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Seasonality of phytoplankton abundance derived from satellite data in the northwest Atlantic during 1998 to 2009.

by

G. Maillet

Department of Fisheries and Oceans, P.O. Box 5667
St. John's, Newfoundland, Canada A1C 5X1

Abstract

The Sea-viewing Wide Field-field-of-view Sensor (SeaWiFS) and Moderate Resolution Imaging Spectrodiometer (MODIS) provides well-calibrated ocean colour time series that can be used to analyze the spatial and temporal variability of phytoplankton abundance. In 2009, the production cycle was delayed (2-4 weeks) and the duration was reduced compared to previous years on the Labrador Shelf (NAFO Subarea 2). The composite satellite imagery during the spring bloom indicated reduced surface blooms throughout the Grand Banks and northeast Shelf (Subarea 3). During the latter part of the production cycle in 2009 (late April through June) intense blooms were detected over a widespread area of the northeast Newfoundland Shelf and southern part of the Labrador Sea. Ocean colour conditions on the Scotian Shelf and Gulf of Maine (Subarea 4, 5) were comparable to recent years throughout the production cycle. A linear relationship between sea surface temperature and phytoplankton abundance was observed in northern waters which may lead to higher productivity with a continued warming trend. The utility of dynamic factor analysis (DFA) was explored to identify common trends in 16 SeaWiFS statistical sub-regions throughout the northwest Atlantic and to evaluate the predictive ability of environmental explanatory variables.

Introduction

The ability to monitor and detect changes in the marine ecosystem requires long-term continuous measurements of relevant variables. The global and regional data on chlorophyll *a* (chla) concentration derived from calibrated ocean colour satellites (e.g. SeaWiFS and MODIS) allow one to investigate the pattern of temporal and spatial variability in phytoplankton abundance and the relative influence of physical forcing (Vantrepotte and Mélin 2009). This study investigates the recent (2008-2009) large-scale spatial distribution of chla from semi-monthly composite images over the northwest Atlantic. In addition, this study examines the seasonality of phytoplankton abundance across 16 SeaWiFS statistical sub-regions occupying NAFO Subareas ranging northwards from the Hudson Strait (Subarea 2G) to the southern waters of the Gulf of Maine (Subarea 5). The application of a statistical decomposition method is used to model the seasonal cycle to generate the temporal trend which is then used as an input to estimate underlying common patterns using a dynamic factor analysis (Zuur et al. 2003). The DFA is then used to address the general patterns and interactions among time series and the utility of explanatory variables to predict the measured variables.

Satellite Imagery in the Northwest Atlantic

Satellite observations provide a comprehensive spatial and temporal view of phytoplankton biomass. We used the Moderate Resolution Imaging Spectrodiometer (MODIS) to view semi-monthly ocean colour composites of the Atlantic zone in 2008-2009 covering 39N to 62.5N and 42W to 71W, and Sea-viewing Wide Field-of-view Sensor (SeaWiFS) satellite imagery from the Bedford Institute of Oceanography[1] (Dartmouth, NS) to construct time series of surface chla and sea surface temperature (SST) from semi-monthly composite images across 16 statistical sub-regions extending from Hudson Strait (NAFO Subarea 2G) down to Georges Bank (NAFO Subarea 5) during 1998 through to 2009 (see Figure 1).

Comparison of the semi-monthly MODIS composite imagery across the Atlantic zone indicated early timing of the spring bloom in 2009 (late February) on the southeast section of the Grand Banks that is not typically observed until late March in the previous year (Figure 2). The composite imagery indicates no spatially extensive surface blooms across the Grand Banks and Northeast Shelf through early April. The timing and intensity of phytoplankton blooms across the Scotian Shelf and Gulf of Maine were comparable in recent years. The composite imagery reveals some relatively distinct changes during the later part of the production cycle in recent years (Figure 3). In 2009 intense blooms were observed over the northeast NL Shelf around the 200m isobath and into the southern part of the Labrador Sea which propagated through early June. In 2008, most of the production was confined to the Grand Banks with limited surface blooms further north during this period. By early May, most of the surface blooms are depleted across the Grand Banks and Scotian Shelf but productivity within the Gulf of Maine remains relatively high through the summer period.

Time series of semi-monthly surface chla concentrations and SST from the statistical sub-regions display strong seasonality typically with elevated concentrations during the onset of warming in spring and weaker autumn production (Figure 4a). The exception occurs in the northern areas along the northern Labrador Shelf that experience extended periods of ice coverage and generally exhibit a single production cycle. In 2009, the intensity of the spring bloom was similar to previous years but the initiation of the production was delayed and the duration was substantially reduced in NAFO Subarea 2 (Figure 4b). Another significant difference between 2009 and earlier years was the lack of autumn production that is generally observed throughout the Labrador Shelf time series (Figure 4b).

We examined the relationship of annual integrated chla levels and SST values. The results indicate a possible linear temperature dependence in determining phytoplankton abundance, particularly in the northern Labrador Shelf ; 2G - Hudson Strait and 2H - Northern Labrador Shelf (Figure 5a). The relationship begins to weaken further south on the southern Labrador Shelf (2J - Hamilton Bank). The temperature influence accounted for less than 50 % of the annual integrated chla levels indicating uncertainty of possible further impacts of warming in surface waters in this region (Figure 5b).

Time series of semi-monthly chla concentrations and SST for the Newfoundland statistical sub-regions (NAFO Subarea 3) provided insight into the magnitude, duration, and timing of surface blooms during the past decade. The seasonal cycle of chla concentration displayed relatively large interannual changes while the pattern for SST largely repeats each year with small annual deviations in timing and amplitude (Figure 6). In 2009, the initiation of production was earlier in general across Subarea 3 and duration of spring blooms longer compared to previous years. The reverse was true for the autumn bloom cycle with many of the statistical sub-regions showing reduced intensity and duration of production (Figure 7). The annual integrated chla values were near the long-term mean or slightly above (Figure 8). The only exceptions were for the Avalon Channel (3LNO) with the highest record, and St. Anthony Basin (3K) with the lowest record during the respective time series. We also examined the annual integrated chla and SST values for each of the statistical sub-regions and observed no linear relationship between phytoplankton abundance and temperature (Figure 8).

Strong seasonal cycles were apparent for both chla and SST semi-monthly time series across the statistical sub-regions in NAFO Subareas 4 and 5 (Figure 9). In general, the time series of chla were higher than normal in recent years, in contrast to the late 1990's. High interannual variability is also apparent throughout the time record. The trends in the SST time series indicate a general cooling over the statistical sub-regions most noticeable for the southern part of the Scotian Shelf (4W and 4X) and the Gulf of Maine (Georges Bank). A number of differences

[1] http://www.mar.dfo-mpo.gc.ca/science/ocean/ias/seawifs/seawifs_3.html

were observed in production during 2009 compared to earlier years; reduced duration of the spring bloom from the eastern Scotian Shelf (4Vs) to the western Scotian Shelf (4X); intense autumn blooms along the central Scotian Shelf and Western Bank (4W); and sustained high productivity on the southern Scotian Shelf (4W) and Gulf of Maine (5) from spring through autumn (Figure 10). In general, the integrated chla levels were at or near the highest values observed in the 12-year time series (Figure 11). The trend for the integrated SST values support the overall cooling trend across Subarea 4/5 but abrupt increases in surface temperatures were consistently observed in 1999 and 2006 across all statistical sub-regions (Figure 11). Again, no linear relationship was observed between phytoplankton abundance and temperature (data not shown).

The chla semi-monthly time series for each of the 16 statistical sub-regions were processed to extract the 12-year trend component during 1998 – 2009. The trend time series is modeled using a locally-weighted smoothing function (LOESS) and reflects the differences between the original and seasonal model (Figure 12). To estimate the underlying common trends, a DFA using a constant plus linear combination of M common trends and a noise term (no explanatory variables were included in the initial model evaluations) was explored (Brodgar 2009). The results indicated that 3 common trends provided the best fit using Akaike information criterion (Table 1). The AIC value is defined as the difference between the maximum loglikelihood and the number of parameters used in the model (including the # of trends, explanatory variables, and error covariance structures). The first common trend indicated peaks in phytoplankton biomass during 1999, 2002, and 2006-08 with substantial reductions in 2005 and again in 2009 (Figure 13a). This common trend was largely driven by the St. Anthony Basin sub-region showing a > 0.9 positive correlation. The majority of the other sub-regions displayed weaker correlations (Figure 13b). The second common trend was an overall decline from 1998-2009 with the largest changes occurring in 2006 and 2009 (Figure 13c). The pattern of the correlations indicated the northern sub-regions (Labrador Shelf) followed this pattern but the northeast Newfoundland Shelf - Grand Banks and southern Scotian Shelf deviated based on strong negative correlations (Figure 13d). A peak in 1999 followed by a declining trend until 2007 and a rapid increase into recent years (2008-09) characterizes the third common trend (Figure 13e). Most sub-regions revealed strong positive coherence to this pattern with the only exception being the northerly areas including Subarea 2 (Labrador Shelf) and 3K-St. Anthony Basin (Figure 13f). The utility of synoptic explanatory environmental variables was also explored such as an environmental composite and the North Atlantic Oscillation (Rogers Index) annual indices as potential forcing functions on production dynamics (Colbourne et al. 2009). The DFA analysis with explanatory variables did not substantially reduce the AIC values indicating limited utility for these particular indices to further explain the common trends in phytoplankton abundance. This may indicate the relative importance of local and regional environmental conditions in contrast to large-scale atmospheric and ocean forcing.

Summary and Conclusions

- Ocean colour remote sensing provides an invaluable tool for monitoring and detecting changes in the marine ecosystem.
- The composite imagery indicates no spatially extensive surface blooms across the Grand Banks in 2009.
- The timing and intensity of phytoplankton blooms across the Scotian Shelf and Gulf of Maine were comparable in recent years.
- In 2009 intense blooms were observed over the northeast NL Shelf around the 200m isobath and into the southern part of the Labrador Sea which propagated through early June.
- In 2009, the intensity of the spring bloom was similar to previous years but the initiation of the production was delayed and the duration was substantially reduced in NAFO Subarea 2.
- The link between temperature and phytoplankton abundance suggests increasing production with continued warming of northern waters but potential impacts on other key processes remain unclear and warrant further study.

- The DFA method identified 3 common trends that can be used to model the phytoplankton abundance time series.

- The utility of synoptic explanatory environmental variables was also explored such as an environmental composite and the North Atlantic Oscillation annual indices as potential forcing functions on production dynamics.

- Future work will continue to utilize the DFA methodology to detect common patterns in a multivariate set of time series and relationships between those time series and explanatory variables.

- This type of analysis can naturally been expanded to investigate the relationships between environmental variables and multiple trophic levels including zooplankton and commercially-important invertebrate and fish stocks.

Acknowledgements

Glen Harrison, Carla Caverhill and Heidi Mass at the Bedford Institute of Oceanography provided access to SeaWiFs and MODIS composite imagery and data from statistical sub-regions. Mariano Koen-Alonso and Pierre Pepin provided guidance and assistance with Dynamic Factor Analysis and associated R-statistical routines.

References

Brodgar 2009. Software for univariate and multivariate analysis, and multivariate time series analysis, version 2.6.4., September 2009. Highland Statistics Ltd., 6 Laverock road
Newburgh, AB41 6FN, Aberdeenshire, Scotland, UK.

E. Colbourne, J. Craig, C. Fitzpatrick, D. Senciall, P. Stead, and W. Bailey. 2009. An assessment of the physical oceanographic environment on the Newfoundland and Labrador Shelf during 2008. Canadian Science Advisory Secretariat Research Document, 2009/032, 23pp.

A.F. Zuur, R.J. Fryer, I.T. Jolliffe, R. Dekker, and J.J. Beukema 2003. Estimating common trends in multivariate time series using dynamic factor analysis. Envirometrics 14: 665-685.

V. Vantrepotte and F. Mélin. 2009. Temporal variability of 10-year global SeaWiFS time-series of phytoplankton chlorophyll a concentration. ICES J. Mar. Sci., 66: 1547-1556.

Table 1. Estimated parameters for dynamic factor analysis models using M common trends applied to 16 SeaWiFS ocean colour statistical sub-regions in the northwest Atlantic. The model uses two explanatory variables including the North Atlantic Oscillation (NAO) index and an environmental composite index that incorporates a variety of conditions (sea ice, ocean climate, temperature and salinity). A diagonal error covariance matrix was applied. The log likelihood and AIC values provide measures for goodness of fit in the various model formulations.

	Explanatory Variables				
# Trends	NAO	Environmental Composite Index	# Parameters	Loglikelihood	AIC
1			48	-221.0	538.0
2			63	-201.2	528.4
3			77	-183.8	521.0
4			90	-175.3	530.7
1		X	64	-204.8	537.5
2		X	79	-232.1	622.0
3		X	93	-187.9	561.0
1	X		64	-217.1	562.2
2	X		79	-195.8	549.5
3	X		93	-178.6	543.2
1	X	X	80	-199.9	559.8
2	X	X	95	-187.6	565.2
3	X	X	109	-174.0	565.9

Figure 1. Location of statistical sub-regions used by the Atlantic Zone Monitoring Program – "AZMP Petrie Boxes". Station locations used in the analysis include NAFO Subarea 2 (Hudson Strait, Nain and Hamilton Banks), Subarea 3 (St. Anthony Basin (StAnth), NE Newfoundland Shelf (NENFS), Avalon Channel, Hibernia, Southeast Shoal, Flemish Pass, and St. Pierre Bank, Subarea 4 and 5 including Eastern Scotian Shelf (ESS), Western Bank (WBank), Central Scotian Shelf (CSS), Western Scotian Shelf (WSS), Lurcher Shoals, and Georges Bank.

Figure 2. Top panels show semi-monthly MODIS composite ocean colour images across the northwest Atlantic in 2008 starting in the later part of February through to the first part of April. The bottom panels are the identical time periods for 2009. White areas represent ice and cloud masking. The 200m depth contour is displayed on all image panels. Images obtained from the Bedford Institute of Oceanography web site at:
(http://www.mar.dfo-mpo.gc.ca/science/ocean/ias/seawifs/seawifs_3.html).

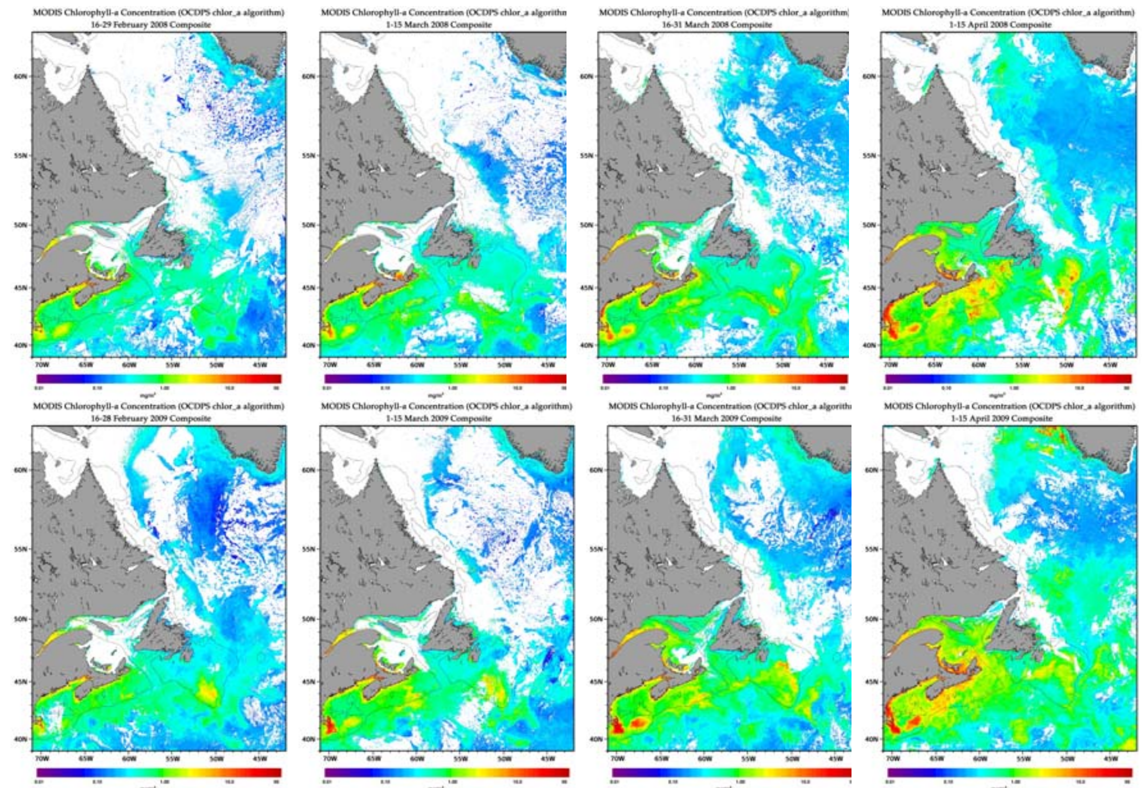

Figure 3. Top panels show semi-monthly MODIS composite ocean colour images across the northwest Atlantic in 2008 starting in the second half of April through to the first half of June. The bottom panels are the identical time periods for 2009. White areas represent ice and cloud masking. The 200m depth contour is displayed on all image panels. Images obtained from the Bedford Institute of Oceanography web site at: (http://www.mar.dfo-mpo.gc.ca/science/ocean/ias/seawifs/seawifs_3.html).

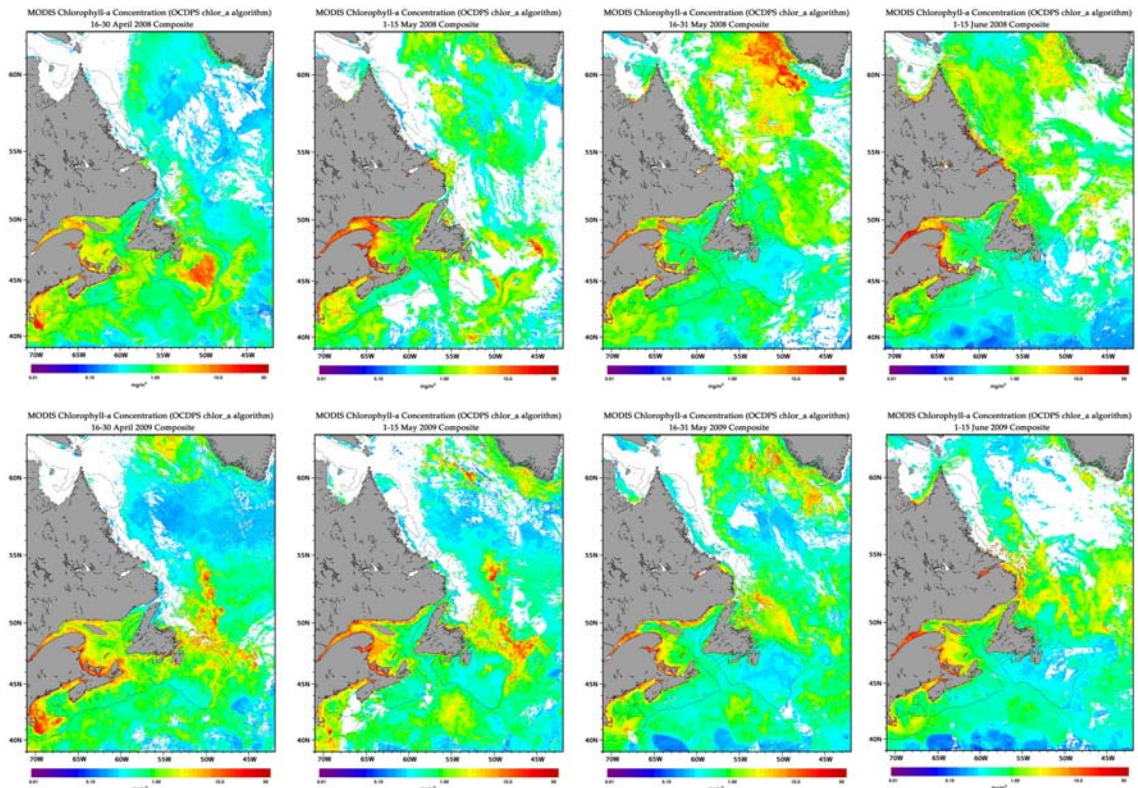

Figure 4. Semi-monthly time series of SeaWiFS derived chlorophyll *a* concentration (mg m^{-3}) and sea surface temperature (SST; ^{o}C) for NAFO Subarea 2 on the Labrador Shelf during 1998-2009 (a). Contour plots (month versus year) of surface chlorophyll *a* concentration, data are log transformed (b).

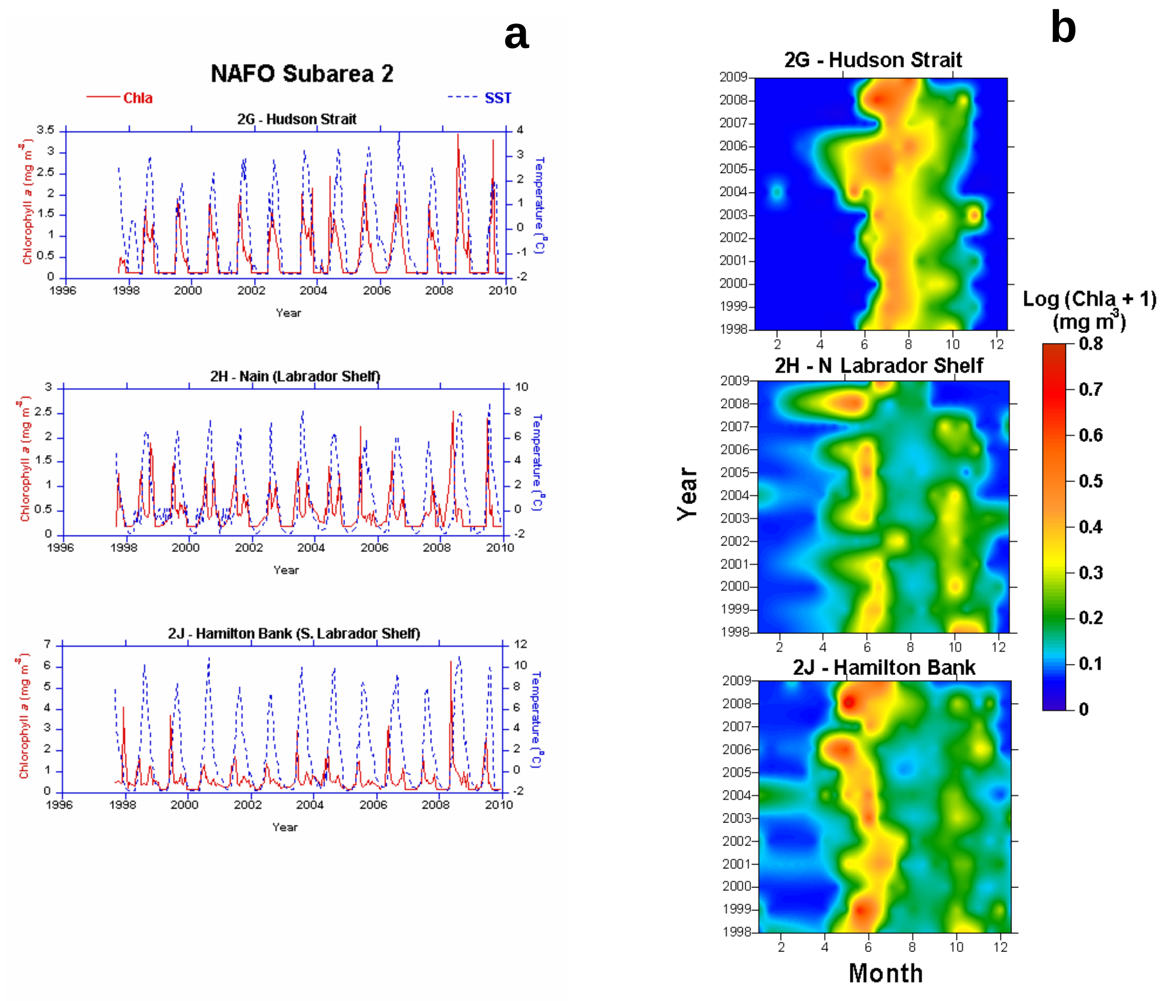

Figure 5. Time series of annual integrated chlorophyll *a* concentration (mg m^{-3}) and sea surface temperature (SST; ^{o}C) for NAFO Subarea 2 during 1998-2009 (a). Linear relationship of annual integrated chlorophyll *a* concentration versus integrated temperature (b).

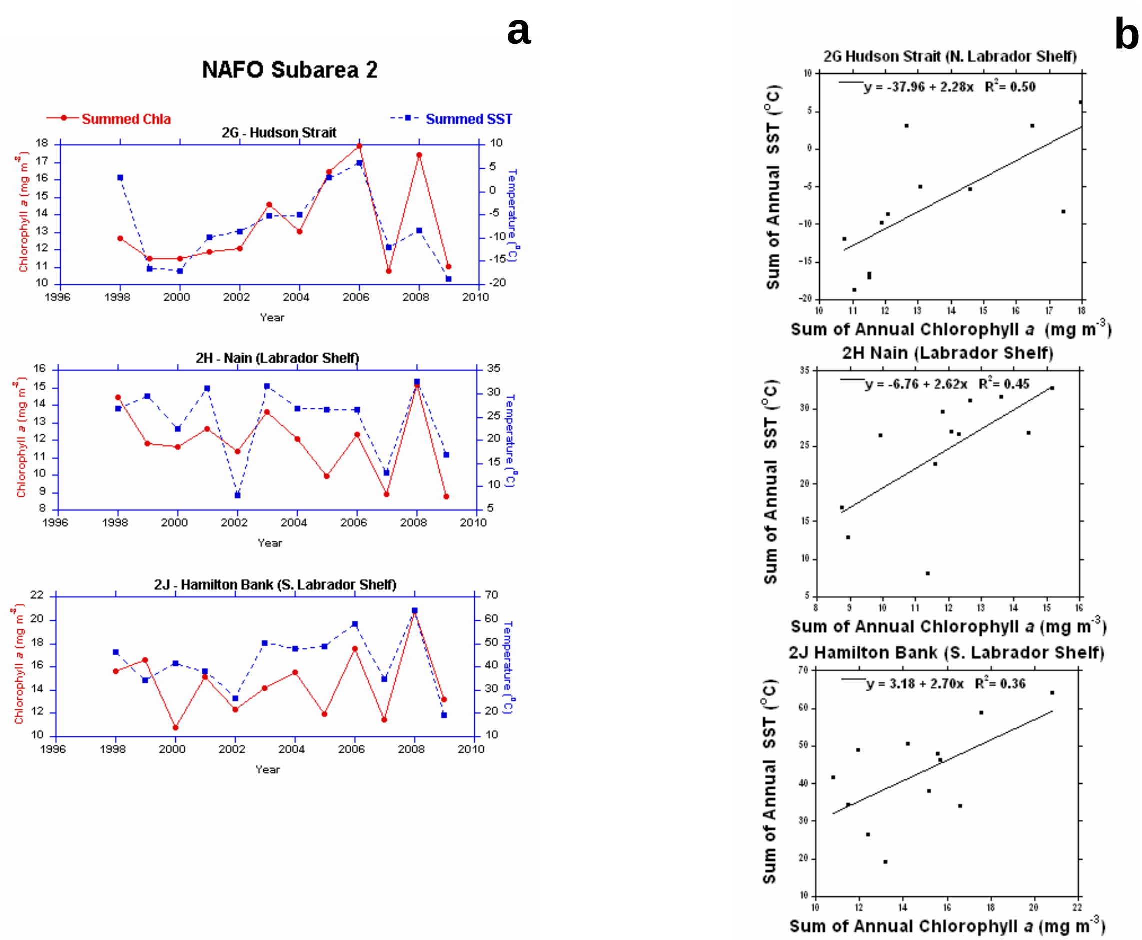

Figure 6. Semi-monthly time series of SeaWiFS derived chlorophyll *a* concentration (mg m^{-3})and sea surface temperature (SST; °C) for NAFO Subarea 3 on the northeast Newfoundland Shelf and Grand Banks during 1998-2009.

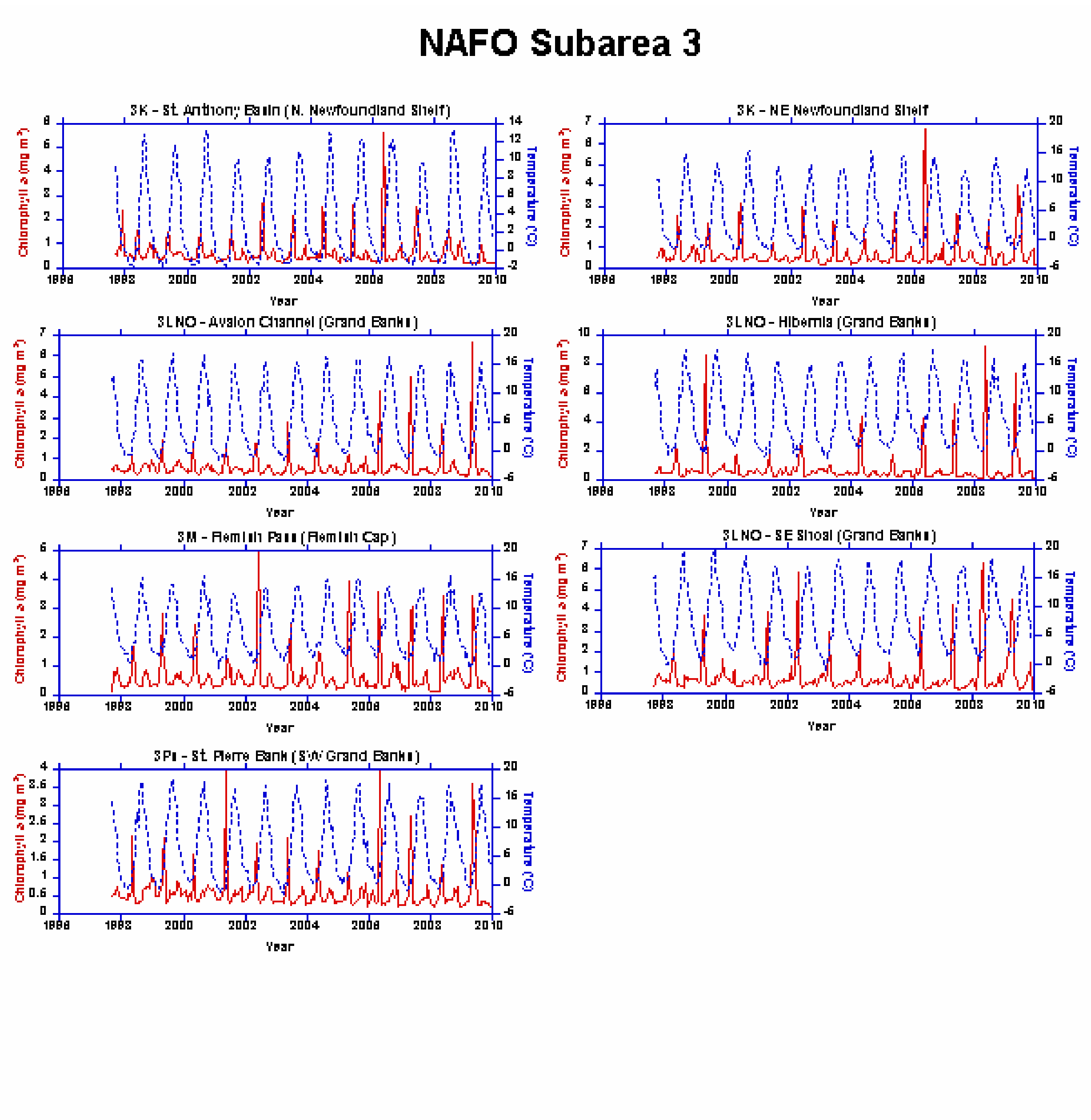

Figure 7. Contour plots (month versus year) of surface chlorophyll *a* concentration (mg m^{-3}) across the SeaWiFS statistical sub-regions during 1998-2009, data are log transformed.

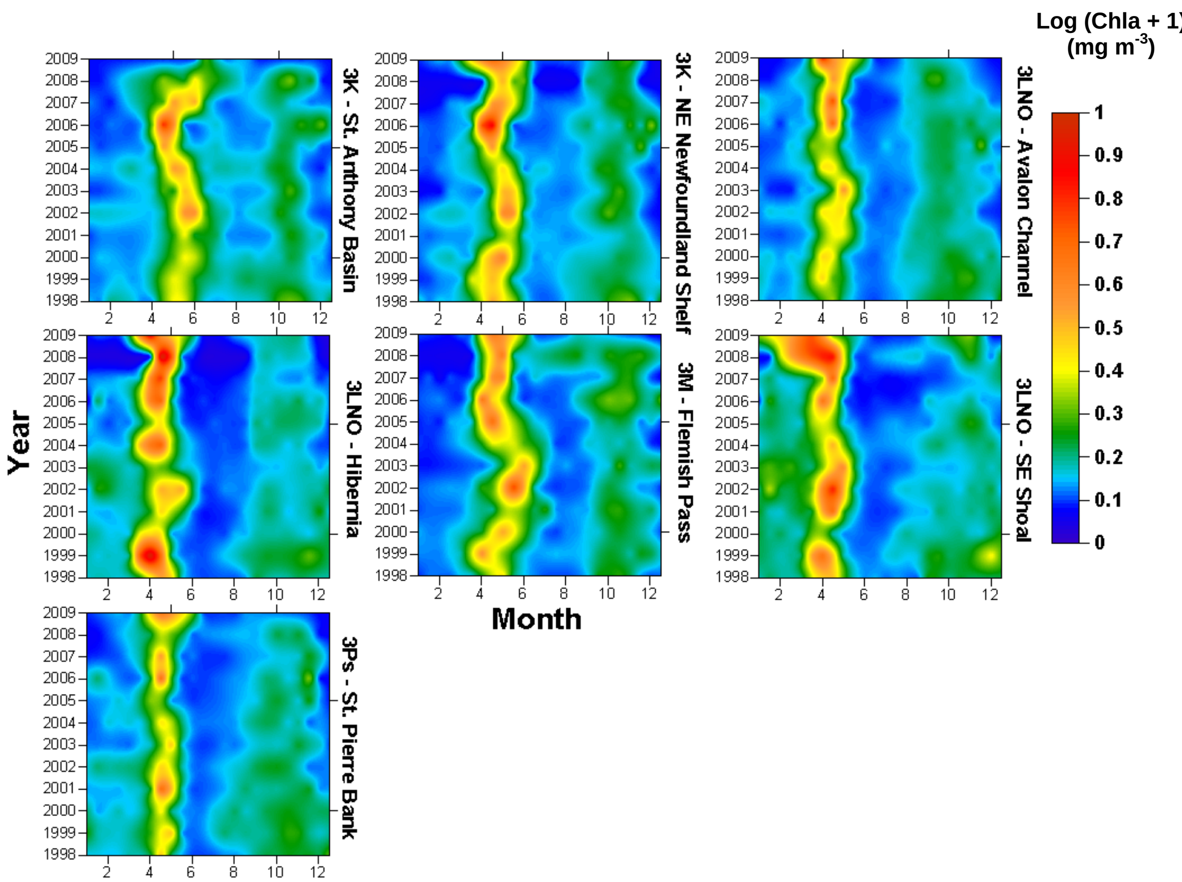

Figure 8. Time series of annual integrated chlorophyll *a* concentration (mg m^{-3}) and integrated sea surface temperature (SST) for NAFO Subarea 3 during 1998-2009.

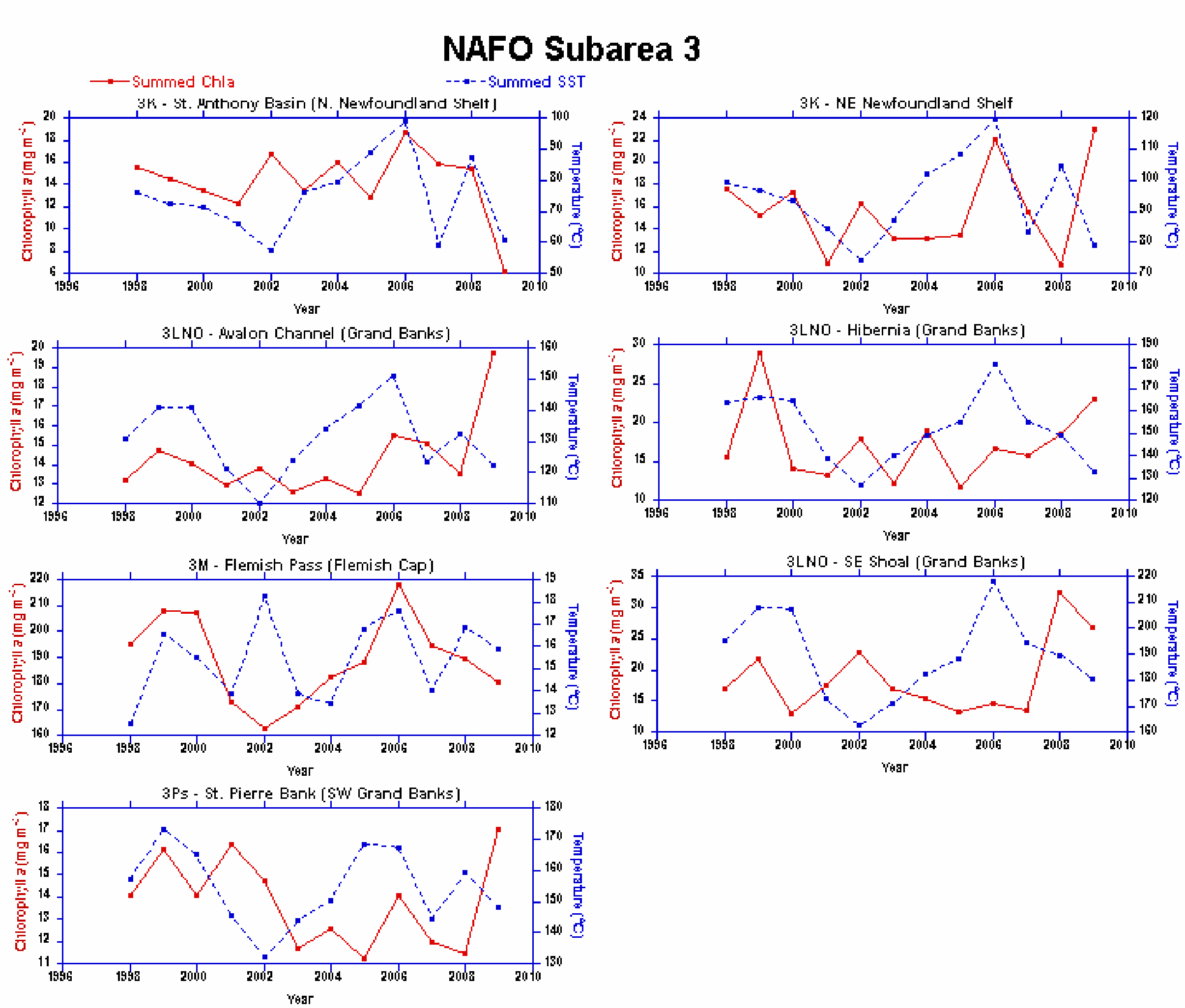

Figure 9. Linear relationship of summed annual integrated chlorophyll *a* concentration (mg m^{-3}) versus summed annual integrated temperature (^{o}C) in NAFO Subarea 3 during 1998-2009.

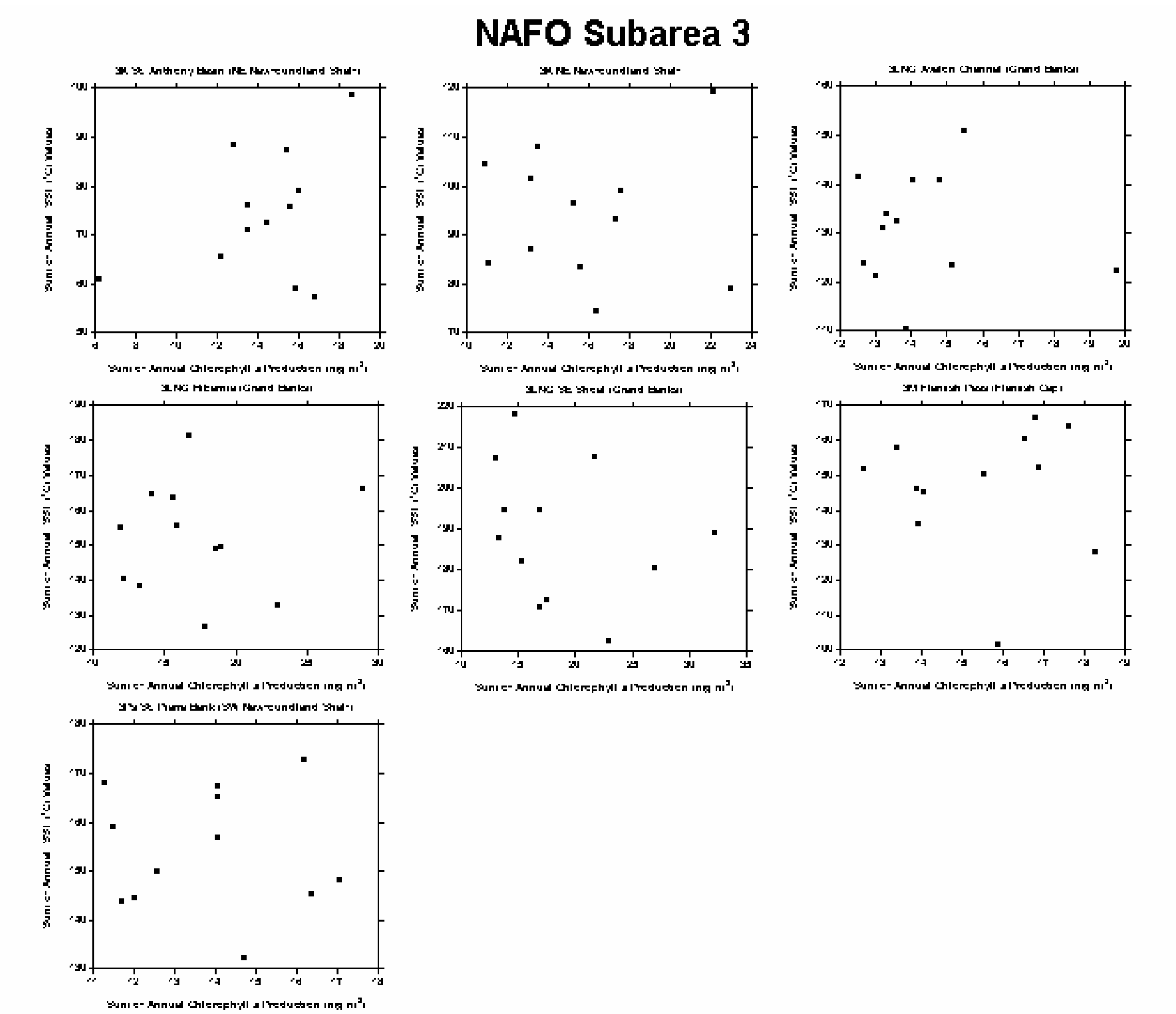

Figure 10. Semi-monthly time series of SeaWiFS derived chlorophyll *a* concentration (mg m^{-3}) and sea surface temperature (SST; ^{o}C) for NAFO Subarea 4 and 5 on the Scotian Shelf and Gulf of Maine.

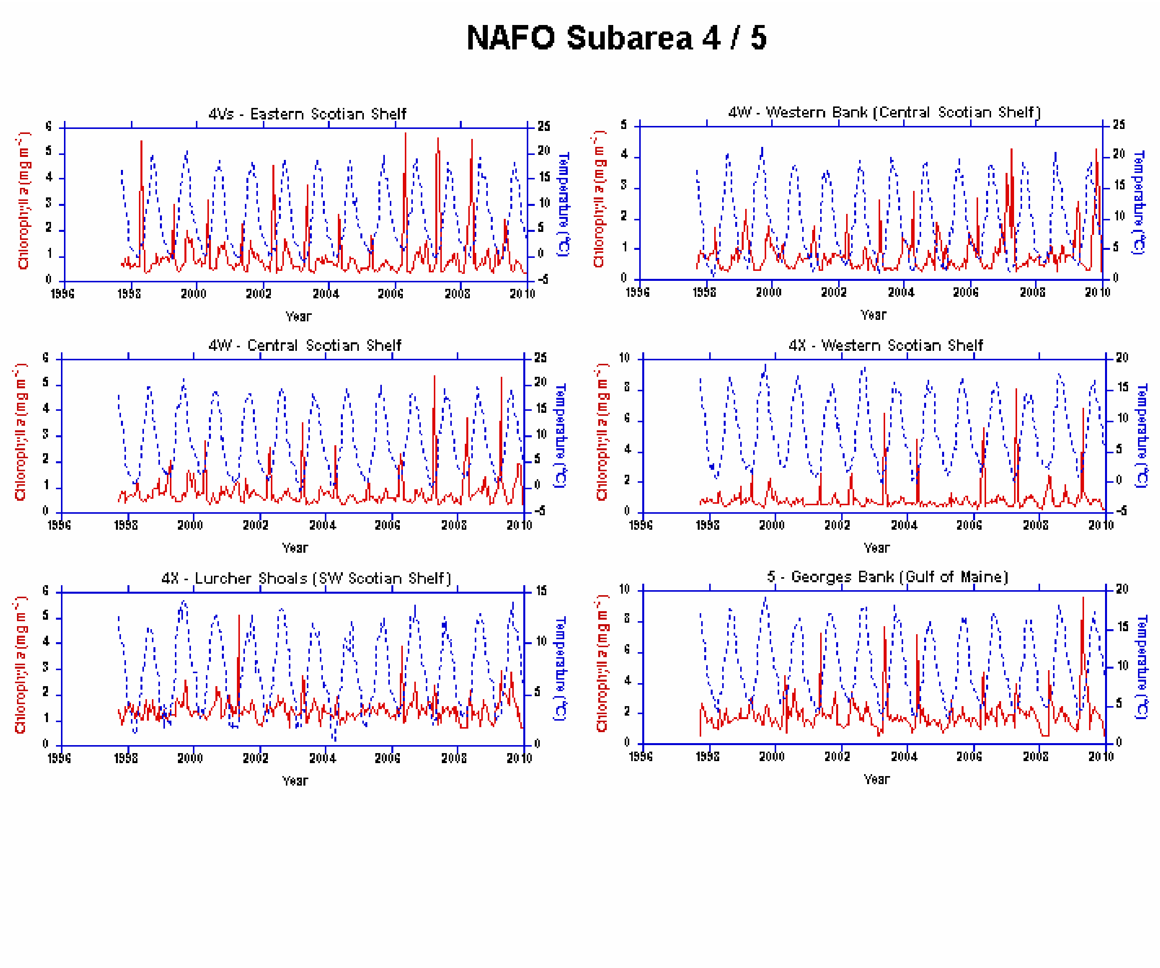

Figure 11. Contour plots (month versus year) of surface chlorophyll *a* concentration (mg m^{-3}) during 1998-2009, data are log transformed.

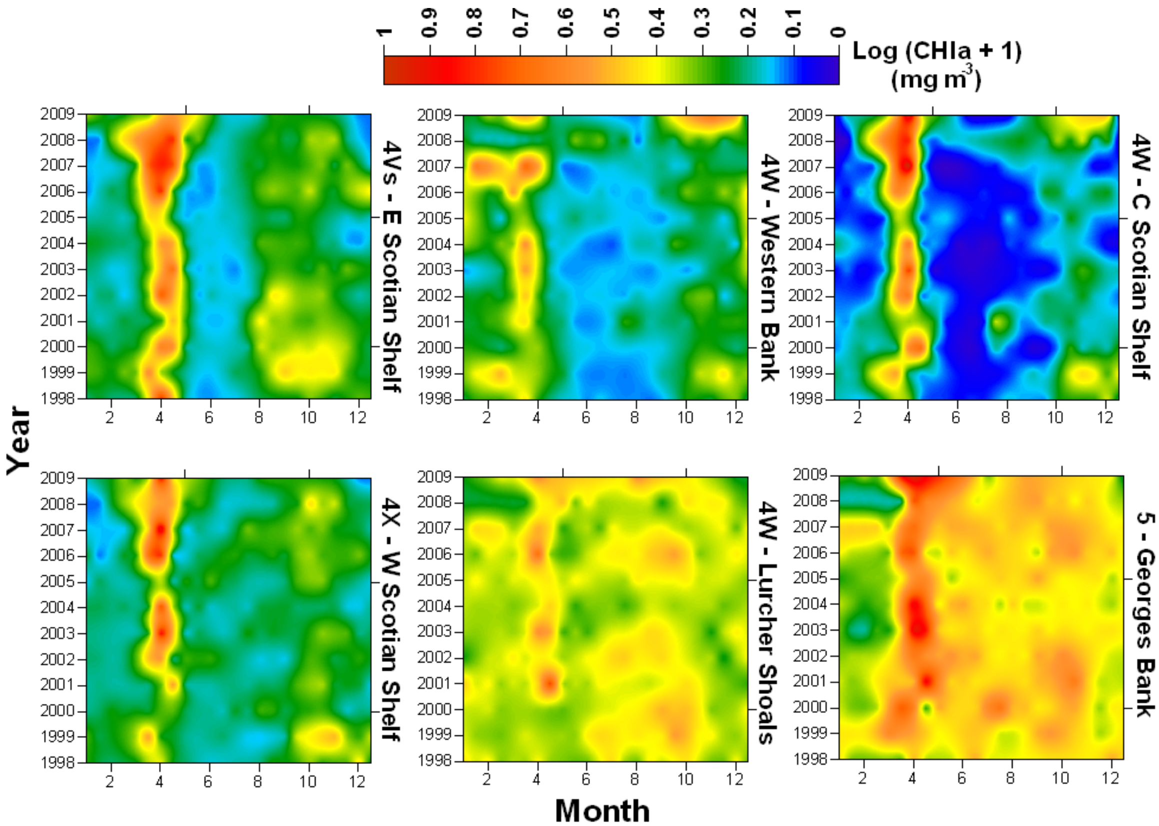

Figure 12. Time series of annual integrated chlorophyll *a* concentration (mg m^{-3}) and integrated sea surface temperature (SST; ^{o}C) for NAFO Subarea 4 and 5 during 1998-2009.

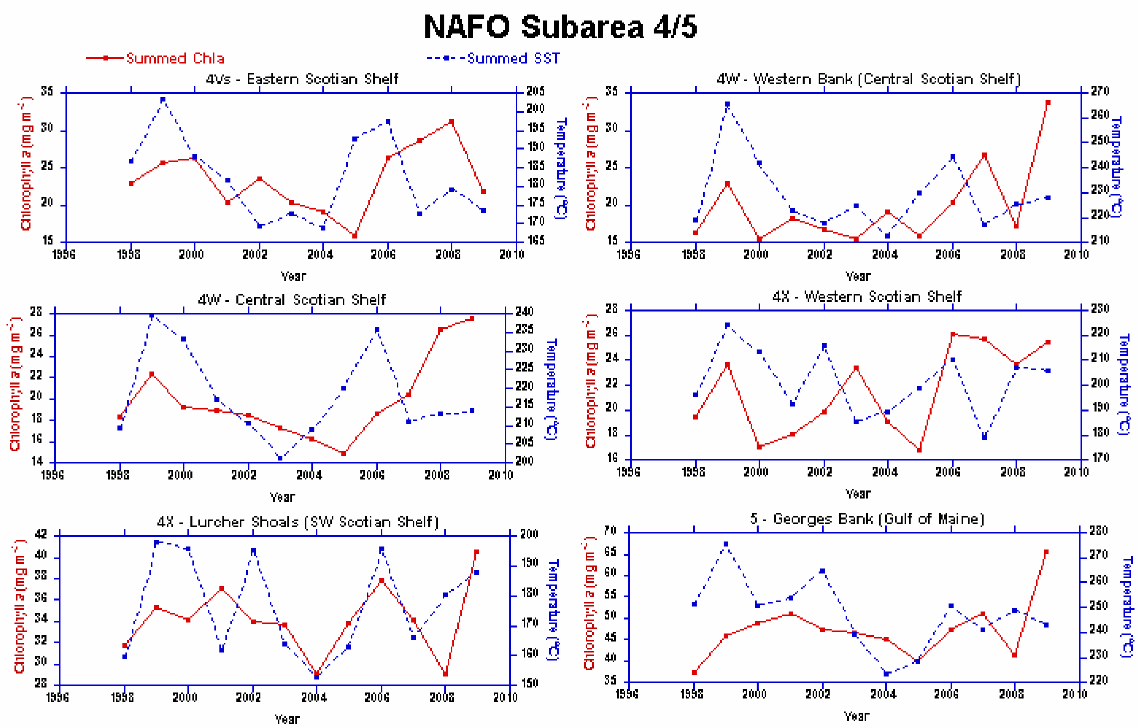

Figure 13. Seasonal trend decomposition using LOESS (STL) plots showing the four components. The top panel shows the original series followed by the constant seasonal model, the trend time series and finally the residual variation in the bottom panel. The original series has been normalized to zero mean allowing visualization of the magnitude of changes during the time record.

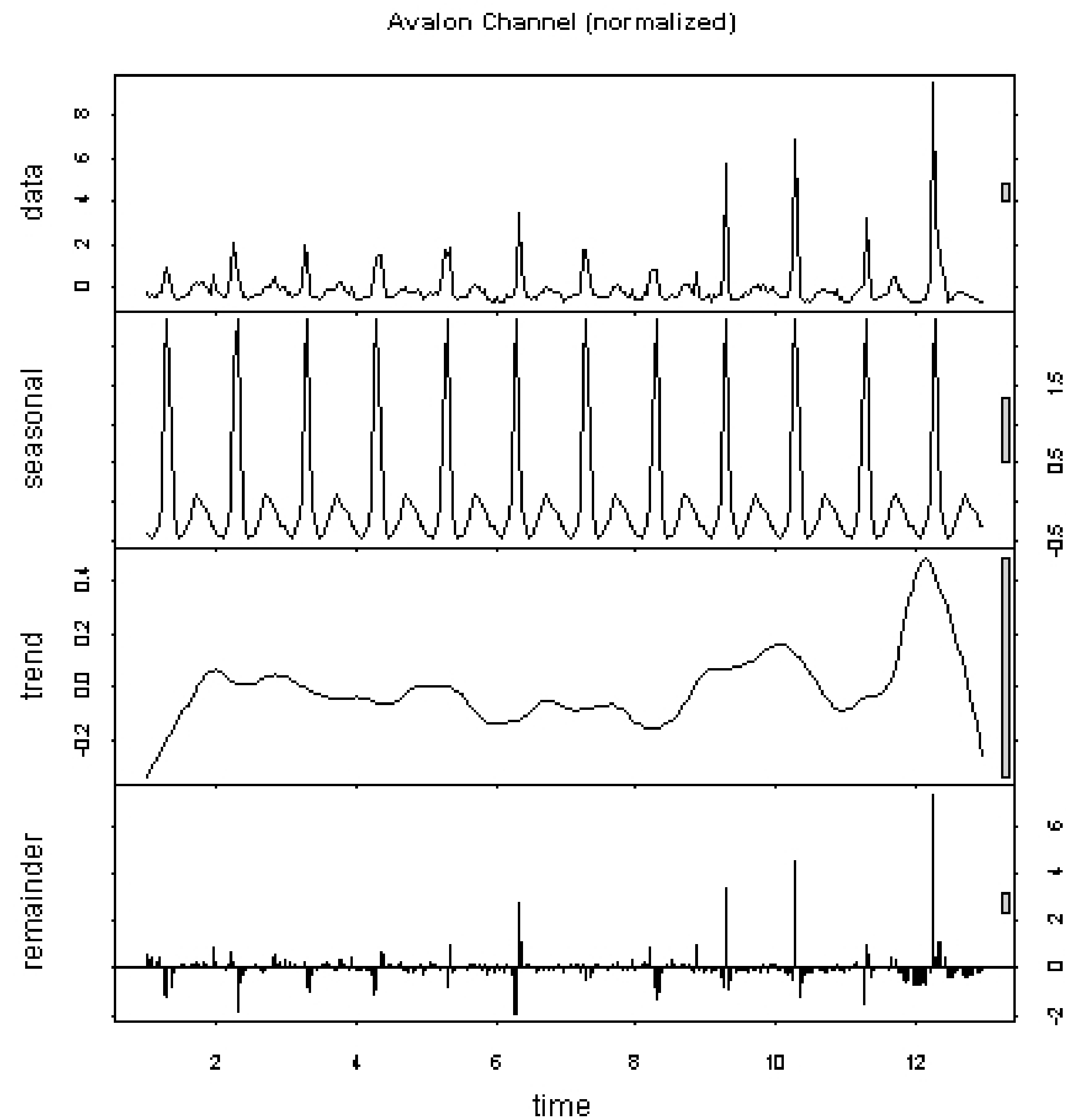

Figure 14. The top panels contain the common trend output from the dynamic factor analysis. The trend time series are normalized to zero mean and thus the y-axes are unitless. The x-axes are year beginning in 1998 and ending in 2009. The dashed lines represent the 95 % confidence bands. The bottom panels show the canonical correlations that indicate how the trends are related to the original time series.

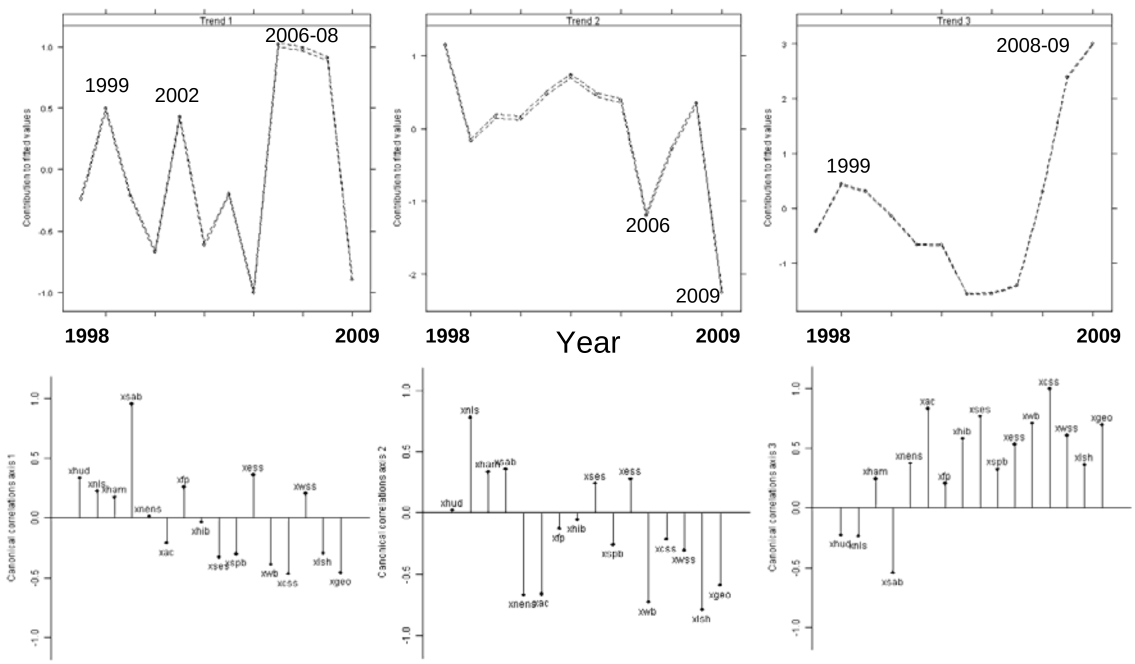

Figure 15. Fitted values (line) and standardized observed values of the trend component for each of the 16 statistical sub-regions ordered by latitude (lower left – Hudson Strait to upper right – Georges Bank. The trend time series are normalized to zero mean and thus the y-axes are unitless. The x-axes are year beginning in 1998 and ending in 2009.