.80	-0.36

Figure 16. Composite sums across all NAFO Subareas for each zooplankton index during 1999-2010 and total sum combining the first four zooplankton abundance (composite 1) and dry weight (composite 2) indices.

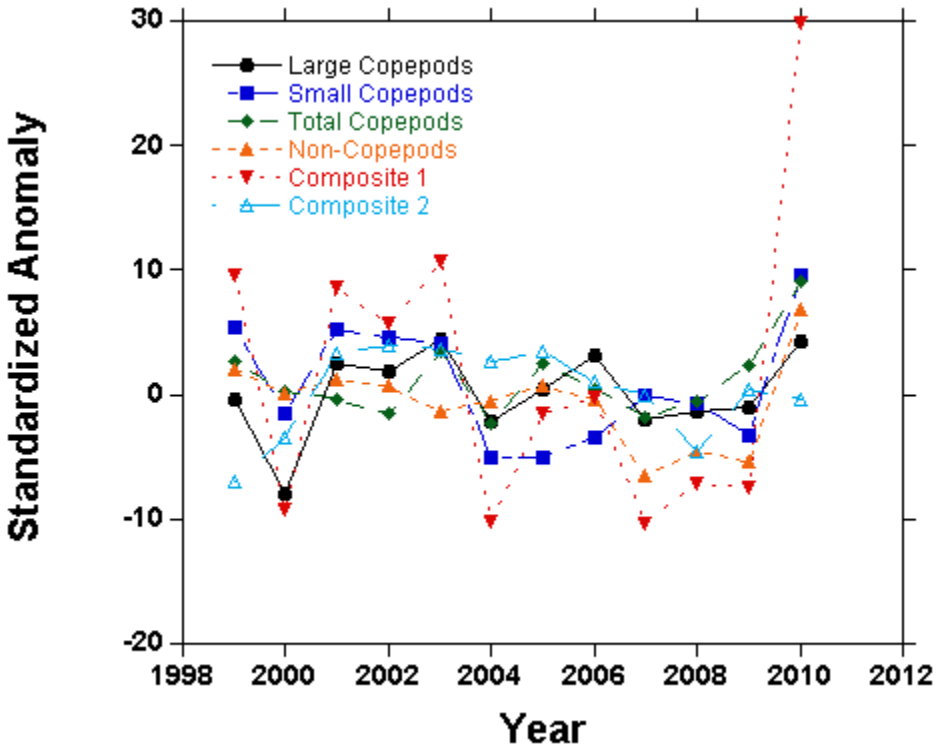

Figure 17. The combined indices of inventories and abundances across trophic levels (nutrients, phytoplankton and zooplankton) and all NAFO Subareas during 1999-2010. Note satellite data is only available from MODIS starting in 2003.