

Influence of plankton and environment on condition and abundance of capelin

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ABSTRACT

Fuentes-Yaco, C., Mowbray, F., Murphy, H., Pepin, P., Ringuette, M., Caverhill, C. and Clay, S. 2020. Influence of plankton and environment on condition and abundance of capelin. Can. Tech. Rep. Fish. Aquat. Sci. 3363 : xv + 103 p.

This study supports the departmental strategic outcome of Sustainable Aquatic Ecosystems (SAE) by furthering our knowledge of forage fish drivers through the integration of environmental data derived from remote sensing. It uses a suite of environmental indices indicative of ecosystem productivity to study predator-prey dynamics and interdependencies of species on the Newfoundland and Labrador Shelf. This research assesses Theme 2 (Assessing and Reporting on Aquatic Ecosystems), and Priority 6 (Predator-prey dynamics and species interdependencies) of the Strategic Program for Ecosystem-based Research and Advice (SPERA).

Capelin data have been analyzed to estimate somatic condition and abundance. Abundance indices of key zooplankton species (*Calanus finmarchicus*) young stages (copepodites 1 to 3) were derived from Atlantic Zone Monitoring Program data, and remotely-sensed SST data were used to derive rates of spring warming and autumn cooling. Remotely-sensed Chlorophyll-a spring and autumn bloom parameters were derived for target areas. Non-parametric methods were used to derive relationships between physical and biological environmental characteristics and zooplankton and capelin age 2.

In general, the inter-annual variabilities of capelin at age-2 are largely explained using General Additive Models (GAM) produced in the present study. In the northern region, the capelin's body condition was reproduced within one standard error in eighty percent of years during both seasons: spring and autumn. Regarding the southern region, the models replicated ninety percent of the measured data within one standard error during spring and eighty percent in autumn seasons. The modeled results for capelin body condition outside the variance range are relatively close except for the spring of 2005 in the north and 2006 in south. The capelin abundance are within one standard error for sixty percent of the model data, and most of the values outside the range are very close to the limits except for 2014.

In conclusion, evidences provided in the literature mentioned above confirms the explanatory power of the forcing variables used in the GAMs (CHLMAXMAG, CHLINIDOV, and CALFINPDI) when used to investigate inter-annual variation of the body condition in capelin age-2 in the northern and southern region and spring and autumn, and WARMRATE and CALFINPDI to investigate capelin age-2 abundance during spring in the southern region. These outcomes seem to hold for both analyzed regions and seasons in the present study.

RÉSUMÉ

Fuentes-Yaco, C., Mowbray, F., Murphy, H., Pepin, P., Ringuette, M., Caverhill, C. and Clay, S. 2020. Influence of plankton and environment on condition and abundance of capelin. Can. Tech. Rep. Fish. Aquat. Sci. 3363 : xv + 103 p.

La présente étude appuie le résultat stratégique ministériel en ce qui concerne les écosystèmes aquatiques durables (EAD) en approfondissant notre connaissance des facteurs de croissance des poissons fourrage grâce à l'intégration de données environnementales issues de la télédétection. Elle utilise une série d'indices environnementaux indicatifs de la productivité des écosystèmes pour étudier la dynamique prédateur-proie et les interdépendances des espèces sur le plateau continental de Terre-Neuve-et-Labrador. La présente recherche évalue le thème 2 (évaluation et production de rapports concernant les écosystèmes aquatiques), et la priorité 6 (dynamique prédateurs-proies et interdépendances des espèces) du Programme stratégique de recherche et d'avis fondés sur l'écosystème (PSRAFE).

Les données sur le capelan ont été analysées pour estimer la condition somatique et l'abondance. Les indices d'abondance des jeunes stades (copépodites 1 à 3) des principales espèces de zooplancton (*Calanus finmarchicus*) ont été dérivés des données du Programme de monitorage de la zone atlantique, et les données de télédétection de la TSM ont été utilisées pour calculer les taux de réchauffement printanier et de refroidissement automnal. Les paramètres de la prolifération printanière et automnale ont été calculés pour les zones ciblées, d'après la télédétection de la chlorophylle a. Des méthodes non paramétriques ont été utilisées pour établir des relations entre les caractéristiques physiques et biologiques de l'environnement et le zooplancton et le capelan à l'âge de deux ans.

En général, les variabilités interannuelles du capelan à l'âge de deux ans sont largement expliquées à l'aide des modèles additifs généralisés produits dans la présente étude. Dans la région du nord, l'état corporel du capelan a été reproduit avec une erreur type pour quatre-vingts pour cent des années pendant les deux saisons : le printemps et l'automne. En ce qui concerne la région du sud, les modèles ont reproduit quatre-vingt-dix pour cent des données mesurées avec une erreur type au printemps, par rapport à quatre-vingts pour cent à l'automne. Les résultats modélisés pour l'état corporel du capelan en dehors de la plage de variance sont relativement proches, sauf pour le printemps 2005 dans le nord et 2006 dans le sud.

L'abondance du capelan se situe dans une fourchette d'erreur type pour soixante pour cent des données du modèle, et la plupart des valeurs en dehors de la fourchette sont très proches des limites, sauf pour 2014.

En conclusion, les données probantes fournies dans la documentation mentionnée ci-dessus confirment le pouvoir explicatif des variables de forçage utilisées dans les modèles additifs généralisés (CHLMAXMAG, CHLINIDOY et CALFINPDI) lorsqu'elles sont utilisées pour étudier la variation interannuelle de l'état corporel du capelan à l'âge de deux dans la région nord et sud et au printemps et à l'automne, et des modèles WARMRATE et CALFINPDI pour étudier l'abondance du capelan à l'âge de deux ans au printemps dans la région sud. Ces résultats semblent être valables pour les régions et les saisons analysées dans la présente étude.

1. INTRODUCTION

1.1 PURPOSE AND OBJECTIVE

This study supports the departmental strategic outcome of Sustainable Aquatic Ecosystems (SAE) by furthering our knowledge of forage fish recruitment drivers through the integration of environmental data derived from remote sensing. We use a suite of environmental indices indicative of ecosystem productivity to study predator-prey dynamics and interdependencies of species on the Newfoundland and Labrador Shelf.

This research was funded under the Strategic Program for Ecosystem-based Research and Advice (SPERA) and addresses Theme 2 (Assessing and Reporting on Aquatic Ecosystems), Priority 6 (Predator-prey dynamics and species interdependencies). Specifically we ask how environmentally-driven changes in sea surface water temperature, phytoplankton production and zooplankton timing influence capelin (*Mallotus villosus*), a key commercial forage species of the Northwest Atlantic food web.

There are many factors that affect the timing and magnitude of seasonal phytoplankton blooms making them difficult to predict; however, remote sensing readily captures bloom characteristics. Using daily information on the ocean's surface colour, phytoplankton abundance and temperature can be estimated over large spatial and temporal scales. Since 1997 there has been a steady stream of remotely sensed ocean colour data from various sensors (e.g. SeaWiFS, MODIS, MERIS, and VIIRS) that capture the strength and variability of the phytoplankton blooms in Canada's Atlantic Zone. The indices examined in this study are of particular relevance to fisheries, as previous research has shown that recruitment for several fisheries (e.g. haddock, shrimp) is related to the timing of the spring phytoplankton bloom (Platt *et al.*, 2003; Fuentes-Yaco *et al.*, 2007; Koeller *et al.*, 2009), with an earlier bloom favoring larval fish survival in haddock (Runge, 1988). At the ecosystem level, recent studies have suggested that there will likely be a shift in phytoplankton community composition towards species of smaller cell size due to climate change (Bopp *et al.*, 2005; Hoegh-Guldberg and Bruno, 2010; Morán *et al.*, 2010). This has important implications, particularly for the autumn bloom, as most of the available carbon in planktonic food webs consisting primarily of small autotrophic cells contributes to pelagic fish production (Marquis *et al.*, 2011). Consequently, autumn phytoplankton blooms in the Northwest Atlantic may be critical to the abundance/condition of the copepod that enable capelin to better survive the winter and favor recruitment in the fisheries the following year (Carruthers and Mowbray 2014, Murphy *et al.*, 2018; Shikon *et al.*, 2019). Recent work shows that a combination of remote-sensing biological (phytoplankton bloom characteristics) and physical (spring warming) environmental indices have significant correlation with *Calanus finmarchicus* (copepodites 1+2) and *Pandalus borealis* (age 2) abundances in the Labrador Sea and Davis Strait, respectively (Fuentes-Yaco *et al.*, 2016).

Forage fish typically exhibit boom and bust cycles influencing the feeding conditions of their main predators and the abundance of their prey (Hassel *et al.* 1991, Gerasimova 1994, Gjøsæter, *et al.*, 2002, Plourde *et al.*, 2015). Such fluctuations are observed with capelin on the Newfoundland and Labrador shelves with high abundances observed in the late 1980s, a collapse in 1991 followed by a prolonged period of decreased abundances (Mowbray 2014, Johnson *et al.*, 2014, Dalpadado *et al.*, 2014, Buren *et al.*, 2019) until a moderate improvement again in 2013-14 (DFO 2015). Much of the current literature points to how resources (food source, habitat, space) allow growth of capelin. Changes in capelin biomass (Buren *et al.*, 2014) and the timing of capelin spawning (Dalpadado and Mowbray 2013) have been linked with the

retreat of sea ice and its impact on plankton phenology. Mismatches of larval capelin with the spring bloom may compromise survival during this first year (Mullowney *et al.*, 2016), and impact larval growth (Murphy *et al.*, 2018) thus impacting subsequent years' fisheries. Spawning capelin schools targeted by the fishery in NAFO Divisions 2J3KL are generally composed of ages 2-4 with age 2 fish comprising up to 80% of the spawning biomass in some years. Consequently predicting the strength of the age 2 year class is important for forecasting capelin abundance.

The objective of this study is to characterize the influence of physical and biological environmental conditions on capelin condition and abundance. Satellite-derived ecological indicators (Fuentes-Yaco *et al.*, 2016) and *in situ* ocean observations are assessed to improve understanding of how changes in annual surface temperature and seasonal spring and autumn plankton production cycles influence capelin condition and abundance (Dalpadado and Mowbray 2013).

This objective is realized through three steps: i) the analysis of remotely-sensed sea surface temperature (SST) to derive the rate of spring warming and autumn cooling, and remotely-sensed Chlorophyll a (CHL) spring and autumn bloom parameters for areas where acoustic surveys for capelin are operating; ii) linking this information with abundance and developmental indices of key zooplankton species, in particular copepods which have been positively associated with capelin abundance throughout the year; and iii) linking capelin somatic condition and abundance with metrics of prey and environmental conditions.

1.2 STUDY AREA

The geographical study area is located in the Northwest Atlantic, on the relatively shallow regions of the Labrador Shelf and the Grand Banks of Newfoundland (Figure 1). The region is affected by the Labrador Current, the western boundary current of the North Atlantic subpolar gyre. The study area extends around the seaward coast of Newfoundland to Cabot Strait and Laurentian Channel. The Northwest Atlantic region is a hydro-dynamically complex and interconnected system. The circulation on the continental shelf transports relatively cold, fresh water of Arctic origin, toward the equator, reaching as far south as the Gulf Stream. Most of this current flows onto the Northeast Newfoundland Shelf and continues southward into the Grand Banks region. The resulting composition is relatively fresh, with a large seasonal temperature range (Loder *et al.*, 1998). The state of physical, chemical and biological conditions in the Northwest Atlantic region is monitored on an ongoing basis by DFO (Atlantic Zone Monitoring Program) and assessed annually by the Canadian Science Advisory Secretariat (Pepin *et al.*, 2017, DFO 2018).

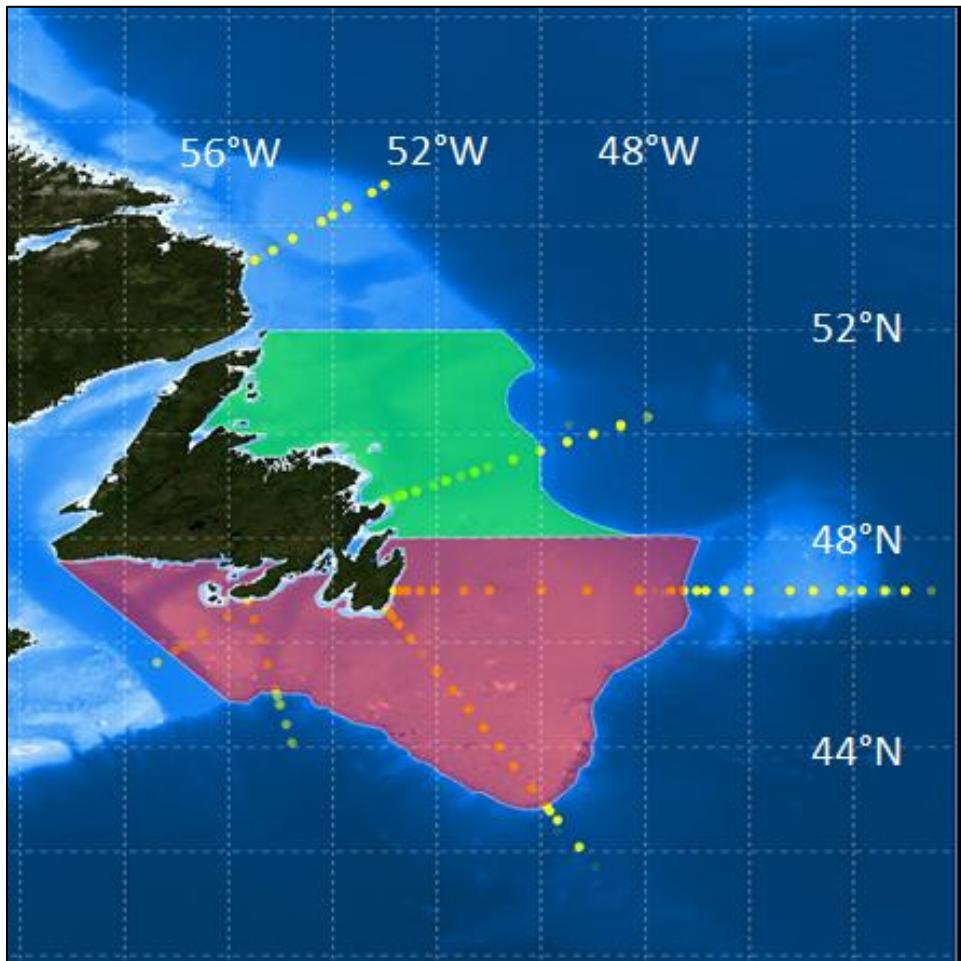


Figure 1. The study area is located in the North West Atlantic, from 42° to 52° N, and between 50m (adjacent to the coast) and 600 m depth. The North (green) and South (red) separation is a function of high, low and persistent SST, as well as high and persistent CHL concentration. Explanations are detailed below. Yellow dots represent sampling locations of copepods.

2. METHODS

2.1 SATELLITE-DERIVED DATA

The remote sensing group at BIO processes daily images of ocean colour data (Chlorophyll_a concentration, CHL) of satellite-borne sensors from the National Aeronautics and Space Administration (NASA -US) agency. Sea-Viewing Wide Field-of-View Sensor (SeaWiFS) weekly data of 9 km resolution were downloaded for the period between 1998 and 2007. The second set of data was acquired from the Moderate Resolution Imaging Spectroradiometer (MODIS_{Aqua}) images, which are received at 1 km resolution, but were later remapped at 1.5 km for the period from 2008 until 2011. A third source of daily images came from Visible Infrared Imaging Radiometer Suite (VIIRS) at 4 km resolution.

The data were obtained from NASA's Ocean Color anonymous ftp site. NASA uses real-time altitude/ephemeris files which are required for precise geolocation, and the most recent near real-time (not climatological) MET/OZONE files for atmospheric processing. Details about these processing steps can be found on their websites¹. The Level-2 data from SeaWiFS and MODIS sensors were processed using SeaDAS (version 6.4) to obtain chlorophyll concentrations. Further description of the algorithms can be found at this address². The resulting MODIS files have a nominal resolution of 1 km² and do not need to be geographically navigated because the geolocation values are estimated to be within 100 m of the actual locations. The processing masks applied in Level 1 to Level 2 processing were: high solar zenith angle, high satellite zenith angle, and stray light. Finally, cloud albedo was set at 0.015, which is different from NASA's default value (0.027). Information used in this research is from the 2012 reprocessing by NASA's Ocean Biology Processing Group. VIIRS data were downloaded in June 2016, belonging to the R2014.0.1 reprocessing.

The annual cycle of sea surface temperature (SST) has been analyzed by generating weekly composites from individual passes of the Advanced Very High Resolution Radiometer (AVHRR, National Oceanic and Atmospheric Administration –NOAA, –USA) and MetOP (EUMETSAT –European Organization for the Exploitation of Meteorological Satellites) (Eumetsat, 2012) instruments. Both datasets were processed using Terascan software, which is a product of the SeaSpace Corporation (Sea Space, 2013). Analogous to MODIS, the data are received at 1 km resolution and later remapped at 1.5 km.

The 18 years of images were averaged to produce Level-3 weekly composite images mapped using a cylindrical projection. They represent the core of data used to compute biological (CHL) and physical (SST) seasonal cycles characteristics (ecological indices). Specifications are detailed in Figure 3.

¹ http://oceancolor.gsfc.nasa.gov/DOCS/SW_proc.html and
http://oceancolor.gsfc.nasa.gov/DOCS/MODISA_processing.html

² <http://oceancolor.gsfc.nasa.gov/REPROCESSING/R2009/ocv6/>

Sensor	Spatial Resolution (km/pixel)	Time – Period (years)	Number of Pixels by Week South (nominal)	Number of Pixels by Week North (nominal)
SeaWiFS	9.0	1998 – 2006	2623	4745
MODIS	1.5	2008 - 2011	116073	62906
VIIRS	4.0	2012 - 2015	18913	10236
AVHRR	1.5	1998 - 2015	116136	62910

Figure 2. Description of sensors' spatial resolution, time period and nominal number of pixels per weekly composite by region of study (South and North of 48 degrees, respectively).

2.1.1 North/South subdivisions

The latitudinal gradient variabilities of water temperature and phytoplankton biomass in the study area necessitated a regional separation in North and South. The approach for this separation considers persistently high and low values of these environmental components (Fuentes-Yaco *et al.*, 2015, Gomez *et al.*, 2017, Moors-Murphy *et al.*, 2019).

Briefly, sea surface temperature (SST) was assessed using Advanced Very High Resolution Radiometer (AVHRR, with units in °C), and chlorophyll concentration (CHL) derived from the Moderate-resolution Imaging Spectrometer (MODIS, with units in mg m⁻³), both products at 1.5 km/pixel spatial resolution and annual average from 1997 until 2017.

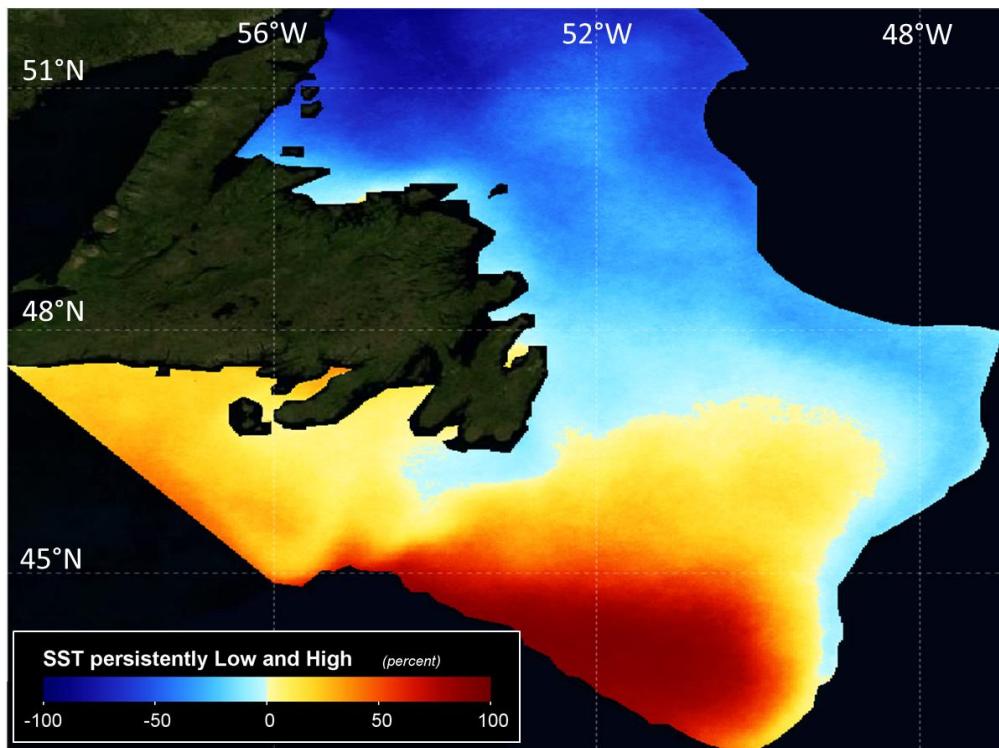
For the study area, weekly climatology composite images of the median and standard deviation of each variable were computed. Every pixel in the composite image was compared against a specific threshold value represented by its own median plus a half standard deviation ($\frac{1}{2}\sigma$) (plus and minus for SST). Pixel values beyond the threshold were assigned a value of one, and the remaining pixels were set to zero. These assigned values are termed transformed temperature and chlorophyll indicators.

To account for the indicators' fluctuations (temperature and chlorophyll concentrations) throughout the year as a whole, for each pixel, the transformed variable indicators were added, then multiplied by 100 and divided by 48, which is the total number of weekly layers for the year.

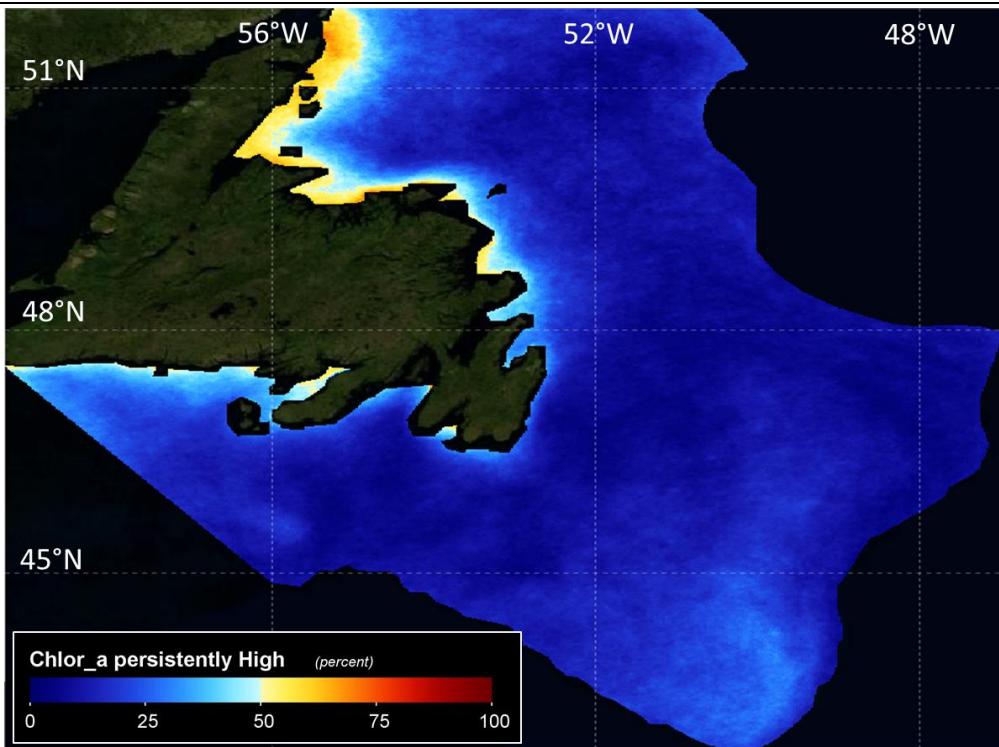
$$P_i = \left(\frac{\sum_{j=1}^{48} c_{ij}}{48} \right) \times 100 \quad (1)$$

In this notation P_i is the annual contribution (%) to high phytoplankton biomass or high and low sea surface temperature, i is pixel number, j is week number and c is the transformed indicator having a value of 1 or 0. The weeks are numbered in a sequence: 1 = first week of January until 48 = last week of December.

This process resulted in the creation of maps (see Figure 3) showing the climatology proportion (%) of each pixel's contribution to high and low sea surface temperature, and high phytoplankton biomass at the annual time scale. The gradient in the maps, particularly in Figure 3a for SST, suggests the latitudinal separation should be made at 48 °N.



a)



b)

Figure 3. Annual Averages (1997 to 2017) of a) persistent high and low SST (AVHRR), and b) persistent high Chl_a concentration (MODIS_{Aqua}), both at 1.5 km/pixel spatial resolution.

2.1.2 Annual and Seasonal Cycles

Annual water temperature and seasonal phytoplankton pigment cycles were analyzed, and an objective set of metrics determined by optimizing the parameters of a split Gaussian curve to weekly mean satellite SST or CHL in the region of interest. This gives the fitted curves more flexibility by allowing asymmetry around the maxima. The method was incorrectly cited as a modified version of the Ricketts and Head (1999) five-parameter logistic model in Fuentes-Yaco et al. (2016), however this study follows a similar approach by simultaneously optimizing new parameters to account for asymmetry in the curve.

The left and right sides of the curve were modelled as follows:

$$\hat{y}_{left} = \beta_{left} + \alpha \left(\exp \left(\frac{-(X_{left} - \mu)^2}{2(\sigma_{left}^2)} \right) \right) \quad (2)$$

$$\hat{y}_{right} = \beta_{right} + \alpha \left(\exp \left(\frac{-(X_{right} - \mu)^2}{2(\sigma_{right}^2)} \right) \right) \quad (3)$$

where β is the “background” chlorophyll-a, X is the week number, μ is the value of X at the height of the curve, α is the height above the background (i.e. maximum CHL or SST), and σ is used to determine the width of the curve. Parameters α , μ , β_{left} , β_{right} , σ_{left} , and σ_{right} were optimized simultaneously using R software (R Core Team, 2012).

2.2 COMPUTATION OF ECOLOGICAL INDICES

An objective characterization of the physical and biological cycles was made through simple indices, based on significant points on the fitted curve (Figure 4). This approach was adapted from Fuentes-Yaco *et al.* (2016). Note that the curve was fitted using the week number, X , but the indices were computed using the corresponding days of the year. The indices are: i) the cycle initiation (beginning of exponential growth – green line), ii) the maximum value (maximum value of the fitted Gaussian curve – red line); iii) the timing of this maximum concentration, iv) the termination of the cycle (end of exponential decay – blue line), and v) the duration of the bloom (number of days elapsed between bloom initiation and termination). The initiation and end of the cycles were computed using the same approach. For initiation (left side of the curve), the lowest pigment (or SST) value was subtracted from the highest value and multiplied by 0.1 to get 10% of the difference in Chlorophyll_a concentration (SST) throughout the first half of the cycle. This was added to the lowest amount on that side of the curve, and the week closest to that value was selected as the initiation point, under the assumption that a 10% increase in Chlorophyll-a concentration (SST) likely signifies the start of the cycle. The end of the cycle (right side of the curve), was computed using the same approach, with the assumption that a 10% decrease in the pigment before the minimum value signifies the end of a cycle. Derived indices of SST were computed to synthesize environmental processes, such as the rate of warming in the spring and the rate of cooling in the autumn. The warming rate was calculated by subtracting the initial temperature from the maximum temperature, dividing by the difference of initial time minus end time of the annual cycle, and multiplying the ratio by 100, as follows:

$$(100 * (\text{max_data} - \text{init_data}) / (\text{max_time} - \text{init_time})) \quad (4)$$

An equivalent estimation was performed for the SST rate of cooling, where the denominator was transposed:

$$(100 * (\text{max_data} - \text{end_data}) / (\text{end_time} - \text{max_time})) \quad (5)$$

The climatology and yearly anomalies for each index and variable were produced. The normalized anomalies (difference between the annual average and the long-term mean, divided by the standard deviation) indicate if a given index in a year is lower, higher, or unchanged from the long-term average. The normalized anomalies for the satellite-derived indices were used as input to non-parametric statistical methods to develop relationships between the environmental variables and zooplankton abundance and fish abundance and somatic condition.

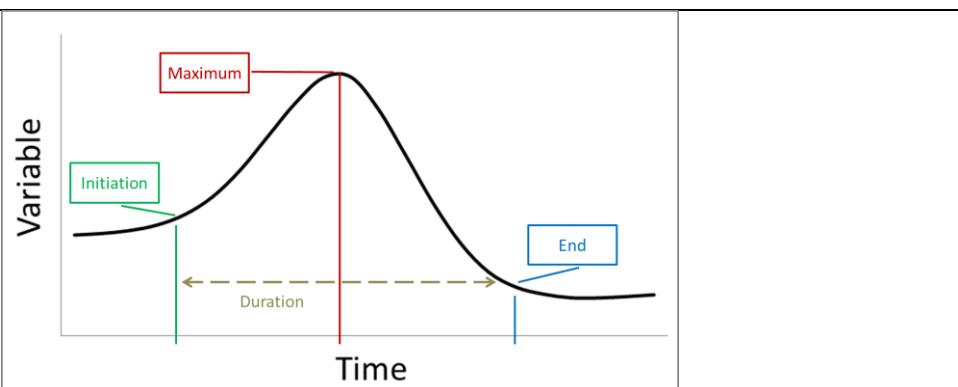


Figure 4. Identification of satellite-derived ecological indices for the annual SST and seasonal CHL cycles.

2.3 *Calanus finmarchicus* PDI

Abundance indices of *Calanus finmarchicus* were computed from collections obtained along the grid shown in Figure 1, between 1999 and 2015. The Atlantic Zone Monitoring Program (AZMP) sections include, from North to South: Seal Island, Bonavista, Flemish Cap, Southeast Grand Banks and two more lines south of Newfoundland. Methods of sampling and preservation adhered to the AZMP operational protocols (Mitchell *et al.*, 2002). The total of 2173 stations were sampled during two sampling seasons: North spring (April, May and July) n = 456, North autumn (November and December) n = 234; South spring n = 916, South autumn n = 567. The *Calanus* Population Development Index (PDI) used in this study represents the proportion of copepodites C1 to C3 over the entire population expressed in percent. This indicator shows the number of recently produced young stages. Normalized anomalies of PDI were used as inputs for the biological relationships with capelin; Figure 5 illustrates *C. finmarchicus* life cycle.

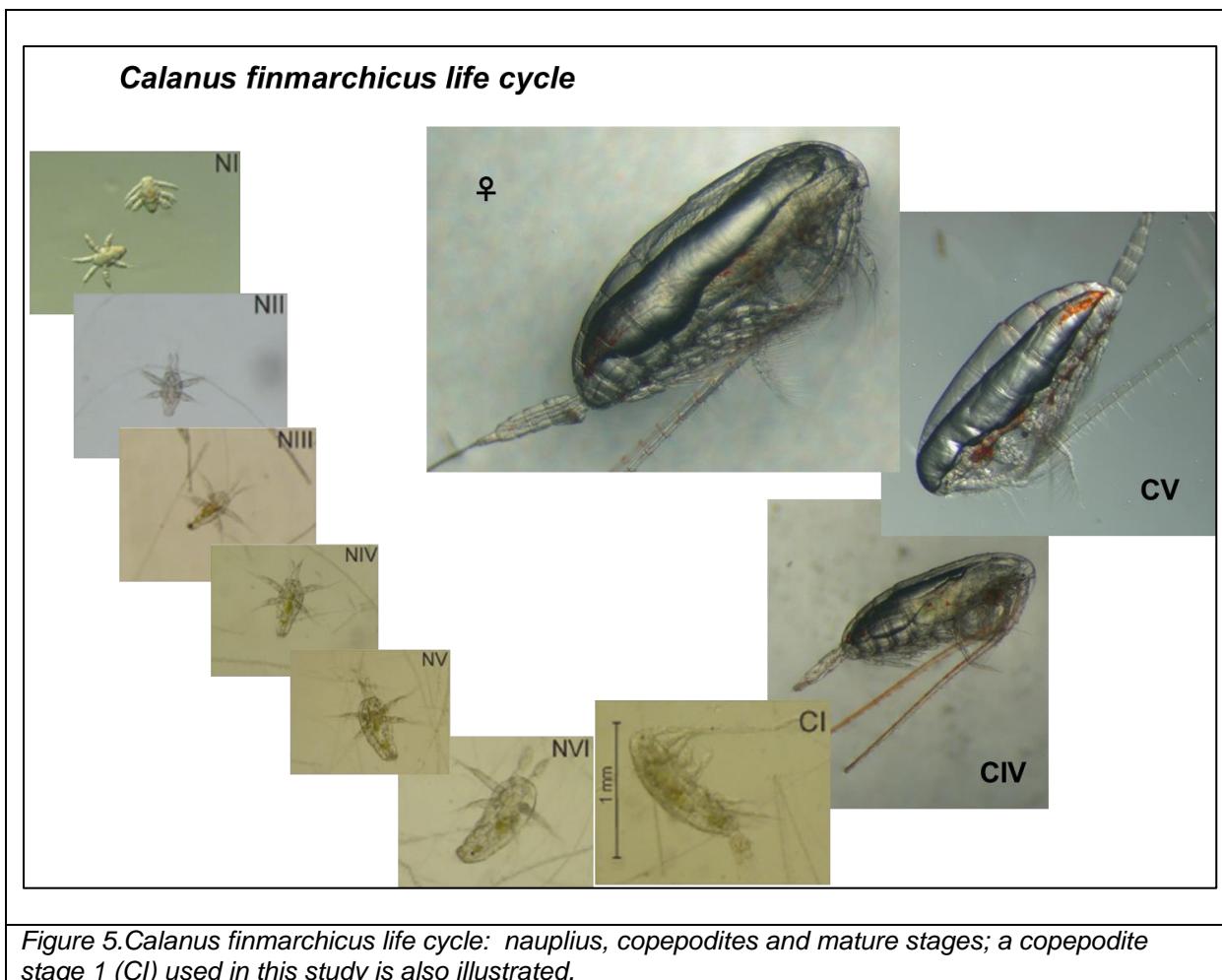


Figure 5. *Calanus finmarchicus* life cycle: nauplius, copepodites and mature stages; a copepodite stage 1 (CI) used in this study is also illustrated.

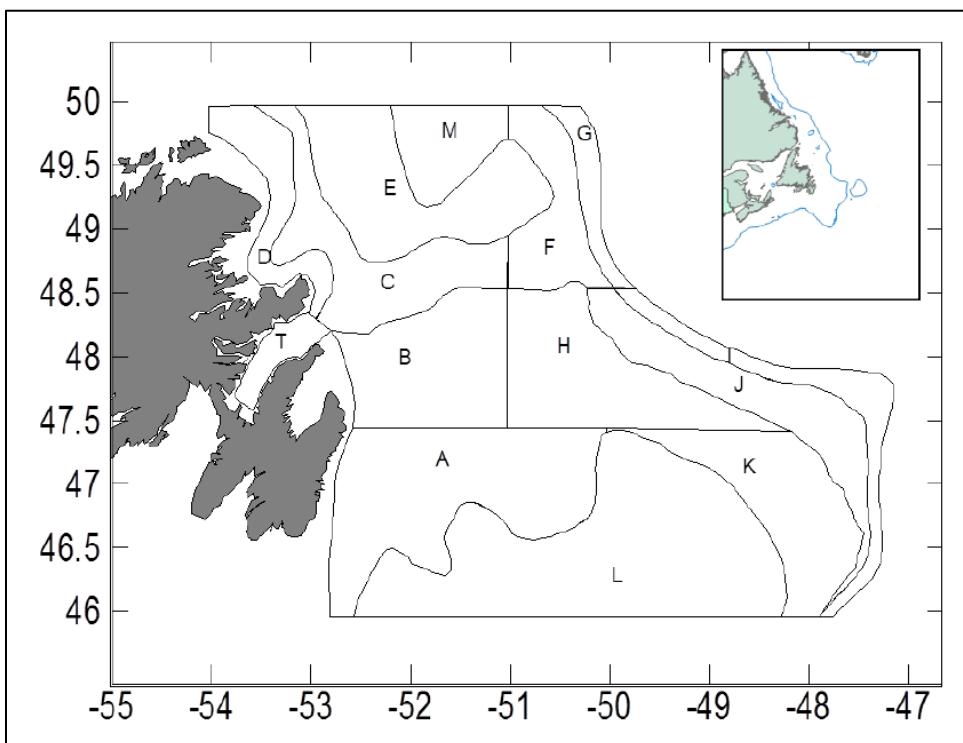
2.4 CAPELIN DATA

Information on capelin abundance and its biological characteristics (length, weight, age) for the spring period were taken from samples collected from the annual spring (May) acoustic survey of NAFO Division 3L (Mowbray 2014). Samples of capelin were collected from fishing sets targeted at back-scatter signals identified on echograms (Figure 6). Fish were obtained using a Campelen 1800 trawl fished midwater or on bottom depending on the vertical positioning of the acoustic signal. The biological characteristics of capelin in the autumn were derived from fish sampled during annual random stratified bottom trawl surveys conducted from October–December in NAFO Divisions 2J3KLNO (Brodie and Stansbury 2007). Capelin were sampled throughout the surveyed areas. Both spring and autumn samples were divided into two groups, those collected above and below 48 N (Figures 2 and 6a).

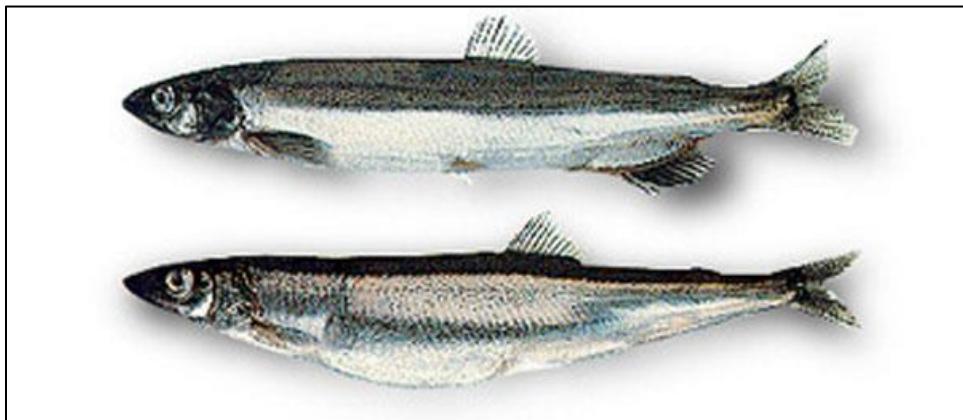
For body condition analyses, only male age 2 capelin were considered. Age 2 capelin are the predominant age class in both the spring and autumn surveys, in addition they are not impacted by previous spawning history as it is the age of first maturity. Age 2 males were selected for this analysis because during the spring survey a variable portion of the age 2 capelin are maturing. Since maturation and spawning may lead to a loss of overall condition, particularly as post-spawning fish in the autumn, we chose to use only males in the study as energy allocation to gonad production in males is considerably lower than in females. The somatic condition was represented by the residuals of a length weight regression (LWR), and these values were averaged to provide seasonal indices. The capelin age 2 abundance index used both sexes and is only available for the spring in NAFO's 3L division, which corresponds with the southern region of this study.

2.5 GENERALIZED ADDITIVE MODELS

The environmental variables were tested for potential relationships by applying stepwise regressions. This process removed related variables one at a time. The functional relationships among the environmental variables (SST and CHL) cycles and the zooplankton as well as capelin were investigated using non-parametric curve fits, an approach known as Generalized Additive Models (GAM) (Hastie and Tibshirani, 1986). GAMs are a category of statistical models that generalize the original information using non-linear smoothing functions by local fitting to subsections of the time-series to simulate and capture the non-linearity in the data. This study applied the Loess (Locally Estimated Scatterplot Smoothing) technique to fit the independent variables. The GAMs algorithm fits a smooth curve to each independent variable and then combines the results additively. As a rule for comparison, GAMs attempt to achieve the minimal residual deviance on the fewest degrees of freedom, consequently the tested regressions were selected by their residual deviance, with the model with the minimum residual deviance considered the best model. In order to avoid overfitting only two environmental variables were selected to build the relations between zooplankton or fish. This study developed the models with S+ (TIBCO Spotfire S+® 8.2 for Windows).



a)



b)

Figure 6. a) Map of capelin stock survey area showing boundaries of depth-delimited strata, from Mowbray (2014). b) Male (top) and female (bottom) of *Mallotus villosus* (Müller, 1776). (<http://www.fao.org/fishery/species/2126/en>)

3. RESULTS

3.1 PHYSICAL AND BIOLOGICAL CYCLES

3.1.1 Climatology (average 1998 – 2015)

The climatology cycles (averaged between 1998 and 2015) of annual sea surface temperature (SST) and seasonal (spring, autumn) concentration of phytoplankton pigment (CHL) for the northern and southern regions are shown in Figure 7 (a and b, respectively).

The northern SST annual cycle shows satellite-derived minimum values of approximately -1.2°C in day of year (doy) 72, while the maximum temperature is centered at 12.6°C on doy 232 (Table 1). Note that a doy > 365 means the temporal scale is extended to the following year. As expected, the southern thermal cycle is warmer with minimum values of approximately 0.2°C during the same doys as in the north, and the maximum temperature increases to almost 16.7°C on the corresponding doy 232 (Table 3).

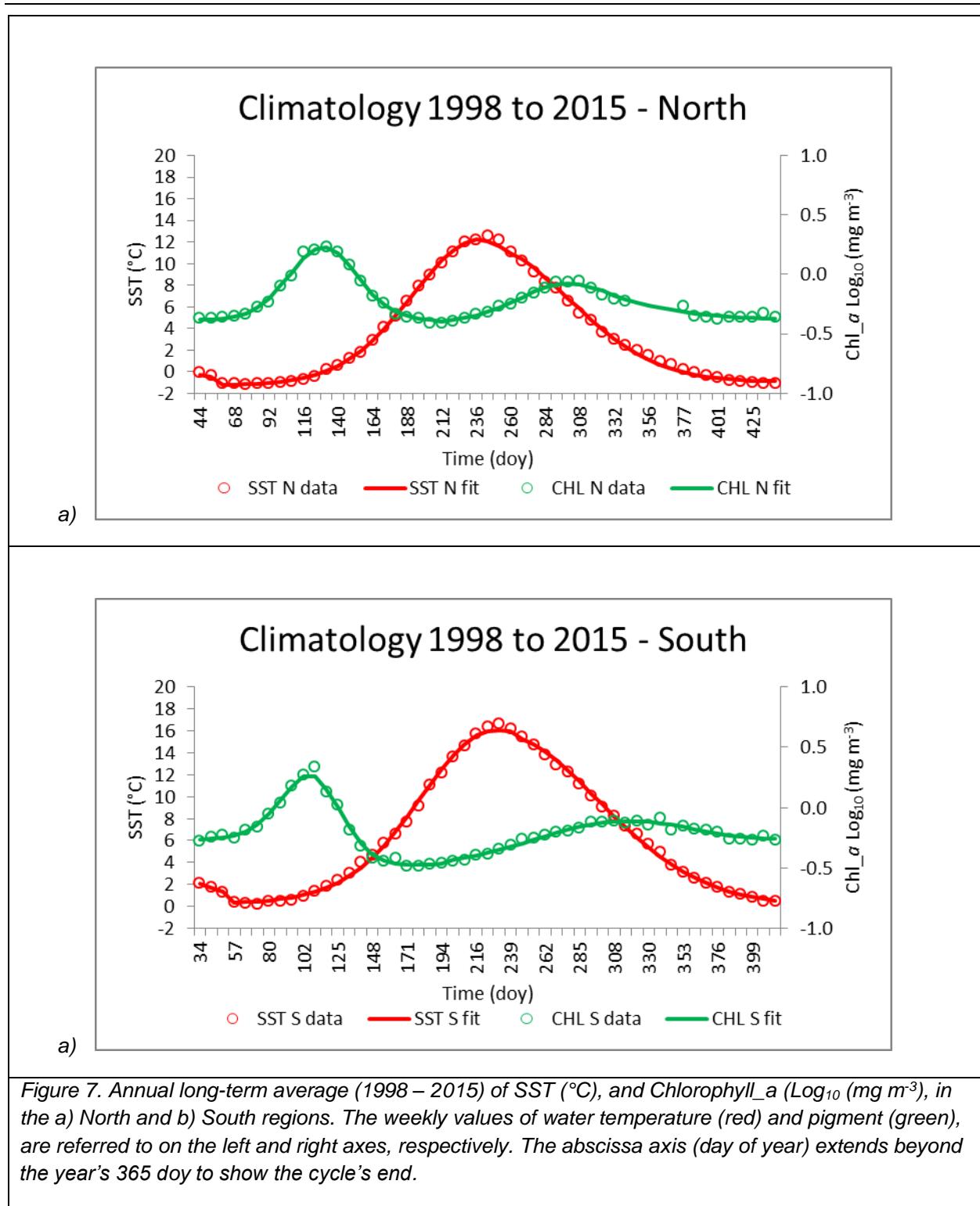
Remotely-sensed CHL climatology cycles in the study area are asymmetric in both regions and seasons. The northern area in spring shows CHL minima of -0.37 and -0.41 [$\text{Chl}_a \text{ Log}_{10} (\text{mg m}^{-3})$] at doys 44 and 204, and a maximum of 0.24 [$\text{Chl}_a \text{ Log}_{10} (\text{mg m}^{-3})$] on doy 132. The autumn cycle in this region is defined by minima of -0.41 and -0.38 [$\text{Chl}_a \text{ Log}_{10} (\text{mg m}^{-3})$] on doys 204 and 32 (of the next year), with a maximum of -0.06 [$\text{Chl}_a \text{ Log}_{10} (\text{mg m}^{-3})$] centered at doy 300 (Table 5).

Spring CHL cycle in the southern region is shorter and stronger than in the north, with minima of -0.28 and -0.49 [$\text{Chl}_a \text{ Log}_{10} (\text{mg m}^{-3})$] at doys 34 and 178, and a maximum of 0.33 [$\text{Chl}_a \text{ Log}_{10} (\text{mg m}^{-3})$] on doy 110. The autumn cycle in this region is longer but weaker than the northern region, and characterized by minima of -0.49 and -0.27 [$\text{Chl}_a \text{ Log}_{10} (\text{mg m}^{-3})$] on doys 178 and 56 (next year), and a maximum of -0.09 [$\text{Chl}_a \text{ Log}_{10} (\text{mg m}^{-3})$] centered at doy 338 (Table 7).

3.1.2 Week/year physical and biological data

Weekly SST and CHL between 1998 and 2016 for northern and southern areas, as well as their averages and standard deviations, are compiled in Tables 1 to 8 and Appendix 1. Figures APX1-1-6, show graphs of the annual thermal and seasonal phytoplankton blooms (spring and autumn) in the north region. The corresponding graphs for the southern region are illustrated in Figures APX1-7-12

Relative consistency of the SST annual cycle can be seen along the time-series for each year. However there is a high variability in the temporal structure of both seasonal phytoplankton blooms along the years of study. This latter observation is well shown in the southern and the northern regions of assessment.



3.2 ECOLOGICAL INDICES

3.2.1 Thermal indices

Annual ecological indices of SST in the northern and southern areas between 1998 and 2016 were derived from the fitted annual cycles (Tables 2 and 4, respectively). These thermal indices are compiled in Table 9. The indicators are initiation, maximum, and end (values and times to reach the indicators), duration, and rates of warming and cooling during the cycle.

Statistical analyses in this study were performed using the normalized anomalies of the indices. The yearly anomaly was computed by subtracting the long term average from each annual value and dividing by its standard deviation: $(x - \mu)/\sigma$. In Appendix 2, Figure APX2-1 shows the corresponding time-series for the northern region, Figure APX2-2 is for the southern region, and Figure APX2-3 shows the derived rates of warming and cooling on both regions.

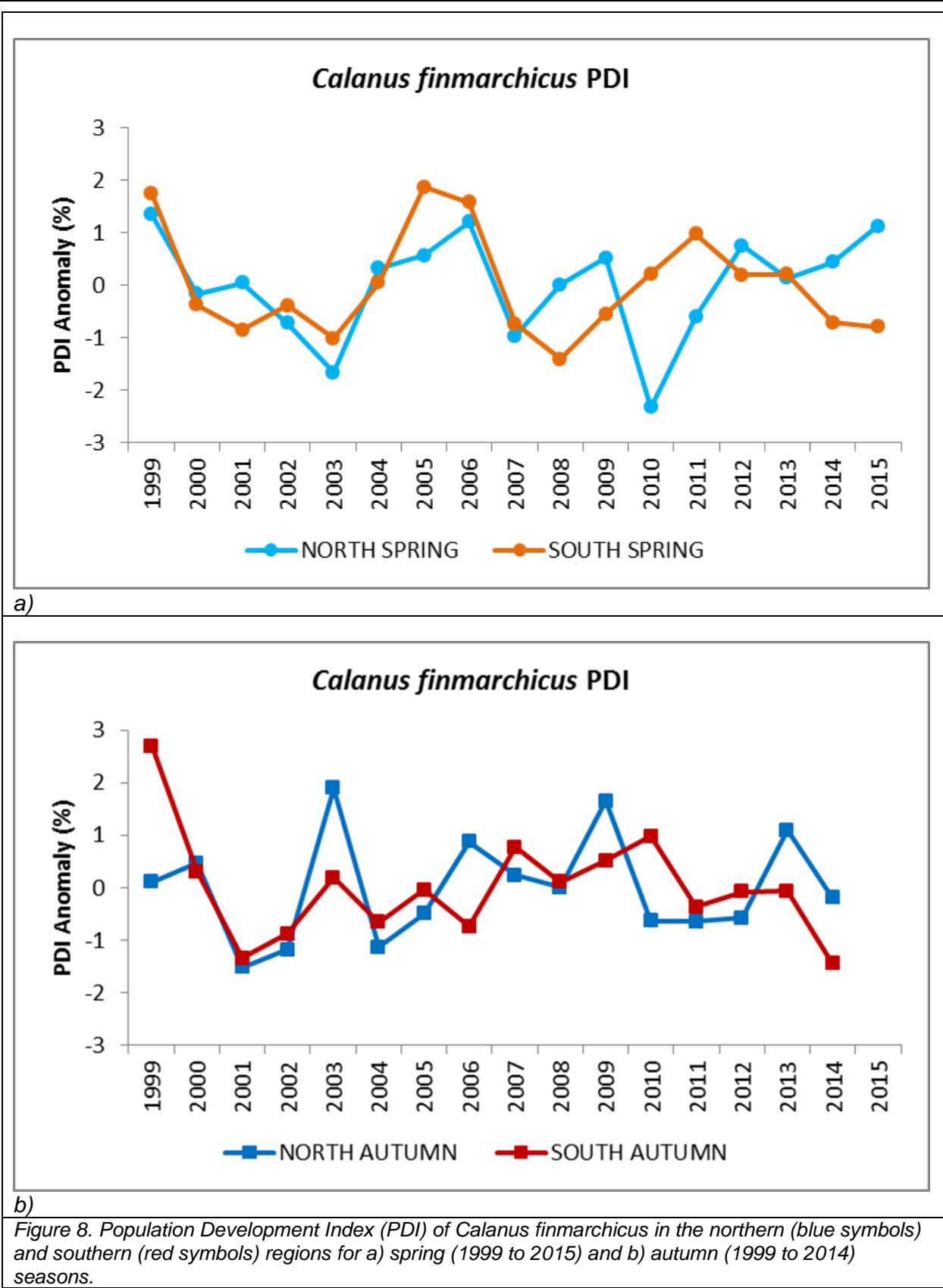
3.2.2 Phytoplankton bloom indices

Seasonal phytoplankton bloom indices in the northern and southern areas were also computed using the fitted time-series (Tables 6 and 8, respectively). The CHL indices are shown in Tables 10 for spring and Table 11 for autumn, from 1998 until 2015. The pigment bloom indices are analogous to the SST cycle: initiation, maximum, and end (values and times to reach the indices), as well as the duration. Rates of increasing and decreasing were also processed but not used in this study.

As specified for SST, the functional statistical links of CHL with other components of this study were computed using normalized anomalies of the CHL bloom indices. Figures APX2-4 and APX2-5, in Appendix 2, show time-series of the northern region during spring and autumn, respectively. The southern region anomalies are illustrated in the same appendix but in Figures APX2-6 and APX2-7 for the spring and autumn, respectively.

3.3 *Calanus finmarchicus* (PDI)

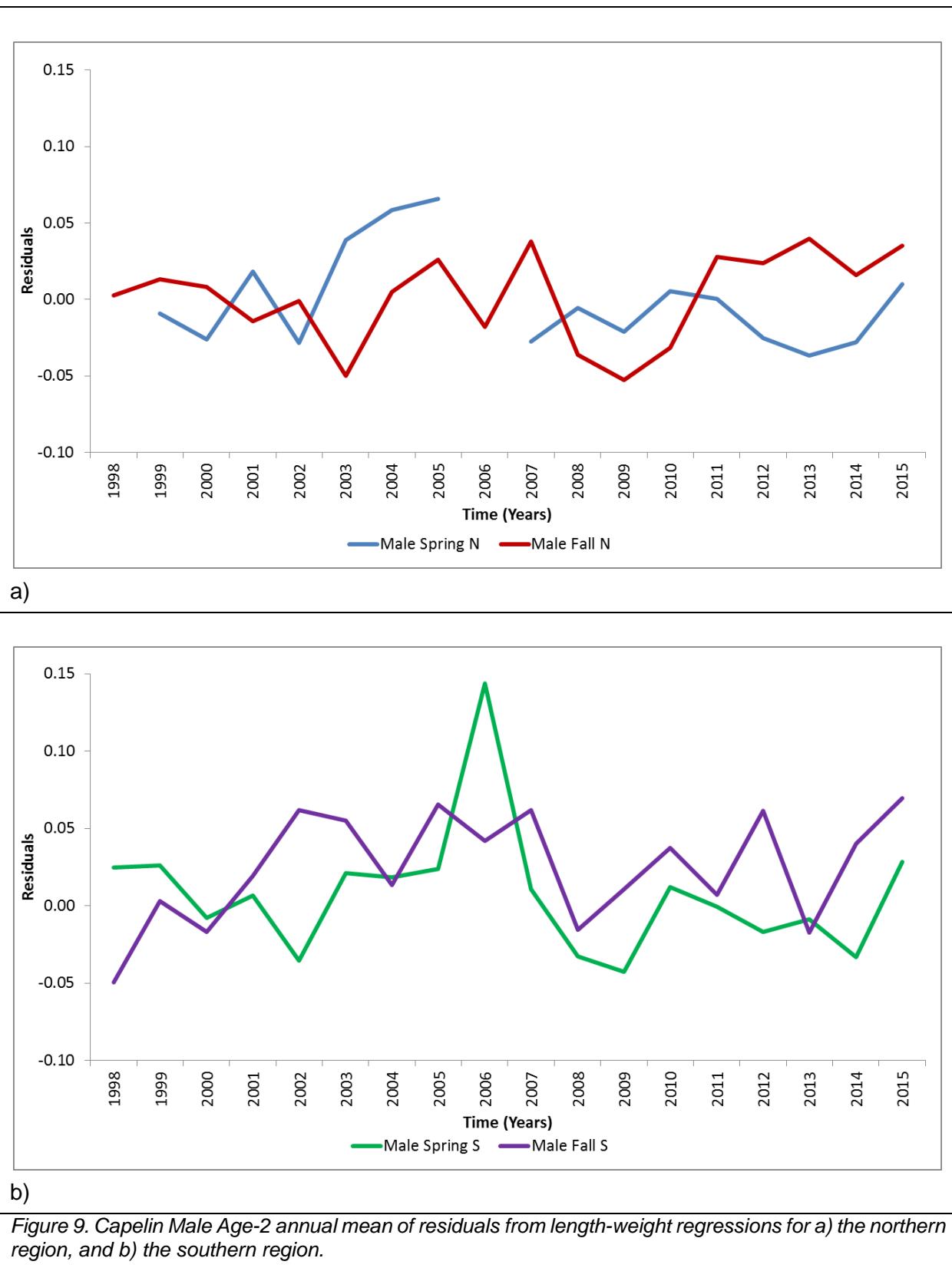
The *Calanus finmarchicus* Population Development Index (PDI) for both regions (north and south) as well as its seasonal values are compiled in Table 12. Figure 8 illustrates the inter-annual variability that is used as input to search for environmental relationships with capelin. Temporal oscillations of *C. finmarchicus* PDI normalized anomalies during spring in both regions are shown in Figure 8a, and Figure 8b illustrates the same information but for the autumn.



3.4 CAPELIN (*Mallotus villosus*)

3.4.1 Somatic condition

The mean residuals of length-weight regressions for male age-2 capelin captured during spring (acoustic) and autumn (bottom trawl) surveys are illustrated in Figures 9a and b (north and south regions, respectively). These values, which provide an index of capelin body condition, integrate feeding success both over the current and, to some extent, the former season.



3.4.2 Abundance

The age 2 abundance index of capelin in spring (May) comes from NAFO 3L acoustic survey (Figure 6a); its time-series is shown in Figure 10. No survey was conducted in 2006.

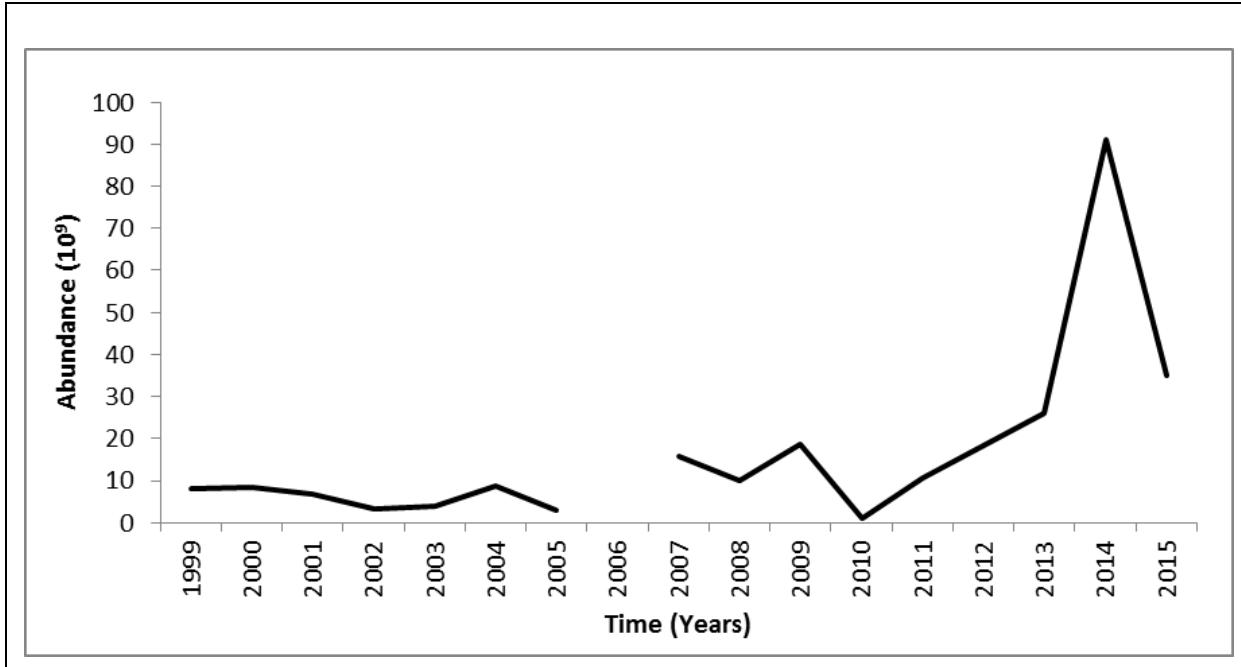


Figure 10. Abundance index of capelin (2 years old) from the spring NAFO 3L acoustic survey between 1999 and 2015.

3.5 STATISTICAL RELATIONSHIPS

Potential functional links between *Calanus* PDI, capelin somatic condition, capelin abundance, and environmental conditions were investigated with GAMs. The environmental explanatory variables in both regions (north and south) included the rate of SST warming in spring and the rate of SST cooling in the autumn. Selected moments of the phytoplankton blooms during spring and autumn were incorporated as detailed below. *Calanus* PDI was included as a proxy for the availability of this primary capelin prey species.

3.5.1 Drivers of feeding

During Spring in the Northern region, the zooplankton indicator (CALFINPDI) was related with the SST warming rate (*WARMRATE*) (Figure 11a), and the time at the maximum concentration of phytoplankton biomass (*CHLMAXDOY*) (Figure 11b). Inclusion of both environmental variables provided the most parsimonious GAM model with a deviance of 2.0912 (Figure 11c). Complete descriptions of the GAM's statistics are in Appendix 3 (Figures APX3-1, 2, and 3, respectively).

During Autumn in the Northern region, CALFINPDI was weakly related to SST cooling rate (*COOLRATE*) (Figure 12a) and the corresponding season *CHLMAXDOY* (Figure 12b). Together, these environmental variables generated a GAM model with a deviance of 4.8595 (Figure 12c). Complete descriptions of the GAM's statistics are in Appendix 3 (Figures APX3-4, 5, and 6, respectively).

During Spring in the Southern region, CALFINPDI was related to *WARMRATE* (Figure 13a), and the maximum concentration of phytoplankton biomass (*CHLMAXMAG*) (Figure 13b). Figure 13c shows the observed and modeled results for the addition of both environmental variables, where the deviance was equal to 4.6731. Complete descriptions of the GAM's statistics are in Appendix 3 (Figures APX3-7, 8, and 9, respectively).

During Autumn in Southern region, CALFINPDI was weakly related to *COOLRATE* (Figure 14a), and *CHLMAXMAG* (Figure 14b). The sum of both predictor variables had a deviance equal to 7.1217 (Figure 14c). Complete descriptions of the GAM's statistics are in Appendix 3 (Figures APX3-10, 11, and 12, respectively).

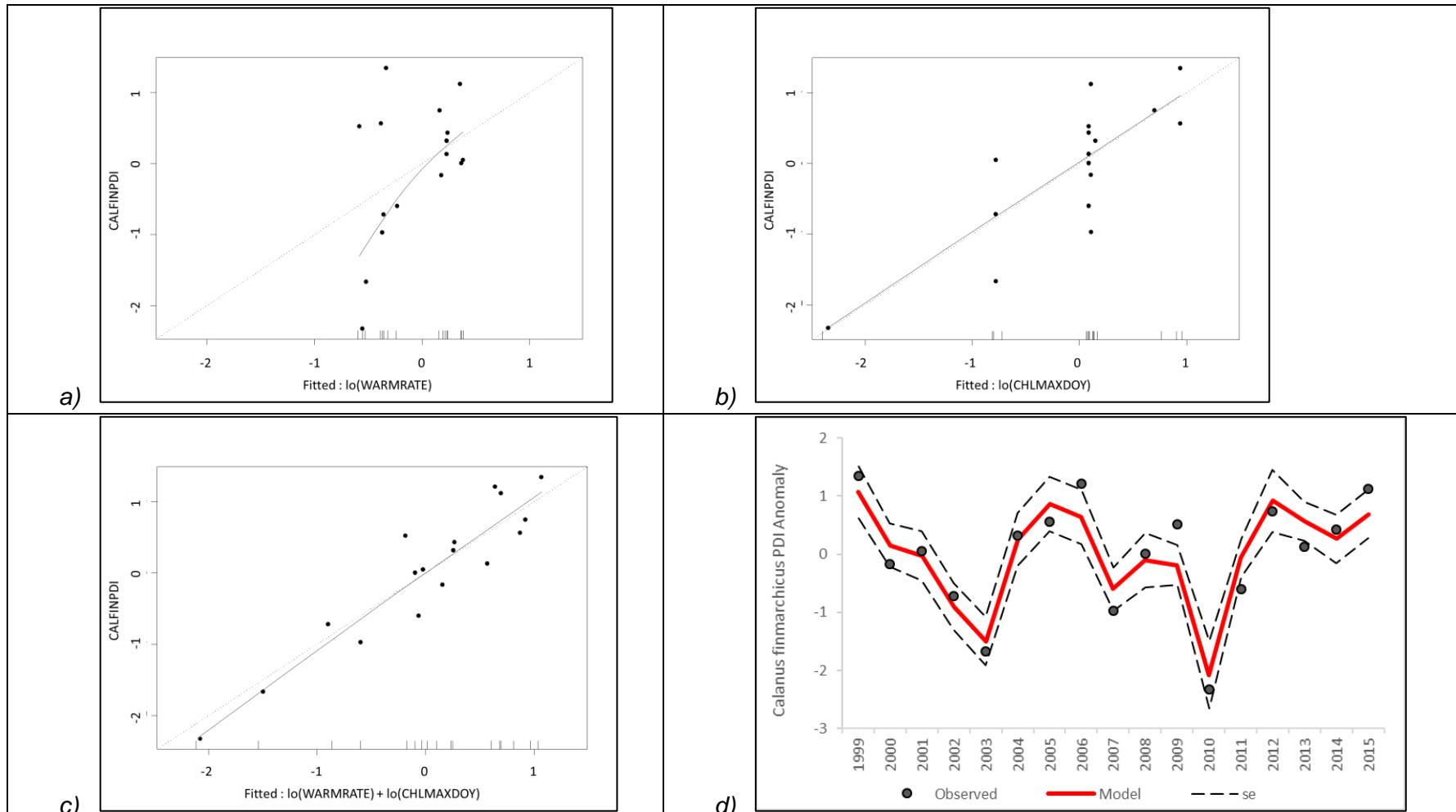


Figure 11. *Calanus finmarchicus* PDI anomalies (CALFINPDI) and the most parsimonious GAM models using environmental variables during Spring in the northern region. a) CALFINPDI and surface water's WARMRATE, b) CALFINPDI and phytoplankton's CHLMAXDOY, c) CALFINPDI and both variables, and d) Time-series (1999 until 2015) of CALFINPDI and both variables. Black symbols represent measured data, red line is the GAM model and the hatched line is \pm one standard error.

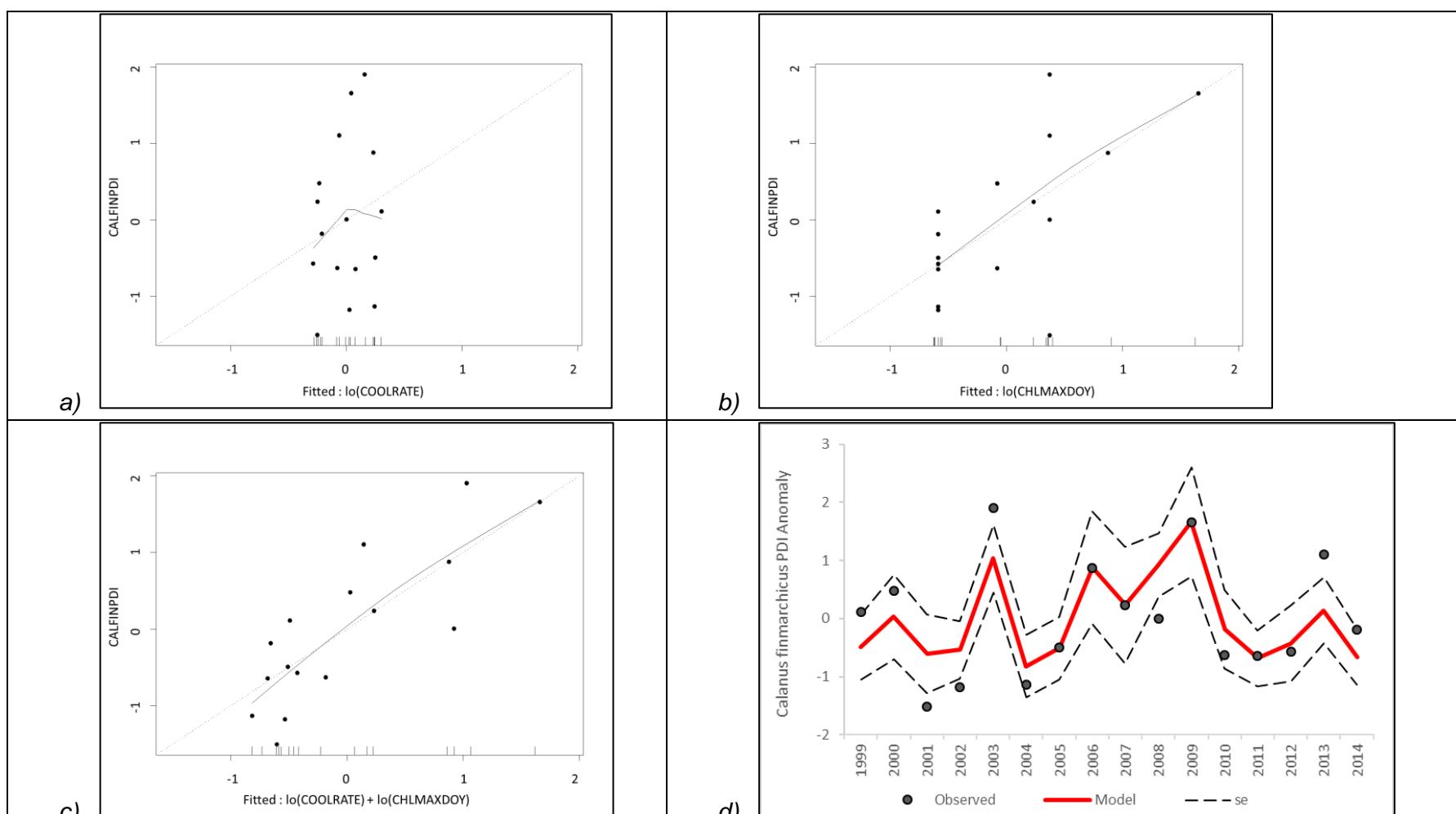
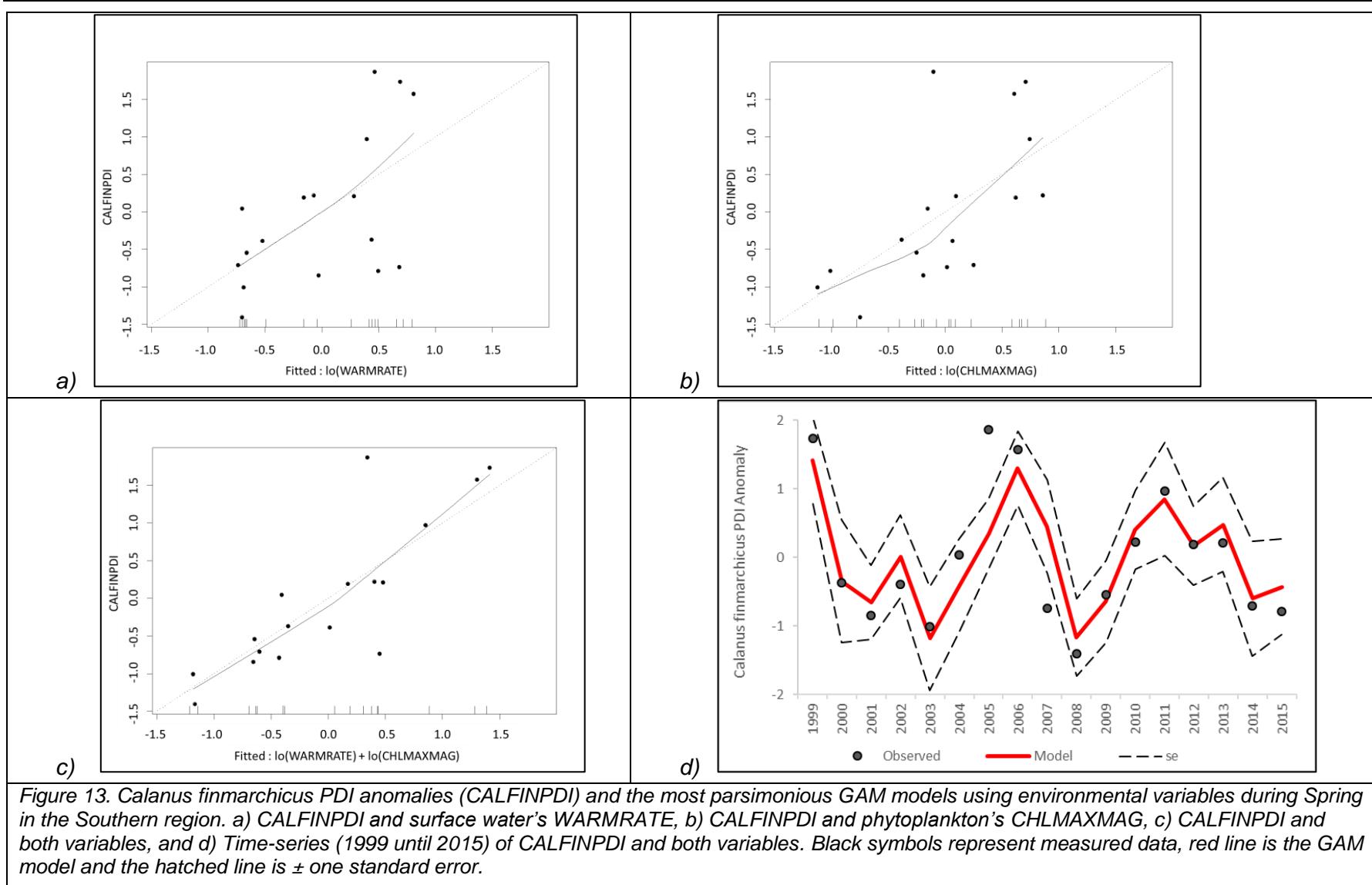


Figure 12. *Calanus finmarchicus* PDI anomalies (CALFINPDI) and the most parsimonious GAM models using environmental variables during Autumn in the Northern region. a) CALFINPDI and surface water's COOLRATE, b) CALFINPDI and phytoplankton's CHLMAXDOY, c) CALFINPDI and both variables, and d) Time-series (1999 until 2014) of CALFINPDI and both variables. Black symbols represent measured data, red line is the GAM model and the hatched line is \pm one standard error.



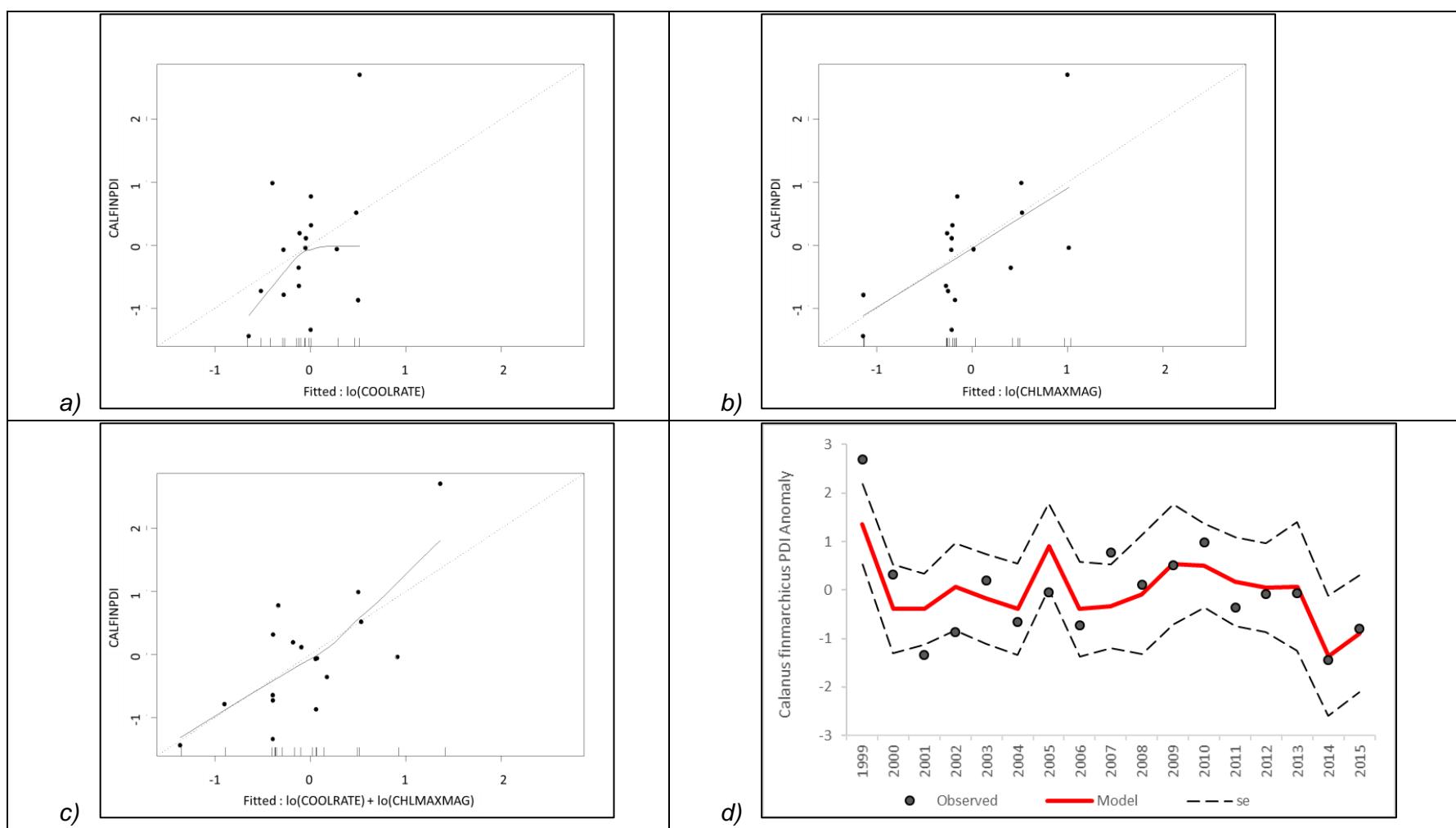


Figure 14. *Calanus finmarchicus* PDI anomalies (CALFINPDI) and the most parsimonious GAM models using environmental variables during Autumn in the Southern region. a) CALFINPDI and surface water's COOLRATE, b) CALFINPDI and phytoplankton' CHLMAXMAG, c) CALFINPDI and both variables, and d) Time-series (1999 until 2015) of CALFINPDI and both variables. Black symbols represent measured data, red line is the GAM model and the hatched line is \pm one standard error

3.5.2 Capelin somatic condition

During the Spring in the Northern region, capelin's somatic condition (LWRSPRNOR) was related to CALFINPDI (Figure 15a), and CHLMAXMAG (Figure 15b). Addition of both variables resulted in the most parsimonious GAM with deviance equal to 0.0066 (Figure 15c). Complete descriptions of the GAM's statistics are in Appendix 3 (Figures APX3-13, 14, and 15, respectively).

During the Autumn in the Northern region, LWRFALNOR was related to CALFINPDI (Figure 16a), and CHLMAXMAG (Figure 16b). The GAM incorporating both variables produces a model with deviance equal to 0.003 (Figure 16c). Complete descriptions of the GAM's statistics are in Appendix 3 (Figures APX3-16, 17, and 18, respectively).

During the Spring in the Southern region LWRSPRSUR was related to CALFINPDI (Figure 17a), and CHLINIDOF (Figure 17b). Combination of both predictors produced a deviance equal to 0.0083 (Figure 17c). Complete descriptions of the GAM's statistics are in Appendix 3 (Figures APX3-19, 20, and 21, respectively).

During the Autumn in the Southern region, capelin somatic condition (LWRFALSUR) was related to CALFINPDI (Figure 18a) and CHLINIDOF (Figure 18b). Relating these two predictors, the final GAM generated a deviance equal to 0.0033 (Figure 18c). Complete descriptions of the GAM's statistics are in Appendix 3 (Figures APX3-22, 23, and 24, respectively).

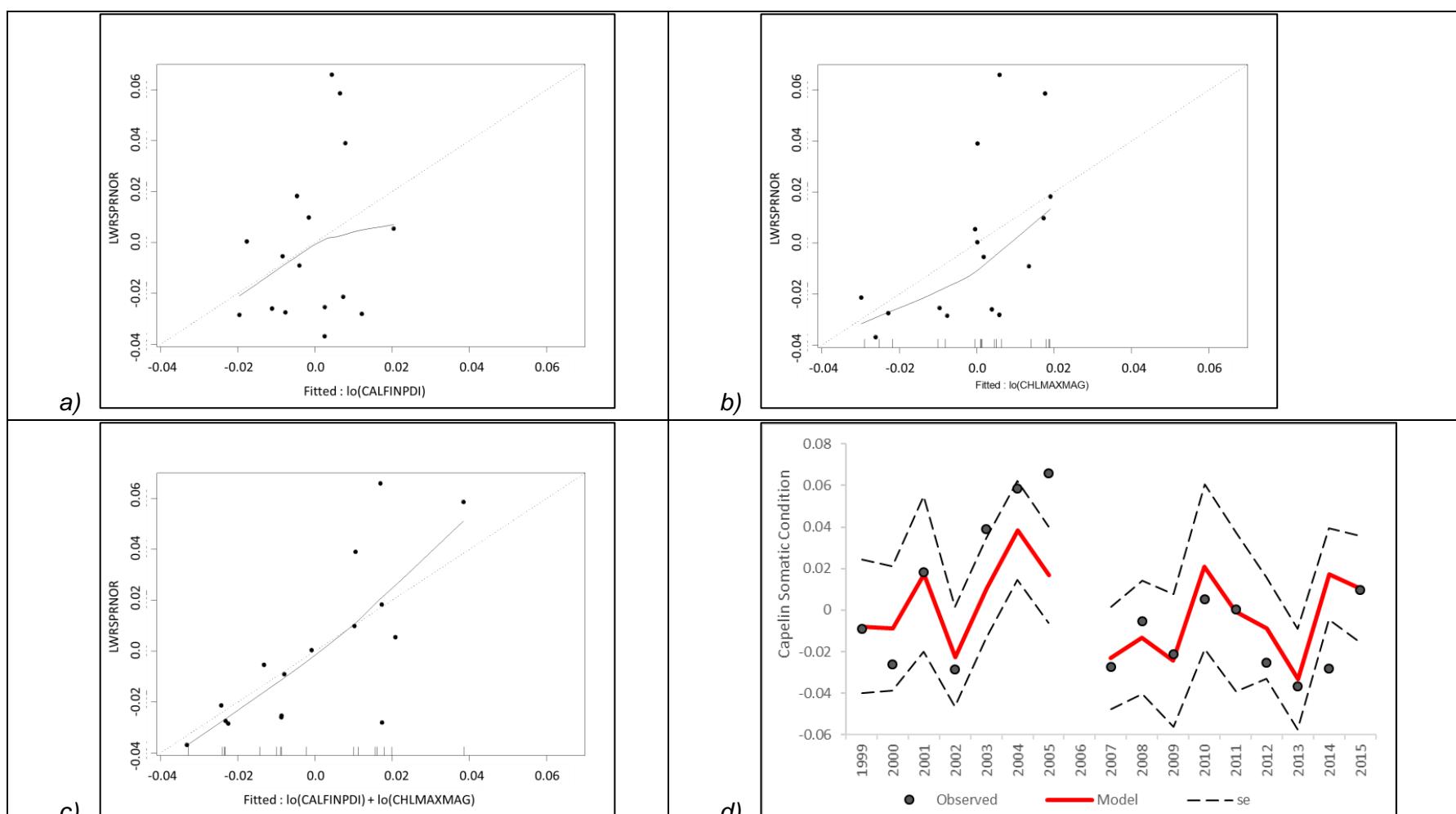
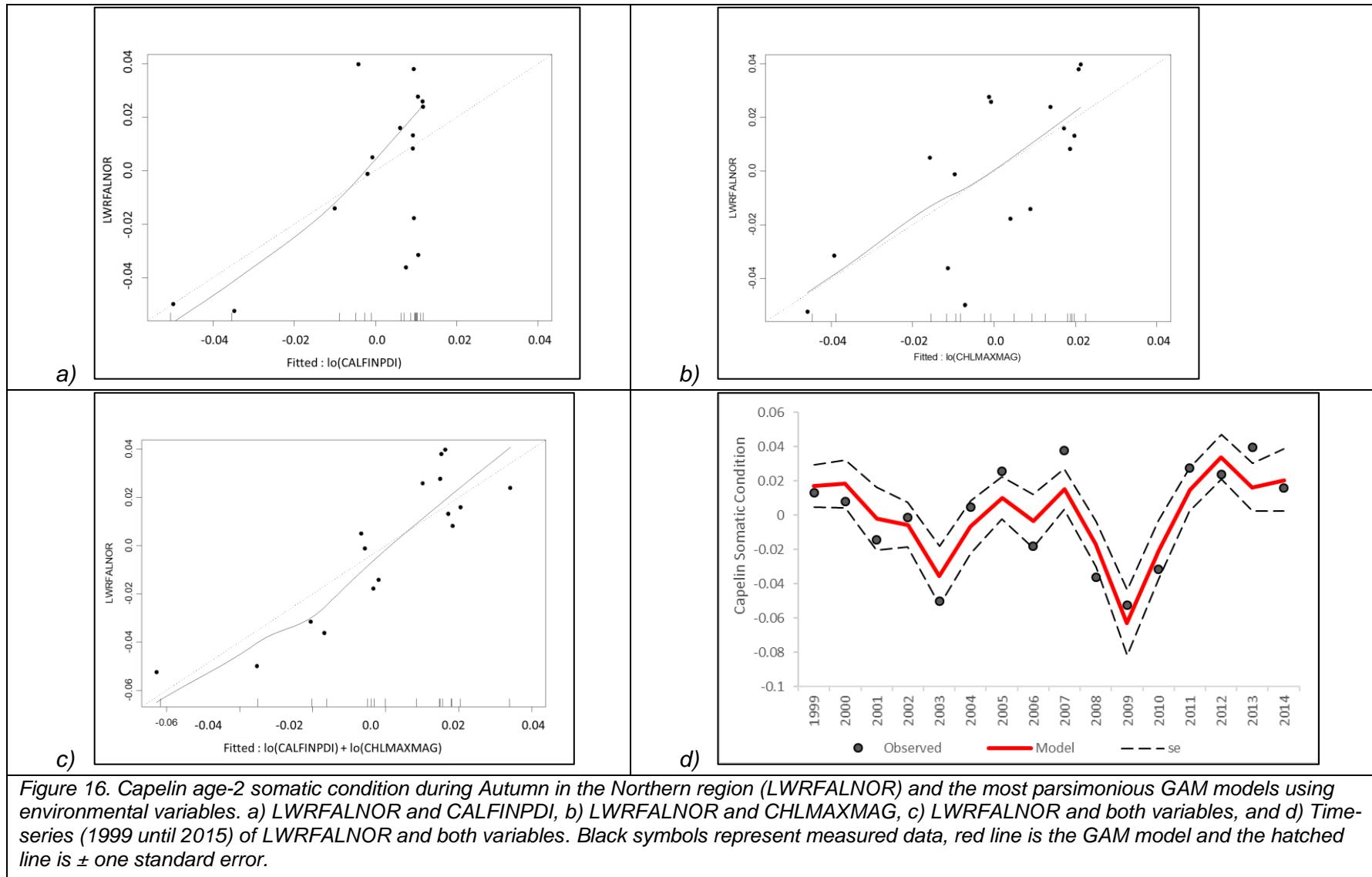


Figure 15. Capelin age-2 somatic condition during Spring in the Northern region (LWRSPRNOR) and the most parsimonious GAM models using environmental variables. a) LWRSPRNOR and CALFINPDI, b) LWRSPRNOR and CHLMAXMAG, c) LWRSPRNOR and both variables, and d) Time-series (1999 until 2015, during 2006 there are no data) of LWRSPRNOR and both variables. Black symbols represent measured data, red line is the GAM model and the hatched line is \pm one standard error.



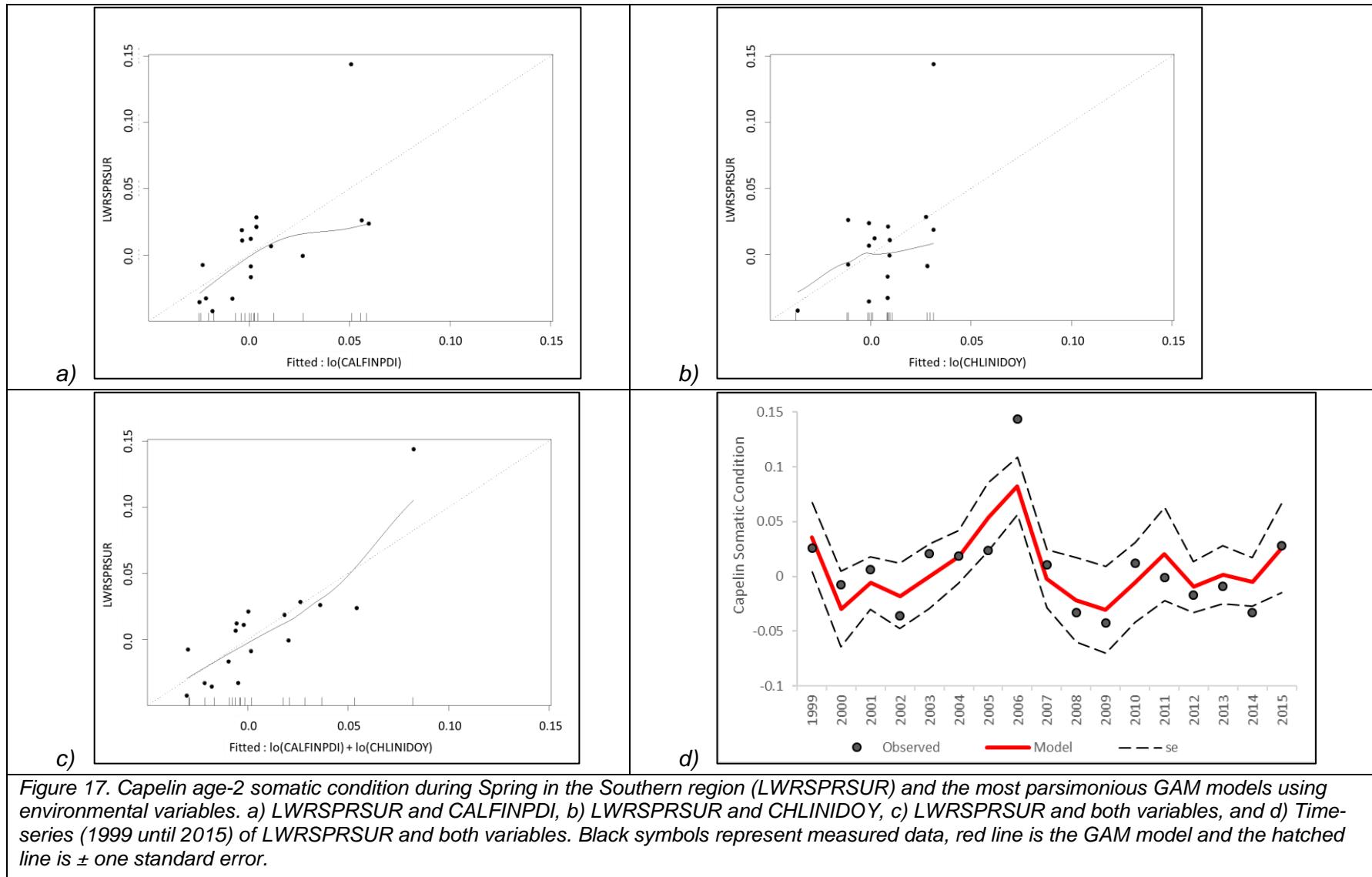


Figure 17. Capelin age-2 somatic condition during Spring in the Southern region (LWRSPRSUR) and the most parsimonious GAM models using environmental variables. a) LWRSPRSUR and CALFINPDI, b) LWRSPRSUR and CHLINIDOF, c) LWRSPRSUR and both variables, and d) Time-series (1999 until 2015) of LWRSPRSUR and both variables. Black symbols represent measured data, red line is the GAM model and the hatched line is \pm one standard error.

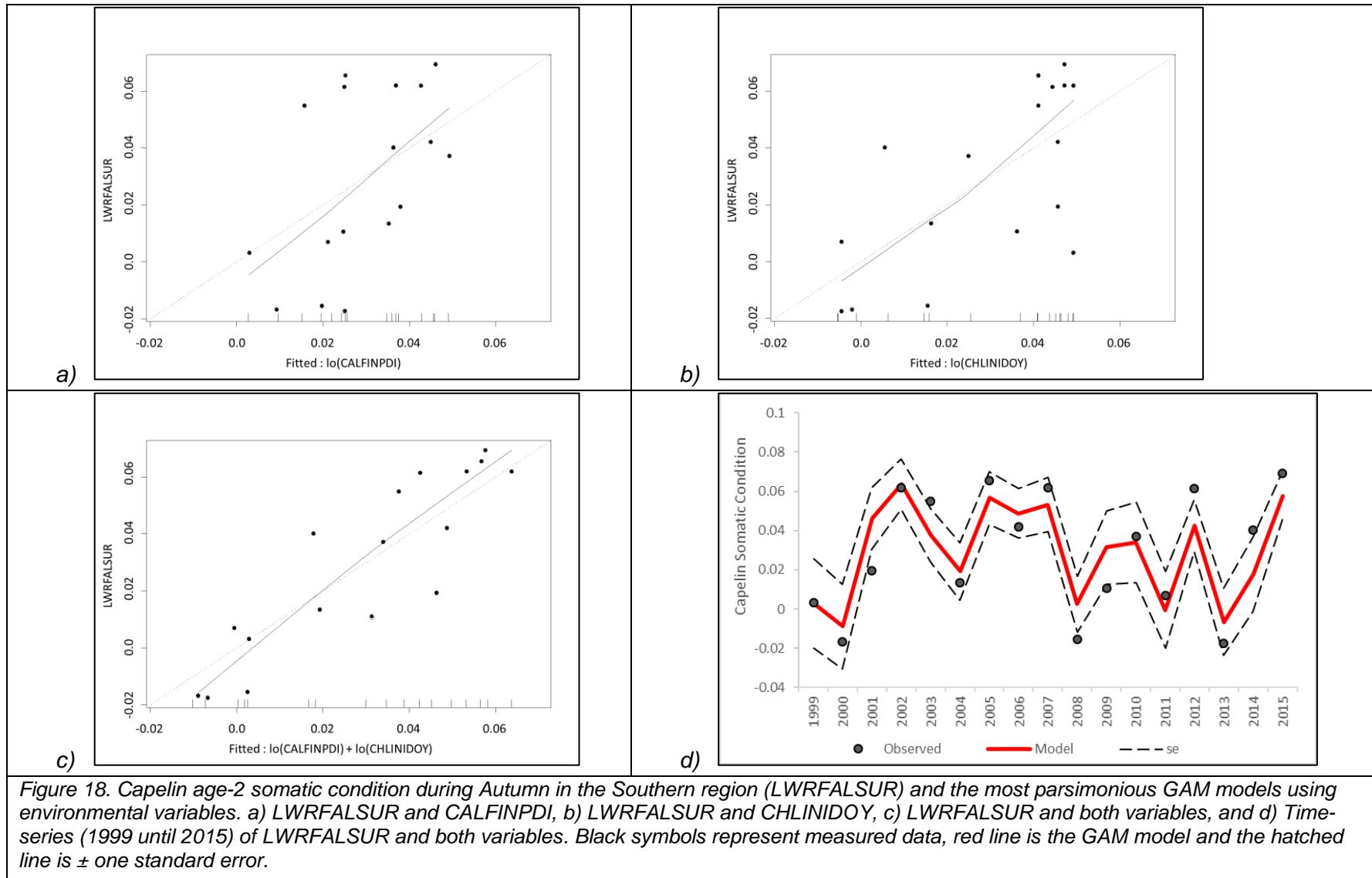


Figure 18. Capelin age-2 somatic condition during Autumn in the Southern region (LWRFALSUR) and the most parsimonious GAM models using environmental variables. a) LWRFALSUR and CALFINPDI, b) LWRFALSUR and CHLINIDOFY, c) LWRFALSUR and both variables, and d) Time-series (1999 until 2015) of LWRFALSUR and both variables. Black symbols represent measured data, red line is the GAM model and the hatched line is \pm one standard error.

3.5.3 Capelin abundance

Capelin's abundance (ABUSPRSUR) was weakly related to the SST warming rate (*WARMRATE*) (Figure 19a), and CALFINPDI (Figure 19b). Adding both environmental variables gave the most parsimonious GAM model with a deviance of 3.0649 (Figure 19c). Complete descriptions of the GAM's statistics are in Appendix 3 (Figures APX3-25, 26, and 27, respectively).

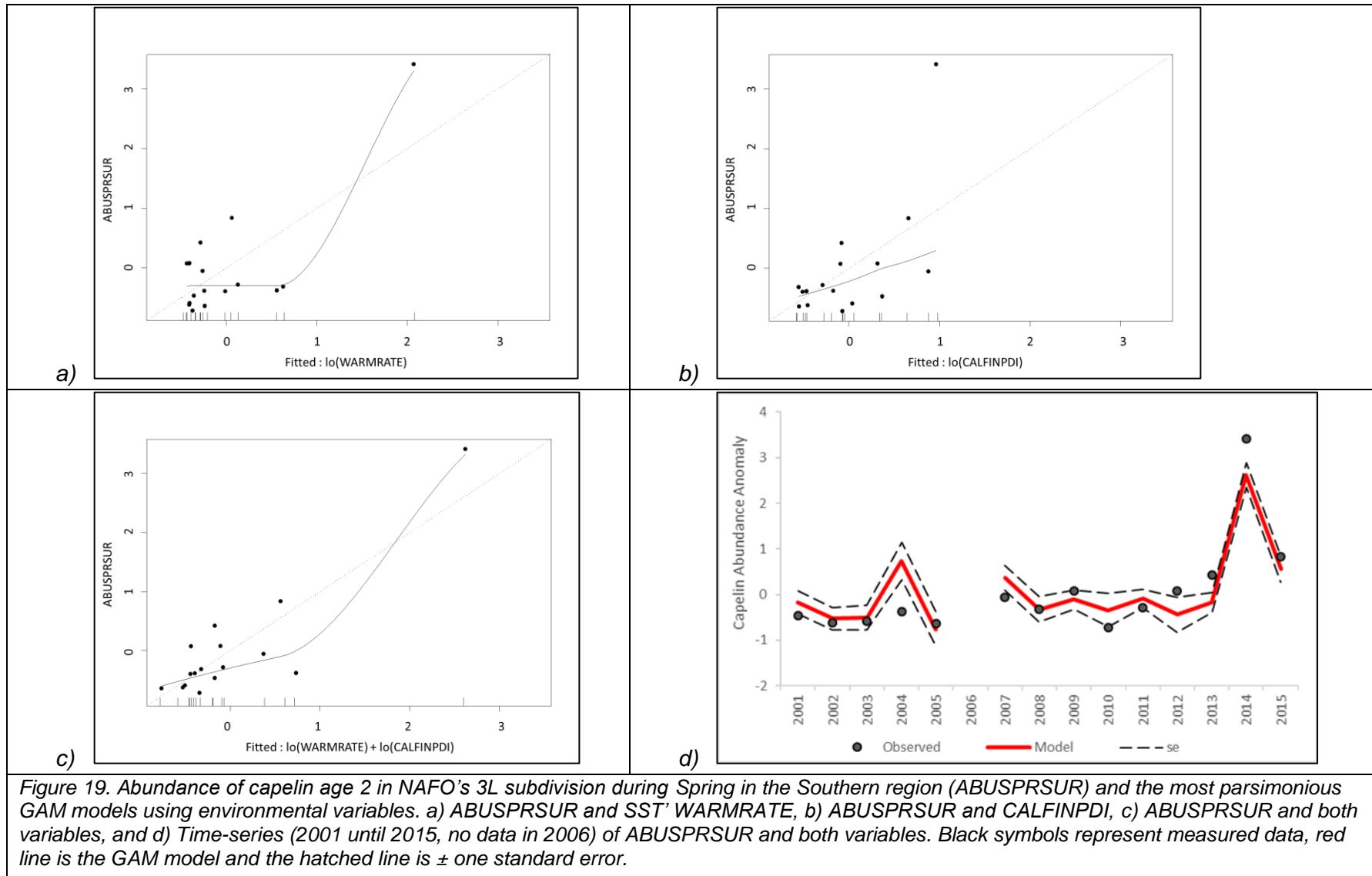


Figure 19. Abundance of capelin age 2 in NAFO's 3L subdivision during Spring in the Southern region (ABUSPRSUR) and the most parsimonious GAM models using environmental variables. a) ABUSPRSUR and SST' WARMRATE, b) ABUSPRSUR and CALFINPDI, c) ABUSPRSUR and both variables, and d) Time-series (2001 until 2015, no data in 2006) of ABUSPRSUR and both variables. Black symbols represent measured data, red line is the GAM model and the hatched line is \pm one standard error.

4. DISCUSSION AND CONCLUSION

Remotely-sensed SST and phytoplankton pigments are very useful in studying marine ecosystems, in particular by relating primary producers and environment to fisheries productivity. This study used satellite-derived weekly composites of SST and chlorophyll_a concentrations to assemble an 18-year-long time-series. The asymmetric evolution of each of these series was used to find phenological moments such as the change of water temperature in spring and autumn and different features of the phytoplankton pigment cycle. This study describes the interaction and potential influence of these objective characteristics on the ecology of copepods (*Calanus finmarchicus*) and capelin (*Mallotus villosus*) on the Grand Banks of Newfoundland. It is a preliminary assessment to find the main remotely-sensed derived ecological controllers on two levels of the regional food chain: *Calanus'* copepodites abundance, and body condition and abundance of capelin at age-2.

4.1 PHYSICAL AND BIOLOGICAL CYCLES

Validation of satellite-derived data with *in situ* measurements of temperature and phytoplankton pigments is vital when using remotely-sensed data series. The comparison of *in situ* SST and historical satellite-derived data (Multi-Channel Sea Surface Temperature/AVHRR), within the present study area (Atlantic Zone Monitoring Program's Station 27, Lat. 47.55, Long. 52.58) showed good agreement (Mason *et al.*, 1998). Recent comparisons using satellite-derived SST and near-surface Argo measurements for the global oceans, and in particular for the North Atlantic Ocean, strengthen the confidence in the use of this remotely-sensed signal (Fielder *et al.*, 2019 and included references). Comparisons of chlorophyll_a derived from satellite data and *in situ* measurements were carried out in a smaller area located south and west of the present area (Fuentes-Yaco *et al.*, (2015)). Their results showed that MODIS data overestimated low chl and underestimated high values, which is typical for all sensors used in this study. These results coincide with a recent comparison of *in situ* (High Performance Liquid Chromatography measured) and satellite-derived data in the Northwest Atlantic applying NASA's OCx algorithm (Clay *et al.*, 2019). Notwithstanding, these authors claim a general underestimation of the satellite-derived data. However, these results underline that their matching locations included both coastal and offshore locations, which certainly was a factor in the validation's error. The present study area shows lower optical complex characteristics (Mélin and Vantrepotte, 2015) compared to the coastal locations in the Gulf of Maine and Gulf of St. Lawrence included in Fuentes-Yaco *et al.*, (2015), and consequently the dispersion along the regression lines in the current study should be minor.

We divided the study area into northern and southern regions at 48°N based on the persistence of SST and chlorophyll_a values. The inter-annual SST pattern was more consistent than the variable phytoplankton blooms during both seasons (spring and autumn) and regions (north and south). This latitudinal separation agrees with a study published by Richaud *et al.* (2016) who used *in situ* data of surface water temperature (top 5 meters) to create long-term climatologies (1910 to 2010), which closely correspond with our satellite-derived analyses. In addition, both cycles of phytoplankton blooms found in the present study agree with those described at different latitudes in the North Atlantic (Afanasyev *et al.*, 2001; Friedland *et al.*, 2008; Platt *et al.*, 2010; Winder and Cloern, 2010; Martinez *et al.*, 2011; Kun *et al.*, 2015; Friedland *et al.*, 2016; Coté *et al.*, 2019; Wihsott *et al.*, 2019). A fairly comparable study to the results presented here are those of Zhao *et al.*, (2013) during the spring bloom in our Southern region.

4.2 ECOLOGICAL INDICES

4.2.1 SST indices

The time-series of warming and cooling SST rates in this study are derived from the corresponding annual shifting minimum temperature, not a baseline. Consequently, seasonal and inter-annual environmental variabilities characterize the particular year. In the northern region, SST warming and cooling rates show a lightly decreasing pattern driven by negative changes of temperature values at the initiation, maximum and end. These patterns are consistent in spite of positive variations associated with the times to reach these three moments of the annual cycle. There are no reports on seasonal rates of warming and cooling for the study area, however we made efforts to analyze our results by comparing with analogous approaches. In agreement with the results shown here, Greenan *et al* (2018) found no significant warming patterns in the past century in temperature averaged over all depths at a site on the Newfoundland Shelf, which is in the northern area of this study, nor in the upper ocean of the adjacent Labrador Sea. Nevertheless, on the southern region of our study the directions for warming during spring and cooling in autumn show opposite tendencies. The positive slope of warming rate is driven by the temperature values at initiation and the corresponding times at initiation and maximum temperatures. According with our results, Greenan *et al.* (2018) report a fast rate of warming; and Han *et al.* (2019) show ocean surface warming over the past several years at Station 27 (Newfoundland Shelf) at a rate of 0.13°C per decade since 1950. In Greenan *et al* (2018), the timing of autumn cooling rate was later in the year, like our results showing a pattern toward slower cooling rates in this season (negative slopes) controlled by temperature values at the maximum and end of the cycle, as well during the time at maximum. In comparison to the results presented in our study are the SST anomalies between 1986 and 2018, computed by the AZMP in the NAFO division 3, using a mean from 1998-2010 to derive the surface water anomalies (DFO 2018). The yearly anomalies of this monitoring study show lower than average SST between 1986 and 1997, warmer than average annual values from 1998 until 2014, and very little change between 2015 and 2018 compared to the long-term mean.

4.2.2 CHL indices

The approach used in the present study to derive chlorophyll_a phenological metrics do not rely on any external signals; they are based uniquely on satellite-derived data. They represent objective indicators of these oceanographic events because of their relationship to measured variations in the surface waters. The initiation time of the chlorophyll_a bloom (CHLINIDOFY) in the southern region is related to the capelin age-2 body condition during both seasons (spring and autumn). This timing shows a small positive slope, implying a later onset of the phytoplankton cycle during both seasons. There are also positive slopes of the maximum concentration of pigment (CHLMAXMAG) during both studied blooms and regions. However, the autumn shows relatively smaller slopes than spring, in both regions. The maximum concentration of pigments in spring influences capelin's body condition in the north but *Calanus* copepodites abundances in the southern sector. The time when maximum pigment concentration occurs (CHLMAXDOY) in the northern area during spring shows a negative slope indicating a clear tendency to early arrival of the pigment maximum. Opposite to this pattern, the autumn showed a small positive slope. This phenological metric is related to *Calanus* PDIs in the northern region during both seasons. By the time of writing this report and among the three phenological indices used in the present study area, only the spring bloom's onset (CHLINIDOFY) is routinely evaluated by DFO (2018), and practically coincides with the data set used in this study; however, CHLMAXMAG and CHLMAXDOY are not available. In addition, analogous parameters of the spring bloom assessed in the present study (*bloom initiation* – CHLINIDOFY, and *bloom amplitude* –CHLMAXMAG) are measured southwestern of our study area (Johnson *et al.*, 2018). The temporal evolution of anomalies for these indicators in the

closest subregions (Cabot Strait and Eastern Scotian Shelf) are comparable to the Southern region of the present study; the autumn bloom is not reported for these areas.

4.3 STATISTICAL RELATIONSHIPS

4.3.1 *Calanus finmarchicus* PDI

The SST's rate of warming during Spring is identified as an important driver of abundance of *C. finmarchicus* in both regions, and the SST cooling rate is less influential. The maximum concentration of Chlorophyll_a also appears to be a key component of the process. In the northern region, the time of its arrival is likely important while in the Southern region the amount of pigment is more important. The relationship between *Calanus* PDI and warming thermal rate in the northern region seems to be monotonic (positive slope) during the Spring. In agreement with this result, rearing specimens in the laboratory has shown that the development time of *C. finmarchicus* copepodites decreases with increasing temperature (4, 8 and 12°C) (Campbell *et al.* (2001)). In addition, increasing temperatures (0 to 13°C) have been associated with shorter times for *Calanus*'s body size development (Wilson *et al.*, (2016)). More explicitly for the study area of the present work, observations of abundant phytoplankton, particularly diatoms in the early spring have been associated with the change from cold-winter to warming-spring water (Pepin *et al.*, 2011). In addition, Pepin *et al.* (2011) also found that large cell phytoplankton promote the growth of larger sized *C. finmarchicus* in spring.

Calanus PDI variations during the Spring in the North region are also related to the timing of the maximum concentration of phytoplankton. This GAM component has a greater influence on the final model. Early arrival of the maximum concentration of phytoplankton coincided with low abundance of *Calanus*'s copepodites. These results are similar to the findings that later developing blooms tended to have higher chlorophyll concentrations in this region (Friedland *et al* (2016)). Northerly to the present study, in the Labrador Sea, the abundance of *C. finmarchicus* young copepodite stages (CI-III) is high in the late/post-bloom area (Head *et al*, 2000). In the Gulf of Maine, there was a positive association between delayed spring bloom timing and late spring *C. finmarchicus* (Record *et al.* 2019). If delayed timing of the maximum bloom concentration leads to a longer bloom period, then emergent copepods from diapause could have an extended period for reproduction, and the first generation cohort would be more abundant than in usual years. It is likely that higher water temperatures promote a match between spring bloom and the recruiting cohort by reducing the delay between *Calanus* peak spawning and peak of young copepodites because of higher developmental rates (Basedow *et al.* 2006).

During Autumn, the rate of water cooling at the surface shows a non-linear (dome-shaped) relationship with the *Calanus* copepodites abundance, with an initial positive slope. A similar dome-shaped has been reported in the Northwest Atlantic, with positive pattern of influence on the first part of the curve when related the integrated temperature from zero to 50m depth and *C. finmarchicus* copepodites I to IV (Albouy-Boyer *et al* (2016)). This pattern seems to be associated with the seasonal vertical migration of *Calanus*, and the seasonal water currents for the Northern part of the Atlantic Ocean (Kashkin 1982). On the Newfoundland Shelf during autumn, it has been found that *C. finmarchicus*'s abundance is lower and the body size is not as large as in spring, which could be a consequence of different feeding and thermal histories of individual copepods (Pepin *et al.*, 2011). The other component of GAMs during Autumn in both regions, the maximum concentration of phytoplankton pigment, showed a larger impact than the water cooling rate on the zooplankton abundance. In Georges Bank (Gulf of Maine), inconsistent responses of zooplankton abundance to the magnitude of fall phytoplankton blooms have been found, however Friedland *et al*, (2008) suggest that the phytoplankton

autumn bloom has an important role of improving the adults haddock (*Melanogrammus aeglefinus*) body condition. This improved haddock condition resulted in larger quantity and quality of descendants that also showed better chances of survival.

4.3.2 Capelin somatic condition

Our findings on the consequences of combining the maximum pigment concentrations during phytoplankton blooms (CHLMAXMAG) and zooplankton abundance (CALFINPDI) as forcing on capelin's body condition are consistent with previous reports. For example, the impact of capelin grazing on zooplankton, with *C. finmarchicus* as the dominant species in the Barents Sea has been described by Hassel *et al.* (1991). The same species has been found to be the main food for the whole population of capelin, especially for immature fish during the spring season on the Grand Banks of Newfoundland (Gerasimova, 1994). Reports on copepods, most commonly *Calanus*, as a dominant prey for capelin on the Grand Banks of Newfoundland, with seasonal and temporal variations, were published by O'Driscoll *et al.* (2001). They described a positive relationship between the copepod length and capelin length, with small copepods in capelin stomachs between winter and spring due to their diet transition from large overwintering *Calanus spp.* (copepodite V-VI) to smaller, earlier developmental stages (copepodite I-V) of the next *Calanus* generation. Gjøsæter, *et al.* (2002) highlighted the different impacts of small and large zooplankton on the growth of small and large capelin, respectively, as we found in the present study between capelin age-2 and *Calanus* copepodites I-III. More recently, an efficient and short food chain (phytoplankton via *Calanus* or herbivorous krill to capelin) has been described in the NW Atlantic off the Newfoundland region, identifying capelin as the main prey of copepodite stages IV-VI of *C. finmarchicus* in the spring (May) (Dalpadado and Mowbray, 2013).

The capelin's body condition in the southern study region shows functional links with *Calanus* copepodites I-III (CALFINPDI), as in the northern region; nevertheless the initiation of the phytoplankton bloom (CHLINIDOY) has an impact on the capelin's physiology, as seen in the GAM equations. This second component, CHLINIDOY, is valid in both spring and autumn seasons, when it seems critical for the regional ecology. The abundance of *C. finmarchicus* copepodite VI and adults, as capelin's food availability in the late autumn and early spring, has been linked to the timing of initiation of the phytoplankton spring bloom (Buren *et al.*, 2014). Our study does not refer to older copepodites or adult *Calanus*, but to the first stages (copepodites I to III), that can be considered an index of copepods abundance and potentially more sensitive to the phytoplankton phenology.

4.3.3 Capelin abundance

We found evidences of capelin's sensitivity to thermal changes in the southern region, as their abundance increases when there is a rapid surface water rate of warming in the spring. This fast rate of warming also corresponded with an increased abundance of early stages of *Calanus* copepodites in the same season and region. There is limited literature addressing the seasonal rate of warming for the study area, however capelin's quick reactions to environmental changes have been noticed (Jaákupsstovu and Reinert (2002), furthermore it has also been proposed that the species is an early warning sea "canary" or "messenger of harsh times" for changes that may also affect other species and the ecosystem (Rose (2005). Capelin's displacement to southern areas adjacent to warmer waters where food may have been more available was reported by Frank *et al.* (1996), and Rose (2005). This thermal factor has also been stated as a climatic condition that influences capelin's population structure, feeding, and biological condition by impacting their distribution and that of their main zooplankton prey (Orlova *et al.*, 2010).

The importance of *Calanus* copepodites on capelin's ecology was identified in the present study. Previous work also recognised that food (zooplankton) distribution and density had as much impact as temperature on capelin habitat selection (Rose, 2005). In addition to other forcing variables such as warm temperate conditions and timing of the initiation of the phytoplankton spring bloom, the abundance of *Calanus* (CI-IV) has been reported as a critical component to capelin year-class strength in the Newfoundland Shelf (Mullowney *et al.* (2016), but more recently *Pseudocalanus* sp. was identified as capelin's main larval prey species (Murphy *et al.* 2018).

Overall, the inter-annual variabilities of capelin at age-2 are largely explained using the GAM models produced in the present study. In the northern region, the capelin's body condition was reproduced within one standard error in eighty percent of years during both seasons: spring and autumn. Regarding the southern region, the models replicated ninety percent of the measured data within one standard error during spring and eighty percent in autumn seasons. The modeled results for capelin body condition outside the variance range are relatively close except for the spring of 2005 in the north and 2006 in south. The capelin abundance are within one standard error for sixty percent of the model data, and most of the values outside the range are very close to the limits except for 2014.

In conclusion, evidences provided in the literature mentioned above confirm the explanatory power of the forcing variables used in the GAMs (CHLMAXMAG, CHLINIDY, and CALFINPDI) when used to investigate inter-annual variation of the body condition in capelin age-2 in the northern and southern region and spring and autumn, and WARMRATE and CALFINPDI to investigate capelin age-2 abundance during spring in the southern region. These outcomes seem to hold for both analyzed regions and seasons in the present study.

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REFERENCES CITED

- Afanasyev, Y.D., Nezlin, N.P., Kostianoy, A.G. 2001. Patterns of seasonal dynamics of remotely sensed chlorophyll and physical environment in the Newfoundland region. *Remote Sensing of Environment*. 76:268-282.
- Albouy-Boyer, S., Plourde, S., Pepin, P., Johnson, C.L., Lehoux, C., Galbraith, P.S., Hebert, D., Lazin, G., Lafleur, C. 2016. Habitat modelling of key copepod species in the Northwest Atlantic Ocean based on the Atlantic Zone Monitoring Program. *Journal of Plankton Research*, 38 (3): 589–603.
- Basedow, S.L., Edvarsen, A., and Tande, K.S. 2006. Spatial patterns of surface blooms and recruitment dynamics of *Calanus finmarchicus* in the NE Norwegian Sea. *Journal of Plankton Research*, 28(12): 1181–1190.
- Behrenfeld, M.J. and Boss, E.S. 2014. Resurrecting the Ecological Underpinnings of Ocean Plankton Blooms. *Annu. Rev. Marine Sci.*, 6:167-194.
- Bopp, L., Aumont, O., Cadule, P., Alvain, S., & Gehlen, M. (2005). Response of diatoms distribution to global warming and potential implications: A global model study. *Geophysical Research Letters*, 32.
- Brodie, W. and Stansbury. D. 2007. A Brief Description of Canadian Multispecies Surveys in SA2+ Divisions 3KLMNO from 1995-2006. *NAFO SCR Doc. 07/ 18*.
- Buren, A.D., Koen-Alonso, M., Pepin, P., Mowbray, F., Nakashima, B., Stenson, G., Ollerhead, N., Montevercchi, W.A. 2014. Bottom-up regulation of capelin, a keystone forage species. *PLoS ONE* 9(2):e87589. doi:10.1371/journal.pone.0087589.
- Buren, A.D., Murphy, H.M., Adamack, A.T., Davoren, G. K., Koen-Alonso, M., Montevercchi W. A., Mowbray, F. K., Pepin, P., Regular, P. M., Robert, D., Rose, G. A., Stenson, G., Varkey, D. 2019. The collapse and continued low productivity of a keystone forage species. *Marine Ecology Progress Series*, Vol. 616: 155-170.
- Campbell, R.G., Wagner, M.M., Teegarden, G.J., Boudreau, C.A., Durbin. E.G. 2001. Growth and development rates of the copepod *Calanus finmarchicus* reared in the laboratory. *Mar Ecol Prog Ser.*, Vol. 221: 161–183.
- Carruthers, E., and Mowbray, F. 2014. Capelin (*Mallotus villosus*) fall feeding: an energetic bottleneck limiting the recovery of Newfoundland stocks? *144th Annual Meeting of the American Fisheries Society*, Québec City, 17 to 21 August 2014.
- Carscadden, J.E., Frank, K.T., Leggett, W.C. 2001. Ecosystem changes and the effects on capelin (*Mallotus villosus*), a major forage species. *Canadian Journal of Fisheries and Aquatic Sciences*; 58: 73-85.
- Clay, S., Peña, A., DeTracey, B. and Devred, E. 2019. Evaluation of satellite-based algorithms to retrieve chlorophyll-a concentration in the Canadian Atlantic and Pacific Oceans. *Remote Sensing*.
- Coté, D., Heggland, K., Roul, S., Robertson, G., Fifield, D., Wareham, V., Colbourne, E., Maillet, G., Devine, B., Pilgrim, L., Pretty, C., Le Corre, N., Lawson, J.W., Fuentes-Yaco, C. and Mercier, A. 2019. Overview of the biophysical and ecological components of the Labrador Sea Frontier Area. *DFO Can. Sci. Advis. Sec. Res. Doc.* 2018/067. v + 59 p.
- Dalpadado,P., and Mowbray, F. 2013. Comparative analysis of feeding ecology of capelin from two shelf ecosystems, off Newfoundland and in the Barents Sea. *Progress in Oceanography*. 114: 97–105.

-
- Dalpadado P, Arrigo KR, Hjøllo SS, Rey F, Ingvaldsen RB, et al. 2014. Productivity in the Barents Sea - Response to Recent Climate Variability. *PLoS ONE* 9(5): e95273. doi:10.1371/journal.pone.0095273.
- DFO. 2015. Assessment of Capelin in Subarea 2 and Divisions 3KL in 2015. *DFO Can. Sci. Advis. Sec. Sci. Advis. Rep.* 2015/036.
- DFO. 2016. Oceanographic conditions in the Atlantic zone in 2015. *DFO Can. Sci. Advis. Sec. Sci. Advis. Rep.* 2016/041. DFO.
- DFO. 2018. Oceanographic Conditions in the Atlantic Zone in 2017. *DFO Can. Sci. Advis. Sec. Sci. Advis. Rep.* 2018/039.
- Fiedler, E.K., McLaren, A., Banzon, V., Brasnett, B., Ishizaki, S., Kennedy, J., Rayner, N., Roberts-Jones, J., Corlett, G., Merchant, C.J., Donlon, C. 2019. Intercomparison of long-term sea surface temperature analyses using the GHRSST Multi-Product Ensemble (GMPE) system. *Remote Sensing of Environment*, 222, 18-33.
- Frank, K.T., Simon, J., and Carscadden, J. E. 1996. Recent excursions of capelin (*Mallotus villosus*) to the Scotian Shelf and Flemish Cap during anomalous hydrographic conditions. *Can. J. Fish. Aquat. Sci.* 53: 1473-1486.
- Friedland, K., J.A. Hare, G. Wood, L. Col, L. Buckley, D. Mountain, J. Kane, J. Brodziak, R.G. Lough, and C.H. Pilskaln. 2008. Does the fall phytoplankton bloom control recruitment of Georges Bank haddock, *Melanogrammus aeglefinus*, through parental condition? *Canadian Journal of Fisheries and Aquatic Sciences* 65(6): 1076–1086.
- Friedland, K.D., Record, N.R., Asch, R.G., Kristiansen, T., Saba, V.S., Drinkwater, K.F., Henson, S., Leaf, R.T., Morse, R.E., Johns, D.G., Large, S.I., Hjøllo, S.S., Nye, J.A., Alexander, M.A., Ji, R. 2016. Seasonal phytoplankton blooms in the North Atlantic linked to the overwintering strategies of copepods. *Elementa: Science of the Anthropocene*, 4: 000099 • doi: 10.12952/journal.elementa.000099. Special Feature Climate change impacts: Fish, fisheries and fisheries management.
- Fuentes-Yaco, C., Koeller, P.A., Sathyendranath, S., & Platt, T. 2007. Shrimp (*Pandalus borealis*) growth and timing of the spring phytoplankton bloom on the Newfoundland–Labrador Shelf. *Fisheries Oceanography*, 16, 116-129.
- Fuentes-Yaco, C., A. Hanke, C. Caverhill, G. White and W. Li. 2013. Phytoplankton blooms in the Gulf of St. Lawrence: a remote sensing approach. *Atlantic Canada Coastal and Estuarine Science Society (ACCESS) Conference*, Lawrencetown, Nova Scotia, Canada, May 9th to 11th.
- Fuentes-Yaco, C., King, M., and Li, W.K.W. 2015. Mapping areas of high phytoplankton biomass in the offshore component of the Scotian Shelf Bioregion: A remotely-sensed approach. *DFO Can. Sci. Advis. Sec. Res. Doc.* 2015/036. iv + 40 p.
- Fuentes-Yaco, C., Craig, S., Caverhill, C., Head, E., and Li, W.K.W. 2016. Remote-sensing indices of trophic availability (RITA) for ecosystem status. *Can. Tech. Rep. Fish. Aquat. Sci.* 3166 : xiii + 87 p.
- Gerasimova, O.V. 1994. Peculiarities of spring feeding by capelin (*Mallotus villosus*) on the Grand Bank in 1987–90. *J. Northw. Atl. Fish. Sci.*, Vol. 17: 59–67.
- Gjøsæter, H., Dalpadado, P., and Hassel, A. 2002. Growth of Barents Sea capelin (*Mallotus villosus*) in relation to zooplankton abundance. – *ICES Journal of Marine Science*, 59: 959–967.
- Gomez, C, Lawson, J., Kouwenberg, AL., Moors-Murphy, H., Buren, A., Fuentes-Yaco, C., Marotte, E., Wiersma, Y. and Wimmer, T. 2017. Predicted distribution of whales at risk: identifying priority areas to enhance cetacean monitoring in the Northwest Atlantic

- Ocean. *Endangered Species Research*. Vol. 32: 437–458, 2017.
<https://doi.org/10.3354/esr00823>.
- Greenan, B.J.W., James, T.S., Loder, J.W., Pepin, P., Azetsu-Scott, K., Ianson, D., Hamme, R.C., Gilbert, D., Tremblay, J-E., Wang, X.L. and Perrie, W. (2018): Changes in oceans surrounding Canada; Chapter 7 in (eds.) Bush and Lemmen, *Canada's Changing Climate Report*, Government of Canada, Ottawa, Ontario, p. 343–423.
- Han, G., Ma, Z., Long, Z., Perrie, W., and Chassé, J. 2019. Climate Change on Newfoundland and Labrador Shelves: Results From a Regional Downscaled Ocean and Sea-Ice Model Under an A1B Forcing Scenario 2011–2069, *Atmosphere-Ocean*, 57:1, 3-17.
- Hassel, A., Skjoldal. H.R., Gjosreter. H., Loeng. H. and Omli. L. 1991: Impact of grazing from capelin (*Mallotus villosus*) on zooplankton: a case study in the northern Barents Sea in August 1985. Pp. 371-388 in Sakshaug. E.. Hopkins. C. C. E. & Ørnteland. N. A. (eds.): *Proceedings of the Pro Marc Symposium on Polar Marine Ecology*. Trondheim. 12-16 May 1990. Polar Research 10(2).
- Hastie, T. and Tibshirani, R. 1986. Generalized Additive Models, *Statistical Science*, Vol. 1, No 3, 297-318.
- Head, E.J.H., Harris, L.R., Campbell, R.W. 2000. Investigations on the ecology of *Calanus spp.* in the Labrador Sea. I. Relationship between the phytoplankton bloom and reproduction and development of *Calanus finmarchicus* in spring. *Mar Ecol Prog Ser*, 193: 53-73.
- Hoegh-Guldberg, O., & Bruno, J.F. 2010. The Impact of Climate Change on the World's Marine Ecosystems. *Science*, 328, 1523-1528.
- Jákupsstovu, S. H., and Reinert, J. 2002. Capelin in Faroese waters e a messenger of harsh times? *ICES Journal of Marine Science*, 59: 884-889.
- Johnson, C., Devred, E., Casault, B., Head, E., and Spry, J. 2018. Optical, Chemical, and Biological Oceanographic Conditions on the Scotian Shelf and in the Eastern Gulf of Maine in 2016. *DFO Can. Sci. Advis. Sec. Res. Doc.* 2018/017. v + 58 p.
- Koeller, P., Fuentes-Yaco, C., Platt, T., Sathyendranath, S., Richards, A., Ouellet, P., Orr, D., Skúladóttir, U., Wieland, K., Savard, L., & Aschan, M. 2009. Basin-Scale Coherence in Phenology of Shrimps and Phytoplankton in the North Atlantic Ocean. *Science*, 324, 791-793.
- Kuhn, A.M., Fennel, K., Mattern, J.P. 2015. Model investigations of the North Atlantic spring bloom initiation. *Progress in Oceanography*, 138:176–193.
- Lee, M.A., Chang, Y., Sakaida, F., Kawamura, H., Cheng, C.S., Chan, J.W., Huang, I. 2005. Validation of satellite-derived sea surface temperatures for waters around Taiwan. *Terrestrial, Atmospheric and Oceanic Sciences (TAO)*, 16:5, 1189-1204.
- Loder, W.J., Petrie, B., and Gawarkiewicz, G. 1998. The coastal ocean off northeastern north America: a large-scale view coastal segment (1,W). In: Robinson, A.R. and Brink, K.H. (Eds.), *The Sea*, Vol. 11, Chapter 5, p. 105-133.
- Mason, C.S., Petrie, and Topliss, BJ. 1998. Satellite measurement of Sea-Surface Temperature and the study of ocean climate. *Can. Tech. Rep. Hydrogr. Ocean Sci.* 193: vii + 101 pp.
- Marquis, E., Niquil, N., Vézina, A.F., Petitgas, P., & Dupuy, C. (2011). Influence of planktonic foodweb structure on a system's capacity to support pelagic production: an inverse analysis approach. *ICES Journal of Marine Science*, 68, 803-812.
- Martinez, E., D. Antoine, F. D'Ortenzio, and C. de Boyer Montégut. 2011. Phytoplankton spring and fall blooms in the North Atlantic in the 1980s and 2000s, *J. Geophys. Res.*, 116, C11029, doi:10.1029/2010JC006836.

- Melle, W.R., Runge, J.A., Head, E.J., Plourde, S., Castellani, C., Licandro, P., Chandler, C.L., Jónasdóttir, S.H., Johnson, C.B., Broms, C., Debes, H.H., Falkenhaug, T., Gaard, E., Gislason, A., Heath, M.R., Niehoff, B., Nielsen, T.G., Pepin, P.T., Steinevik, E.K., and Chust, G. 2014. The North Atlantic Ocean as habitat for *Calanus finmarchicus*: Environmental factors and life history traits. *Progress in Oceanography*, 129:244–284.
- Mélin, F. and Vantrepotte, V. 2015. How optically diverse is the coastal ocean? *Remote Sensing of Environment*, 160, 235–251.
- Mitchell, M.R., G. Harrison, K. Pauley, A. Gagné, G. Maillet, and P. Strain. 2002. Atlantic Zonal Monitoring Program Sampling Protocol. Can. Tech. Rep. Hydrogr. Ocean Sci. 223: iv + 23 pp.
- Morán, X.A.G., López-Urrutia, Á., Calvo-Díaz, A., & Li, W.K.W. 2010. Increasing importance of small phytoplankton in a warmer ocean. *Global Change Biology*, 16, 1137-1144
- Mowbray, F.K. 2014. Recent spring offshore acoustic survey results for capelin, *Mallotus villosus*, in NAFO Division 3L. DFO Can. Sci. Advis. Sec. Res. Doc. 2013/040. v + 25 p.
- Moors-Murphy, H.B., Lawson, J.W., Rubin, B., Marotte, E., Renaud, G., and Fuentes-Yaco, C. 2019. Occurrence of Blue Whales (*Balaenoptera musculus*) off Nova Scotia, Newfoundland, and Labrador. DFO Can. Sci. Advis. Sec. Res. Doc. 2018/007. iv + 55 p.
- Mullowney, D., Maillet, G., Dawe, E., Rose, G., Rowe, S. 2016. Spawning delays of northern capelin (*Mallotus villosus*) and recovery dynamics: a mismatch with ice-mediated spring bloom? *Progress in Oceanography* 141:144-152.
- Murphy, H., Pepin, P. and Robert D. 2018. Re-visiting the drivers of capelin recruitment in Newfoundland since 1991. *Fisheries Research* 200:1-10.
- O'Driscoll R.L., Parsons M.J.D., Rose G.A. 2001. Feeding of capelin (*Mallotus villosus*) in Newfoundland waters. *Sarsia* 86:165-176.
- Orlova, E.L., Rudneva, G.B., Renaud, P.E. 2010. Climate impacts on feeding and condition of capelin *Mallotus villosus* in the Barents Sea: evidence and mechanisms from a 30 year data set. *Aquat Biol.*, 10: 105–118.
- Pepin, P., Parrish, C.C., Head, E.J.H. 2011. Late autumn condition of *Calanus finmarchicus* in the northwestern Atlantic: evidence of size-dependent differential feeding. *Mar Ecol Prog Ser.*, 423: 155–166.
- Pepin, P., Maillet, G., Fraser, S., Doyle, G., Robar, A., Shears, T., and Redmond, G. 2017 Optical, chemical, and biological oceanographic conditions on the Newfoundland and Labrador Shelf during 2014-2015. *DFO Can. Sci. Advis. Sec. Res. Doc.* 2017/009. v + 37 p.
- Platt, T., Fuentes-Yaco, C., & Frank, K.T. 2003. Marine ecology: Spring algal bloom and larval fish survival. *Nature*, 423:398-99.
- Platt, T., S. Sathyendranath, G. White, C. Fuentes-Yaco, L. Zhai, and E. Devred. 2010. Diagnostic properties of phytoplankton time series from remote sensing. *Estuaries and Coasts*. 33:428–439.
- Plourde, S., Grégoire, F., Lehoux, C., Galbraith, P.S., Castonguay, M., and Ringuette, M. 2015. Effect of environmental variability on body condition and recruitment success of Atlantic Mackerel (*Scomber scombrus* L.) in the Gulf of St. Lawrence. *Fish. Oceanogr.* 24(4): 347–363. doi:10.1111/fog.12113.
- Record NR, Balch WM, Stamieszkin K. 2019. Century-scale changes in phytoplankton phenology in the Gulf of Maine. PeerJ 7:e6735 <http://doi.org/10.7717/peerj.6735>.

-
- Richaud, B., Kwon, Y-O, Joyce, T.M., Fratantoni, P.S., Lentz, S.J. 2016. Surface and bottom temperature and salinity climatology along the continental shelf off the Canadian and U.S. East Coasts. *Continental Shelf Research*, 124:165–181.
- Rose, G. A. 2005. Capelin (*Mallotus villosus*) distribution and climate: a sea “canary” for marine ecosystem change. *ICES Journal of Marine Science*, 62:1524-1530.
- Runge, J.A. 1988. Should we expect a relationship between primary production and fisheries? The role of copepod dynamics as a filter of trophic variability. *Hydrobiologia*, 167/168: 61–71.
- Semenova, T. N. 1969. On the seasonal phenomena in plankton on the Labrador Shelf, Newfoundland Bank, and Flemish Cap Bank. (*O sezonnnykh yavleniyakh v planktone labradorskogo shélf'a, bol'shoi N'yufaundlendskoi banki i banki Flemish-Kap.*) In: Studies of the Polar Research and Program Institute for sea fishing economy and oceanography, named after N.M. Knipovich (PINRO) (*Trudy polyarnogo Nauchno-Issledovatel's kogo i Proektnogo Instituta Morskogo Rybnogo Khozyaistva i Okeanografi, imoni. N. M. Knipovich (PINRO)*). Researchs in commercial oceanography (*Issledovaniya po promyslovoi okeanografii*), 16: 49-77, 1964.) *Fisheries Research, Board of Canada, Translation Series No. 1315*, 70 p.
- Shikon, V., Pepin, P., Schneider, D.C., Castonguay, M., and Robert, D. 2019. Spatiotemporal variability in Newfoundland capelin (*Mallotus villosus*) larval abundance and growth: Implications for recruitment. *Fisheries Research* 218: 237–245. doi:10.1016/j.fishres.2019.04.015.
- TIBCO Spotfire S+® 8.2 Guide to Statistics Volume 2 TIBCO Software Inc.
- Vladimirskaya, E.V. 1965. Quantitative Distribution and the Seasonal Dynamics of Zooplankton in the Newfoundland Area. *International Commission for the Northwest Atlantic Fisheries Research Bulletin*, 2:53-58.
- Wihs Gott, J.U., Sharples, J., Hopkins, J.E., Woodward, E.M.S., Hull, T., Greenwood, N., Sivyer, D.B. 2019. Observations of vertical mixing in autumn and its effect on the autumn phytoplankton bloom. *Progress in Oceanography*, <https://doi.org/10.1016/j.pocean.2019.01.001>
- Wilson, R.J., Heath, M.R., and Speirs, D.C. 2016 Spatial modeling of *Calanus finmarchicus* and *Calanus helgolandicus*: Parameter differences explain differences in biogeography. *Front. Mar. Sci.* 3:157. doi: 10.3389/fmars.2016.00157.
- Winder, M. and Cloern, J.E. 2010. The annual cycles of phytoplankton biomass. *Phil. Trans. R. Soc. B*. 365:3215–3226.
- Zhao, H., Han, G. and Wang, D. 2013. Timing and magnitude of spring bloom and effects of physical environments over the Grand Banks of Newfoundland, *J. Geophys. Res. Biogeosci.*, 118:1385–1396.

TABLES

Table 1. Weekly SST (°C), averages and standard deviations from AVHRR data, between days of year (DoY) 57 and 437, and years 1998 to 2016, in the Northern region.

DoY	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Average	Stdev
57	-1.35	-0.71	-1.36	0.22	-1.14	-1.55	-0.80	-0.69	-0.67	-1.04	-1.56	-1.45	-1.44	-0.29	-1.09	-1.42	-1.36	-1.65	-1.50	-1.10	0.50
64	-1.30	-1.26	-1.46	-1.38	-1.19	-0.36	-0.54	-1.26	-1.09	-1.05	-1.53	-1.46	0.14	-0.21	-1.25	-0.72	-0.95	-1.53	-1.47	-1.05	0.49
72	-1.24	-1.44	-1.31	-1.41	-1.55	-0.31	-0.57	-1.19	-1.23	-1.55	-0.96	-1.49	-0.79	-0.60	-0.49	-1.53	-1.50	-1.47	-1.51	-1.16	0.41
80	-1.45	-1.02	-1.55	-1.30	-0.64	-1.21	-0.52	-1.07	-0.88	-1.04	-1.53	-0.89	-0.73	-0.42	-0.94	-0.96	-1.43	-1.31	-1.55	-1.08	0.35
87	-1.11	-1.16	-1.14	-1.32	-1.38	-1.08	-0.66	-0.97	-0.71	-0.66	-1.32	-1.28	-1.08	-0.57	-1.27	-1.06	-1.59	-1.55	-1.61	-1.13	0.31
95	-1.51	-0.71	-1.24	-1.26	-1.07	-1.48	-0.70	-0.89	-0.50	0.02	-0.71	-1.27	-0.58	-0.90	-1.30	-0.34	-1.37	-1.62	-1.68	-1.01	0.47
102	-1.13	-1.14	-1.24	-1.20	-1.04	-0.79	-0.64	-0.47	-1.01	-0.40	-1.00	-0.52	-0.65	-0.64	-0.83	-1.56	-1.60	-1.19	-0.95	0.35	
110	0.17	-0.53	-0.81	-1.40	-1.28	-0.66	-0.14	-0.69	-0.36	-0.96	-0.98	-0.86	-1.05	-0.53	-0.84	-0.33	-0.99	-1.24	-1.06	-0.76	0.41
118	0.75	0.18	-0.67	-0.69	-0.76	-0.96	-0.31	0.18	0.86	-0.44	-0.90	-0.96	0.09	-0.36	-0.36	-0.22	-1.19	-1.27	-1.25	-0.44	0.63
125	0.11	0.31	-0.74	-0.31	-0.66	-0.70	0.92	1.65	1.89	0.75	0.40	-0.66	1.02	0.35	0.01	0.44	-0.67	-0.43	-0.46	0.17	0.80
133	0.92	2.34	-0.75	0.75	0.01	0.04	0.35	1.68	3.92	0.85	0.89	-0.28	0.35	0.28	1.16	0.17	-0.70	-0.28	0.19	0.63	1.11
140	0.68	2.43	1.46	0.58	0.63	0.31	1.12	1.79	3.17	0.36	0.61	0.76	1.58	1.99	1.62	1.77	0.81	0.63	0.75	1.21	0.77
148	1.81	2.69	0.98	0.88	0.35	2.11	1.50	3.94	3.29	1.48	1.93	0.93	1.39	2.09	1.82	2.56	0.78	1.58	1.98	1.79	0.89
156	4.32	3.08	2.00	3.96	3.29	1.98	2.33	5.63	5.93	1.35	3.29	2.17	2.35	2.39	2.38	2.46	1.69	2.44	1.98	2.90	1.26
163	6.08	5.20	3.34	3.81	4.43	2.64	2.81	5.52	5.63	3.95	3.51	3.93	3.06	5.09	3.88	4.31	3.39	3.79	4.33	4.14	0.98
171	6.33	5.57	5.57	6.33	4.61	4.63	3.39	5.77	6.32	5.70	8.58	4.36	3.87	4.36	5.89	4.48	4.48	3.85	3.51	5.14	1.28
178	7.92	8.07	6.43	6.87	6.62	6.02	4.77	6.53	9.26	6.27	7.61	7.93	5.04	4.79	7.90	5.75	5.65	6.03	5.20	6.56	1.27
186	8.87	8.73	8.26	7.01	6.58	7.36	8.24	7.62	9.78	8.26	8.06	7.97	6.30	6.32	11.53	6.34	7.90	8.56	7.40	7.95	1.29
194	10.19	10.46	9.50	8.58	9.33	6.97	8.96	9.43	10.38	8.22	10.95	8.31	9.19	6.42	10.20	9.23	9.64	7.79	6.65	8.97	1.31
201	10.62	10.08	10.91	8.14	9.48	10.96	10.57	11.80	13.19	9.72	12.07	8.73	8.90	7.98	10.08	8.40	11.50	8.66	9.06	10.05	1.46
209	12.40	11.58	12.98	9.27	10.22	10.19	12.88	12.44	12.55	11.11	12.93	10.08	9.87	7.85	11.15	9.37	13.76	8.38	11.03	11.06	1.69
216	13.28	13.23	13.99	10.34	10.56	10.83	13.55	12.86	12.01	11.40	13.57	11.87	11.19	10.29	12.67	10.97	14.80	10.10	11.64	12.06	1.41
224	13.75	11.79	13.26	11.51	11.65	11.65	14.44	13.07	12.53	9.70	13.46	11.80	12.29	12.07	14.07	11.15	13.17	9.44	11.76	12.24	1.34
232	12.68	11.37	14.90	11.44	12.53	11.74	13.93	13.14	13.49	9.92	13.16	11.67	13.31	11.93	14.73	11.06	14.89	11.00	12.06	12.58	1.41
239	11.68	11.69	13.74	9.84	10.83	11.88	13.00	12.77	13.35	11.10	13.43	11.30	13.35	12.76	14.80	10.10	12.71	12.31	11.80	12.23	1.28
247	11.22	11.45	9.78	10.40	9.07	11.93	10.42	12.57	12.11	10.36	14.68	9.48	12.64	12.25	12.91	9.80	12.24	9.27	8.67	11.12	1.60
254	11.25	11.04	9.90	11.19	8.66	10.56	11.00	11.77	11.43	9.12	11.51	8.28	10.94	10.16	11.05	10.05	11.75	7.02	8.89	10.29	1.33
262	9.47	9.69	10.31	9.00	7.40	11.22	9.83	10.14	10.65	8.65	10.48	7.37	6.58	8.37	10.84	8.63	10.77	8.03	7.99	9.23	1.36
270	8.92	8.51	9.33	8.38	6.85	9.81	7.62	7.12	10.27	7.09	9.04	7.07	6.07	8.25	10.85	8.29	8.20	7.87	7.43	8.26	1.24
277	7.88	8.89	8.37	7.64	4.77	9.87	7.09	7.52	9.47	6.34	9.48	7.01	6.55	6.63	10.38	7.75	7.76	6.69	6.48	7.72	1.42
285	6.80	7.23	7.22	6.26	4.58	7.98	5.82	6.63	8.44	5.15	7.65	5.20	6.10	5.27	8.67	6.69	7.42	5.76	5.31	6.54	1.19
292	6.48	3.80	3.33	6.29	3.91	7.35	6.43	6.33	7.09	3.65	6.44	3.96	5.76	5.41	5.88	5.28	5.37	4.98	5.11	5.41	1.21
300	4.94	3.40	3.42	6.04	3.76	6.70	6.05	5.38	5.06	3.80	5.54	2.41	4.63	5.72	5.87	5.00	5.27	3.17	4.32	4.76	1.17
308	4.91	2.70	3.25	4.86	2.88	2.46	3.68	3.84	4.37	3.40	4.56	2.33	3.87	3.04	4.76	3.45	4.59	2.50	3.84	3.65	0.86
315	3.25	2.00	4.83	3.73	1.60	2.42	2.65	3.27	3.77	2.27	4.08	1.61	3.66	3.46	3.44	2.83	3.63	1.99	2.96	3.02	0.88
323	2.04	1.31	1.97	2.83	1.46	2.26	2.06	3.04	3.19	2.93	3.16	1.10	3.31	2.82	3.07	2.58	2.24	1.67	3.40	2.46	0.69
330	1.57	1.43	1.25	1.95	1.69	2.10	2.39	2.45	2.52	1.79	3.40	1.10	2.16	2.36	2.31	1.72	1.66	1.61	1.40	1.94	0.55
338	1.12	3.73	1.03	1.24	0.67	1.61	2.59	2.45	1.07	1.59	2.24	0.87	1.70	2.00	1.18	1.32	0.81	0.88	1.06	1.53	0.77
346	0.56	1.04	0.81	-0.11	0.97	0.99	1.46	0.91	0.66	1.49	0.89	2.06	1.00	1.38	0.30	1.30	0.24	0.99	0.94	0.51	
353	0.14	2.61	0.93	0.36	0.04	0.87	1.07	1.33	0.79	0.31	0.36	-0.05	1.81	0.55	0.56	-0.30	0.25	0.28	0.12	0.63	0.70
361	0.16	0.60	-0.55	0.54	0.10	1.19	0.39	0.54	0.70	-0.15	-0.09	-0.02	1.22	0.24	-0.04	-0.79	-0.15	-0.05	-0.14	0.19	0.52
368	-0.60	-0.58	-1.01	0.45	-0.13	0.53	-0.64	0.60	0.02	-0.27	0.27	0.18	1.20	0.82	0.20	-1.00	-0.38	-0.64	-0.10	-0.06	0.61
376	-0.79	-0.42	-1.20	-0.29	-0.89	0.47	-0.53	0.29	-0.07	-0.47	0.00	-0.38	1.00	-0.40	-0.55	-0.93	-1.00	-0.84	-0.34	-0.39	0.55
384	-0.90	-0.35	-1.28	-0.70	-0.77	0.27	-0.35	-0.23	-0.06	-0.08	-0.70	-0.31	0.91	-0.85	-0.49	-0.83	-1.10	-0.95	-0.76	-0.50	0.52
391	-0.69	-0.98	-1.36	-1.44	-1.10	-0.12	-0.89	-0.73	-0.67	-1.10	-1.04	-1.02	0.82	-0.66	-0.98	-1.22	-1.20	-0.70	-0.84	-0.84	0.50
399	-0.44	-1.19	-1.42	-1.31	-0.89	-0.10	-0.08	-0.24	-0.98	-0.78	-0.38	-1.49	0.08	-0.98	-0.99	-1.48	-1.34	-1.19	-1.19	-0.86	0.51
406	-0.97	-1.40	-1.32	-0.65	-0.77	-0.58	0.21	-0.28	-1.39	-0.73	-1.11	-1.21	-0.56	-0.71	-1.38	-1.36	-1.52	-1.38	-1.28	-0.97	0.47
414	-1.28	-1.56	-1.33	-0.62	-1.09	-0.26	-0.82	-0.72	-1.35	-1.25	-1.46	-1.14	-0.18	-1.09	-0.93	-1.47	-1.35	-1.31	-1.50	-1.09	0.40
422	-0.71	-1.36	0.22	-1.14	-1.55	-0.80	-0.69	-0.67	-1.04	-1.56	-1.45	-1.44	-0.29	-1.09	-1.42	-1.36	-1.65	-1.50	-1.40	-1.10	0.50
429	-1.26	-1.46	-1.38	-1.19	-0.36	-0.54	-1.26	-1.09	-1.05	-1.53	-1.46	0.14	-0.21	-1.25	-0.72	-0.95	-1.53	-1.47	-1.60	-1.06	0.50
437	-1.44	-1.31	-1.41	-1.55	-0.31	-0.57	-1.19	-1.23	-1.55	-0.96	-1.49	-0.79	-0.60	-0.49	-1.53	-1.50	-1.47	-1.51	-1.25	-1.17	0.41

Table 2. Weekly SST ($^{\circ}$ C), averages and standard deviations from satellite-fitted data, between days of year (DoY) 57 and 437, and years 1998 to 2016, in the Northern region.

DoY	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Average	Stdev
57	-1.39	-1.21	-1.32	-1.42	-1.35	-1.30	-0.35	-1.18	-1.26	-0.91	-1.50	-1.45	-0.74	-0.58	-1.27	-1.04	-1.35	-1.87	-1.48	-1.21	0.35
64	-1.37	-1.18	-1.31	-1.39	-1.34	-1.28	-0.35	-1.14	-1.17	-0.91	-1.48	-1.44	-0.73	-0.57	-1.24	-1.03	-1.35	-1.84	-1.47	-1.19	0.35
72	-1.33	-1.13	-1.31	-1.35	-1.32	-1.25	-0.35	-1.07	-1.04	-0.90	-1.44	-1.42	-0.72	-0.55	-1.21	-1.01	-1.34	-1.80	-1.46	-1.16	0.34
80	-1.27	-1.06	-1.30	-1.28	-1.30	-1.21	-0.35	-0.98	-0.87	-0.89	-1.37	-1.39	-0.70	-0.52	-1.16	-0.97	-1.34	-1.73	-1.44	-1.11	0.34
87	-1.18	-0.96	-1.28	-1.19	-1.25	-1.14	-0.35	-0.84	-0.64	-0.86	-1.28	-1.35	-0.66	-0.48	-1.08	-0.91	-1.33	-1.63	-1.41	-1.04	0.34
95	-1.04	-0.81	-1.24	-1.06	-1.18	-1.05	-0.34	-0.66	-0.35	-0.82	-1.14	-1.27	-0.60	-0.41	-0.97	-0.82	-1.30	-1.50	-1.35	-0.94	0.35
102	-0.85	-0.60	-1.17	-0.87	-1.07	-0.91	-0.32	-0.41	0.01	-0.74	-0.95	-1.16	-0.52	-0.31	-0.80	-0.68	-1.26	-1.31	-1.26	-0.80	0.37
110	-0.57	-0.32	-1.06	-0.62	-0.90	-0.72	-0.28	-0.08	0.45	-0.62	-0.68	-0.99	-0.39	-0.17	-0.56	-0.49	-1.18	-1.06	-1.11	-0.60	0.41
118	-0.20	0.07	-0.88	-0.29	-0.66	-0.47	-0.21	0.33	1.00	-0.43	-0.32	-0.74	-0.20	0.04	-0.23	-0.22	-1.04	-0.73	-0.90	-0.32	0.48
125	0.30	0.56	-0.60	0.12	-0.32	-0.12	-0.09	0.86	1.64	-0.14	0.16	-0.38	0.06	0.31	0.20	0.15	-0.82	-0.30	-0.59	0.05	0.56
133	0.93	1.19	-0.19	0.65	0.15	0.32	0.13	1.50	2.38	0.28	0.77	0.10	0.42	0.67	0.77	0.62	-0.48	0.22	-0.16	0.54	0.66
140	1.72	1.96	0.39	1.28	0.76	0.87	0.47	2.26	3.23	0.86	1.53	0.72	0.89	1.13	1.48	1.23	0.03	0.86	0.42	1.16	0.76
148	2.68	2.86	1.18	2.04	1.53	1.56	1.00	3.15	4.18	1.62	2.44	1.51	1.50	1.71	2.34	1.97	0.76	1.62	1.17	1.94	0.84
156	3.79	3.90	2.20	2.90	2.47	2.37	1.76	4.16	5.21	2.57	3.51	2.47	2.26	2.42	3.37	2.85	1.74	2.49	2.09	2.87	0.90
163	5.03	5.05	3.46	3.87	3.57	3.31	2.80	5.26	6.30	3.71	4.72	3.58	3.16	3.25	4.55	3.85	2.99	3.46	3.19	3.95	0.94
171	6.37	6.28	4.95	4.91	4.79	4.36	4.14	6.44	7.42	5.00	6.05	4.83	4.22	4.20	5.85	4.93	4.51	4.50	4.43	5.17	0.94
178	7.76	7.53	6.60	6.00	6.10	5.51	5.74	7.66	8.55	6.36	7.45	6.15	5.40	5.24	7.24	6.07	6.26	5.59	5.78	6.47	0.95
186	9.12	8.76	8.34	7.09	7.41	6.71	7.54	8.86	9.64	7.70	8.88	7.49	6.68	6.35	8.66	7.20	8.14	6.69	7.15	7.81	0.97
194	10.39	9.89	10.04	8.14	8.66	7.92	9.40	10.01	10.66	8.92	10.26	8.75	8.00	7.48	10.05	8.26	10.01	7.73	8.46	9.11	1.03
201	11.48	10.85	11.56	9.10	9.76	9.08	11.14	11.05	11.56	9.89	11.53	9.86	9.30	8.58	11.32	9.17	11.72	8.69	9.61	10.28	1.12
209	12.32	11.59	12.78	9.90	10.61	10.14	12.58	11.92	12.30	10.52	12.61	10.72	10.50	9.59	12.42	9.88	13.10	9.49	10.52	11.24	1.22
216	12.84	12.05	13.56	10.52	11.15	11.04	13.52	12.58	12.86	10.74	13.44	11.27	11.54	10.45	13.25	10.32	14.00	10.10	11.10	11.91	1.29
224	13.03	12.21	13.83	10.90	11.34	11.73	13.85	12.99	13.21	10.82	13.95	11.46	12.34	11.11	13.78	10.48	14.31	10.49	11.30	12.27	1.31
232	12.35	11.95	12.75	11.03	10.63	12.16	12.46	13.13	13.32	10.57	14.13	10.86	12.84	11.52	13.96	10.88	13.21	10.62	10.51	12.05	1.21
239	12.04	11.63	12.38	10.67	10.26	12.31	12.12	11.89	12.66	10.17	12.80	10.49	13.01	11.66	13.38	10.62	12.85	9.72	10.25	11.63	1.13
247	11.53	11.11	11.78	10.41	9.69	11.96	11.58	11.54	12.32	9.64	12.45	9.90	9.64	10.07	12.99	10.20	12.29	9.41	9.84	10.96	1.16
254	10.84	10.43	10.99	9.99	8.93	11.53	10.85	10.98	11.76	8.98	11.90	9.12	9.33	9.74	12.37	9.63	11.53	8.92	9.28	10.37	1.13
262	10.02	9.60	10.04	9.42	8.04	10.85	9.98	10.24	11.02	8.24	11.16	8.21	8.83	9.22	11.55	8.95	10.62	8.27	8.61	9.62	1.10
270	9.09	8.68	8.98	8.73	7.06	9.96	9.01	9.36	10.14	7.43	10.27	7.21	8.19	8.53	10.56	8.17	9.59	7.49	7.84	8.75	1.06
277	8.09	7.69	7.86	7.95	6.04	8.92	7.97	8.38	9.14	6.59	9.27	6.17	7.43	7.71	9.46	7.31	8.48	6.63	7.02	7.79	1.01
285	7.06	6.67	6.72	7.10	5.03	7.79	6.91	7.35	8.07	5.73	8.20	5.14	6.60	6.81	8.29	6.42	7.35	5.72	6.15	6.80	0.95
292	6.02	5.66	5.60	6.22	4.07	6.63	5.87	6.30	6.98	4.89	7.10	4.16	5.74	5.86	7.10	5.52	6.22	4.80	5.28	5.79	0.88
300	5.02	4.69	4.54	5.33	3.18	5.50	4.88	5.29	5.90	4.07	6.01	3.25	4.89	4.92	5.93	4.63	5.12	3.91	4.43	4.82	0.81
308	4.08	3.78	3.56	4.47	2.40	4.45	3.95	4.33	4.86	3.31	4.96	2.45	4.09	4.01	4.83	3.78	4.10	3.06	3.62	3.90	0.73
315	3.21	2.95	2.67	3.64	1.72	3.49	3.12	3.46	3.89	2.61	3.98	1.76	3.35	3.17	3.80	2.98	3.16	2.29	2.86	3.06	0.64
323	2.42	2.22	1.90	2.87	1.15	2.66	2.39	2.69	3.01	1.98	3.09	1.18	2.70	2.41	2.88	2.24	2.32	1.61	2.17	2.31	0.56
330	1.74	1.57	1.24	2.17	0.68	1.96	1.75	2.02	2.22	1.42	2.29	0.70	2.14	1.75	2.07	1.58	1.58	1.01	1.55	1.66	0.48
338	1.14	1.03	0.69	1.54	0.32	1.39	1.22	1.46	1.54	0.94	1.60	0.33	1.68	1.19	1.39	0.99	0.95	0.51	1.01	1.10	0.42
346	0.64	0.58	0.24	1.00	0.03	0.94	0.79	0.99	0.97	0.52	1.01	0.04	1.30	0.72	0.81	0.48	0.42	0.10	0.54	0.64	0.36
353	0.23	0.21	-0.12	0.53	-0.18	0.59	0.44	0.62	0.49	0.18	0.52	-0.18	1.01	0.35	0.34	0.05	-0.01	-0.24	0.15	0.26	0.33
361	-0.11	-0.09	-0.40	0.14	-0.34	0.33	0.16	0.33	0.10	-0.10	0.12	-0.34	0.78	0.05	-0.03	-0.31	-0.36	-0.50	-0.17	-0.04	0.32
368	-0.37	-0.32	-0.61	-0.19	-0.45	0.14	-0.05	0.11	-0.21	-0.33	-0.20	-0.46	0.62	-0.17	-0.33	-0.61	-0.63	-0.70	-0.43	-0.27	0.32
376	-0.58	-0.50	-0.77	-0.45	-0.53	0.01	-0.22	-0.06	-0.45	-0.51	-0.45	-0.54	0.49	-0.34	-0.55	-0.85	-0.85	-0.85	-0.65	-0.46	0.33
384	-0.74	-0.63	-0.89	-0.66	-0.58	-0.08	-0.33	-0.18	-0.64	-0.66	-0.65	-0.59	0.41	-0.47	-0.72	-1.04	-1.01	-0.96	-0.81	-0.59	0.35
391	-0.86	-0.73	-0.97	-0.82	-0.62	-0.14	-0.42	-0.27	-0.77	-0.77	-0.79	-0.63	0.35	-0.56	-0.84	-1.19	-1.13	-1.04	-0.94	-0.69	0.37
399	-0.95	-0.80	-1.03	-0.95	-0.64	-0.18	-0.48	-0.33	-0.88	-0.85	-0.90	-0.65	0.31	-0.62	-0.93	-1.31	-1.22	-1.10	-1.03	-0.77	0.39
406	-1.01	-0.86	-1.07	-1.04	-0.66	-0.21	-0.53	-0.38	-0.95	-0.91	-0.98	-0.67	0.28	-0.66	-0.99	-1.39	-1.28	-1.14	-1.11	-0.82	0.40
414	-1.06	-0.89	-1.10	-1.11	-0.67	-0.23	-0.56	-0.40	-1.00	-0.96	-1.03	-0.68	0.27	-0.69	-1.03	-1.46	-1.33	-1.16	-1.16	-0.86	0.41
422	-1.09	-0.92	-1.12	-1.16	-0.67	-0.23	-0.58	-0.42	-1.04	-0.99	-1.07	-0.68	0.25	-0.71	-1.06	-1.51	-1.36	-1.18	-1.20	-0.88	0.42
429	-1.11	-0.93	-1.13	-1.20	-0.68	-0.24	-0.60	-0.44	-1.08	-1.03	-1.12	-0.69	0.24	-0.72	-1.10	-1.57	-1.39	-1.20	-1.24	-0.91	0.44
437	-1.13	-0.94	-1.14	-1.23	-0.68	-0.24	-0.60	-0.44	-1.08	-1.03	-1.12	-0.69	0.24	-0.72	-1.10	-1.57	-1.39	-1.20	-1.24	-0.91	0.44

Table 3. Weekly SST (°C), averages and standard deviations from AVHRR data, between days of year (DoY) 57 and 437, and years 1998 to 2016, in the Southern region.

DoY	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Average	Stdev
57	-0.59	-0.06	1.48	-0.62	0.27	0.05	1.60	0.30	0.67	0.29	-0.35	0.45	0.07	1.34	0.66	0.07	0.33	0.44	0.21	0.35	0.61
64	0.41	0.17	0.85	-0.58	0.06	-1.06	0.16	0.80	0.96	0.46	-0.29	0.79	0.24	0.83	0.98	0.59	-0.74	0.60	0.14	0.28	0.59
72	-0.09	-0.01	1.06	-0.43	-0.16	-0.46	0.75	1.05	0.36	0.09	-0.19	0.27	0.35	0.57	0.57	0.36	-0.19	0.42	-0.05	0.22	0.45
80	-0.07	1.28	1.51	-0.13	-0.41	-0.98	0.46	0.41	0.95	0.52	0.41	0.71	0.57	0.68	1.40	0.75	-0.19	0.52	0.32	0.46	0.62
87	0.28	1.16	0.62	0.49	0.24	-0.61	0.83	0.86	0.75	0.39	1.01	0.81	0.00	0.96	0.45	0.45	-0.20	0.47	0.34	0.49	0.44
95	0.15	1.60	1.86	-0.54	0.62	-0.64	1.09	0.81	1.05	0.08	0.25	0.82	0.53	1.20	0.48	0.79	0.07	0.62	0.16	0.58	0.64
102	0.89	1.15	1.66	-0.14	0.49	0.77		1.59	1.66	0.48	1.07	1.20	1.42	1.45	1.71	0.49	-0.07	0.69	0.80	0.96	0.57
110	1.48	3.51	1.51	-0.20	0.89	0.36	2.09	1.46	2.48	0.52	1.12	2.00	1.62	1.57	3.05	1.42	0.55	0.79	0.56	1.41	0.94
118	2.76	2.64	2.15	0.25	0.79	0.22	1.98	2.44	2.95	1.03	3.45	2.20	2.16	1.83	3.98	1.60	0.67	1.09	1.27	1.87	1.05
125	2.92	3.30	3.06	0.75	1.37	1.57	2.97	3.81	4.43	2.03	1.55	2.03	2.60	2.72	3.33	2.67	0.94	2.12	1.35	2.40	1.00
133	4.25	4.85	2.93	2.12	1.73	1.36	2.68	4.03	5.40	2.15	2.41	3.20	2.93	3.56	4.65	2.82	1.72	2.18	2.66	3.03	1.14
140	5.43	6.05	4.89	2.86	2.56	2.64	3.24	3.45	5.23	3.50	3.33	4.24	3.68	4.07	5.57	5.33	2.78	4.08	3.48	4.02	1.09
148	5.38	7.67	6.39	3.86	2.55	3.81	3.89	4.53	6.57	3.49	4.28	4.81	4.38	5.57	5.48	5.82	3.90	3.38	3.64	4.70	1.30
156	7.16	9.16	5.68	4.22	4.49	4.28	4.74	6.69	7.55	4.48	5.59	6.03	5.14	6.13	7.75	6.40	5.13	4.25	5.32	5.80	1.38
163	10.08	8.29	6.19	6.35	5.77	4.34	5.44	6.55	7.69	6.56	6.37	6.54	4.96	7.33	7.49	7.33	6.13	6.33	6.12	6.62	1.26
171	10.03	10.89	8.51	8.04	6.35	5.77	7.29	7.28	8.43	7.42	7.74	7.99	5.32	7.62	8.78	8.44	7.19	6.73	6.58	7.71	1.35
178	10.46	11.49	9.31	9.24	7.08	7.27	7.89	8.31	13.17	8.81	8.48	9.62	7.18	8.17	10.55	11.24	7.87	7.85	9.88	9.15	1.66
186	11.00	12.88	13.76	10.62	13.07	9.46	9.80	9.54	12.36	9.74	10.09	12.24	9.44	10.82	13.48	11.84	10.31	8.95	10.23	11.03	1.53
194	11.90	13.49	13.49	14.47	11.39	9.17	12.14	9.94	13.55	10.72	13.69	12.47	12.38	11.04	13.65	14.89	13.04	9.60	10.73	12.20	1.67
201	13.20	14.15	14.28	12.64	12.12	14.38	13.72	14.15	15.29	13.04	15.70	14.40	12.56	13.06	14.97	13.91	13.65	10.70	12.78	13.62	1.19
209	14.77	15.66	14.71	13.96	12.39	14.97	14.80	14.73	15.44	15.41	15.65	14.77	13.20	12.56	15.63	15.66	15.82	11.10	15.79	14.58	1.35
216	16.40	17.47	15.75	15.39	13.89	14.73	16.83	15.80	16.02	14.79	16.45	17.26	15.49	12.88	17.09	16.69	18.59	12.27	15.32	15.74	1.57
224	17.41	17.28	15.18	15.66	15.67	15.38	17.47	16.19	16.86	14.99	16.57	16.31	16.34	14.67	19.17	17.04	18.79	13.95	16.21	16.38	1.33
232	17.86	18.29	17.96	17.69	17.78	16.45	16.78	16.73	17.63	15.09	12.77	16.69	15.58	14.51	18.66	16.92	17.77	15.91	15.68	16.67	1.48
239	17.22	17.67	17.31	14.98	15.75	16.36	16.61	16.76	17.15	15.80	12.57	13.79	15.82	15.28	18.68	16.94	16.55	15.70	15.97	16.15	1.39
247	14.24	16.04	15.03	15.46	15.06	16.05	15.13	16.99	15.11	15.24	15.03	13.35	16.44	16.16	16.38	16.62	15.94	15.65	13.72	15.46	0.96
254	13.84	16.10	14.63	16.30	12.87	14.19	13.67	16.63	12.62	14.80	14.00	12.83	16.12	13.29	15.79	16.76	15.79	15.04	14.00	14.70	1.36
262	12.74	15.08	14.96	12.36	13.14	14.89	13.55	13.48	12.51	14.82	13.79	12.10	12.42	12.60	15.39	16.39	14.47	13.68	13.03	13.76	1.23
270	12.53	13.42	12.94	12.35	12.98	13.25	12.09	12.05	12.87	14.02	12.67	11.25	9.67	12.70	16.10	15.00	13.39	12.86	12.69	12.89	1.33
277	12.22	12.59	12.83	12.00	10.85	14.05	10.68	12.07	12.62	13.34	13.02	11.32	10.38	12.74	15.03	12.90	11.76	11.50	11.00	12.26	1.18
285	10.13	11.69	13.02	10.79	10.04	13.22	10.49	9.80	12.26	11.40	11.26	8.26	10.06	10.79	12.63	12.13	11.93	11.47	9.89	11.12	1.27
292	9.96	8.96	9.91	11.02	8.51	12.07	11.15	9.99	11.33	10.37	9.11	5.42	9.75	9.67	11.87	10.25	10.56	11.30	9.39	10.03	1.48
300	9.86	7.50	9.30	10.07	7.00	11.16	9.98	8.34	10.28	8.93	9.39	5.10	9.03	8.56	10.29	9.52	10.61	8.58	9.31	9.10	1.42
308	9.36	6.96	10.46	9.18	5.80	8.68	6.66	7.46	9.38	8.12	9.25	5.22	8.42	6.67	11.03	7.22	9.90	7.34	8.83	8.21	1.57
315	8.97	5.14	11.22	8.43	5.28	5.74	6.00	7.06	8.86	7.02	8.12	4.36	7.94	6.45	8.82	7.68	7.92	6.15	8.27	7.34	1.68
323	6.10	6.68	6.73	6.69	4.34	5.47	5.62	6.92	7.65	7.81	7.86	4.22	7.21	5.73	7.53	6.06	7.01	5.24	10.14	6.58	1.38
330	6.40	4.57	5.68	6.23	3.71	5.14	4.95	6.32	7.88	5.44	7.22	3.42	5.25	4.64	7.29	5.26	6.35	5.07	6.94	5.67	1.20
338	4.83	4.77	3.80	5.24	3.00	5.08	4.94	6.24	5.79	4.79	6.35	3.07	5.18	4.14	5.09	5.13	5.74	4.56	5.65	4.91	0.92
346	2.19	6.22	2.74	3.77	1.76	3.87	3.03	5.27	3.95	2.99	6.48	2.45	4.83	3.06	4.54	3.03	3.90	3.30	4.43	3.78	1.28
353	2.94	3.08	3.99	1.37	3.78	2.44	4.34	3.58	2.32	4.72	1.55	4.64	2.49	2.66	2.50	4.69	2.20	2.25	3.08	1.07	
361	1.32	3.39	1.29	2.93	1.03	3.57	3.15	3.65	2.69	1.96	2.92	1.46	4.09	2.53	3.01	1.23	4.00	2.60	2.22	2.58	0.97
368	1.80	1.81	1.22	2.66	0.82	3.30	1.84	3.21	2.11	0.82	3.23	1.26	4.37	2.10	1.68	1.01	2.82	1.92	1.83	2.09	0.95
376	0.85	2.49	0.41	2.20	1.16	1.80	2.27	3.72	0.97	1.36	2.00	1.51	3.34	2.21	1.47	0.35	2.44	1.26	1.57	1.76	0.89
384	0.83	1.74	-0.23	1.32	0.19	1.72	1.52	3.24	1.34	1.26	1.11	1.04	2.22	1.51	1.78	0.70	1.78	0.70	0.90	1.30	0.76
391	0.90	2.63	-0.43	1.26	0.17	0.81	1.37	2.04	1.56	1.04	0.52	0.31	2.58	1.34	0.24	0.27	2.17	0.64	0.94	1.07	0.85
399	0.37	1.79	-0.61	0.03	-0.12	0.53	1.13	1.96	0.56	-0.07	1.59	0.04	1.78	2.14	0.88	0.05	1.98	0.15	0.73	0.78	0.86
406	0.54	0.60	-0.59	-0.02	0.41	0.44	1.16	1.66	0.12	0.16	0.20	-0.29	1.72	1.45	0.64	0.14	0.67	0.22	-0.06	0.48	0.63
414	0.26	0.78	-0.45	0.20	-0.18	0.72	0.80	1.49	0.57	0.36	0.03	-0.32	1.11	1.13	0.85	-0.12	1.63	-0.24	0.22	0.47	0.61
422	-0.06	1.48	-0.62	0.27	0.05	1.60	0.30	0.67	0.29	-0.35	0.45	0.07	1.34	0.66	0.07	0.33	0.44	0.21	0.13	0.39	0.57
429	0.17	0.85	-0.58	0.06	-1.06	0.16	0.80	0.96	0.46	-0.29	0.79	0.24	0.83	0.98	0.59	-0.74	0.60	0.14	-0.21	0.25	0.60
437	-0.01	1.06	-0.43	-0.16	-0.46	0.75	1.05	0.36	0.09	-0.19	0.27	0.35	0.57	0.57	0.36	-0.19	0.42	-0.05	-0.10	0.22	0.45

Table 4. Weekly SST ($^{\circ}$ C), averages and standard deviations from satellite-fitted data, between days of year (DoY) 57 and 437, and years 1998 to 2016, in the Southern region.

DoY	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Average	Stdev
57	-0.31	0.14	1.01	-0.81	0.05	-0.31	1.30	0.87	0.66	0.16	0.56	0.74	0.58	0.64	0.86	0.13	0.02	0.42	0.27	0.37	0.52
64	-0.22	0.28	1.05	-0.76	0.06	-0.30	1.30	0.89	0.73	0.18	0.56	0.76	0.60	0.71	0.91	0.18	0.02	0.44	0.28	0.41	0.51
72	-0.08	0.46	1.10	-0.69	0.09	-0.28	1.31	0.94	0.83	0.22	0.57	0.79	0.63	0.79	0.99	0.27	0.03	0.48	0.30	0.46	0.51
80	0.10	0.70	1.17	-0.58	0.12	-0.25	1.31	1.00	0.97	0.27	0.59	0.83	0.68	0.91	1.09	0.38	0.05	0.53	0.33	0.54	0.51
87	0.34	1.01	1.28	-0.43	0.18	-0.21	1.33	1.09	1.17	0.34	0.62	0.90	0.74	1.07	1.24	0.55	0.08	0.61	0.38	0.65	0.51
95	0.65	1.39	1.43	-0.22	0.27	-0.13	1.35	1.22	1.43	0.46	0.68	1.01	0.84	1.28	1.45	0.77	0.13	0.73	0.47	0.80	0.54
102	1.06	1.87	1.65	0.05	0.41	-0.02	1.40	1.41	1.78	0.63	0.77	1.18	0.99	1.55	1.73	1.07	0.22	0.89	0.60	1.01	0.59
110	1.57	2.44	1.94	0.40	0.61	0.16	1.49	1.66	2.23	0.87	0.93	1.42	1.19	1.89	2.11	1.47	0.36	1.11	0.79	1.30	0.66
118	2.20	3.11	2.33	0.86	0.90	0.41	1.63	2.00	2.79	1.20	1.18	1.76	1.47	2.31	2.59	1.97	0.59	1.41	1.08	1.67	0.76
125	2.96	3.90	2.84	1.43	1.29	0.77	1.86	2.44	3.49	1.63	1.56	2.22	1.85	2.83	3.20	2.60	0.94	1.79	1.49	2.16	0.88
133	3.84	4.81	3.47	2.13	1.81	1.27	2.21	2.99	4.32	2.20	2.11	2.84	2.34	3.44	3.95	3.37	1.44	2.28	2.04	2.78	1.00
140	4.85	5.82	4.26	2.96	2.49	1.92	2.72	3.68	5.29	2.92	2.86	3.64	2.97	4.16	4.85	4.28	2.13	2.89	2.77	3.55	1.11
148	5.98	6.92	5.19	3.94	3.33	2.75	3.45	4.50	6.39	3.79	3.84	4.62	3.74	4.97	5.90	5.34	3.07	3.62	3.69	4.48	1.20
156	7.20	8.11	6.27	5.05	4.35	3.79	4.41	5.48	7.60	4.83	5.08	5.79	4.67	5.89	7.10	6.54	4.26	4.48	4.81	5.56	1.26
163	8.49	9.36	7.49	6.29	5.54	5.01	5.63	6.59	8.90	6.02	6.56	7.13	5.75	6.89	8.41	7.85	5.72	5.46	6.12	6.80	1.29
171	9.81	10.63	8.81	7.63	6.89	6.42	7.10	7.82	10.25	7.34	8.23	8.60	6.97	7.95	9.83	9.25	7.41	6.56	7.59	8.16	1.28
178	11.10	11.89	10.20	9.05	8.34	7.97	8.78	9.14	11.58	8.75	9.99	10.15	8.31	9.05	11.29	10.69	9.29	7.73	9.15	9.60	1.25
186	12.32	13.10	11.60	10.48	9.86	9.60	10.57	10.51	12.86	10.19	11.73	11.70	9.72	10.15	12.74	12.11	11.24	8.96	10.74	11.06	1.21
194	13.42	14.22	12.95	11.90	11.35	11.23	12.34	11.88	14.01	11.60	13.31	13.16	11.15	11.22	14.13	13.47	13.14	10.18	12.24	12.47	1.17
201	14.33	15.21	14.18	13.23	12.73	12.75	13.96	13.19	14.98	12.90	14.57	14.42	12.53	12.22	15.39	14.69	14.84	11.35	13.55	13.74	1.13
209	15.02	16.02	15.23	14.23	13.93	14.08	15.26	14.38	15.71	14.01	15.38	15.40	13.79	13.11	16.44	15.72	16.19	12.41	14.58	14.79	1.07
216	15.45	16.62	16.02	15.42	14.85	15.11	16.10	15.38	16.17	14.86	15.66	16.02	14.86	13.84	17.24	16.49	17.05	13.31	15.23	15.56	1.00
224	15.60	17.00	16.52	16.17	15.43	15.76	16.39	16.14	16.33	15.39	14.88	16.24	15.68	14.39	17.74	16.98	17.35	13.99	15.45	15.97	0.96
232	16.01	17.13	16.69	16.63	15.63	15.98	16.08	16.62	15.83	15.57	14.73	14.97	16.19	14.73	17.91	17.14	16.78	14.42	14.96	16.00	0.95
239	15.74	16.82	16.19	16.79	15.31	16.31	15.77	16.78	15.62	15.83	14.48	14.58	16.37	14.85	17.62	17.34	16.52	14.56	14.76	15.91	0.96
247	15.32	16.40	15.90	14.46	14.90	16.00	15.27	14.70	15.26	15.53	14.13	13.95	13.54	14.53	17.30	16.96	16.10	15.00	14.43	15.25	1.01
254	14.74	15.73	15.44	14.21	14.25	15.51	14.60	14.40	14.78	15.05	13.70	13.11	13.30	14.16	16.79	16.35	15.53	14.64	13.98	14.75	0.97
262	14.02	14.84	14.81	13.79	13.38	14.84	13.78	13.91	14.19	14.39	13.19	12.11	12.91	13.56	16.10	15.53	14.83	14.06	13.42	14.09	0.94
270	13.19	13.78	14.04	13.22	12.34	14.02	12.85	13.25	13.49	13.58	12.60	11.00	12.39	12.77	15.25	14.53	14.02	13.29	12.76	13.28	0.93
277	12.28	12.60	13.14	12.53	11.18	13.08	11.83	12.46	12.71	12.66	11.96	9.81	11.75	11.83	14.27	13.39	13.11	12.36	12.03	12.37	0.94
285	11.29	11.35	12.14	11.73	9.94	12.06	10.76	11.56	11.86	11.64	11.26	8.61	11.02	10.78	13.20	12.16	12.14	11.31	11.23	11.37	0.96
292	10.27	10.08	11.08	10.84	8.68	10.98	9.67	10.59	10.96	10.56	10.53	7.43	10.22	9.67	12.05	10.87	11.14	10.19	10.38	10.33	0.99
300	9.23	8.84	9.97	9.90	7.44	9.87	8.60	9.59	10.03	9.46	9.77	6.31	9.38	8.55	10.88	9.57	10.12	9.03	9.50	9.26	1.03
308	8.20	7.67	8.85	8.93	6.26	8.78	7.56	8.58	9.08	8.36	8.99	5.28	8.52	7.45	9.69	8.30	9.10	7.88	8.60	8.21	1.05
315	7.19	6.59	7.73	7.95	5.16	7.71	6.58	7.61	8.14	7.28	8.20	4.36	7.66	6.42	8.53	7.08	8.11	6.76	7.71	7.20	1.06
323	6.23	5.63	6.65	6.98	4.17	6.69	5.67	6.69	7.22	6.24	7.41	3.55	6.83	5.47	7.41	5.93	7.16	5.71	6.83	6.24	1.04
330	5.33	4.79	5.61	6.05	3.31	5.75	4.85	5.83	6.33	5.28	6.64	2.85	6.04	4.63	6.36	4.89	6.27	4.74	5.97	5.34	1.01
338	4.49	4.08	4.63	5.17	2.56	4.89	4.12	5.06	5.48	4.39	5.89	2.28	5.31	3.89	5.39	3.95	5.44	3.88	5.16	4.53	0.96
346	3.73	3.49	3.73	4.35	1.94	4.11	3.48	4.38	4.69	3.58	5.16	1.81	4.64	3.27	4.50	3.12	4.69	3.12	4.39	3.80	0.90
353	3.04	3.01	2.91	3.60	1.43	3.43	2.93	3.79	3.95	2.86	4.47	1.44	4.05	2.75	3.70	2.41	4.01	2.47	3.68	3.16	0.83
361	2.44	2.63	2.18	2.93	1.02	2.84	2.47	3.29	3.27	2.24	3.82	1.14	3.52	2.34	3.00	1.81	3.42	1.92	3.02	2.60	0.77
368	1.91	2.34	1.53	2.33	0.70	2.34	2.09	2.88	2.66	1.70	3.20	0.92	3.07	2.01	2.40	1.31	2.89	1.47	2.42	2.11	0.71
376	1.45	2.11	0.96	1.82	0.45	1.91	1.78	2.54	2.11	1.25	2.63	0.76	2.68	1.76	1.88	0.90	2.44	1.11	1.89	1.71	0.66
384	1.07	1.95	0.48	1.37	0.27	1.57	1.53	2.27	1.63	0.87	2.11	0.63	2.36	1.57	1.44	0.57	2.06	0.82	1.41	1.37	0.63
391	0.74	1.83	0.06	0.99	0.13	1.28	1.33	2.06	1.20	0.55	1.63	0.55	2.09	1.43	1.08	0.32	1.74	0.60	0.99	1.08	0.62
399	0.48	1.74	-0.28	0.68	0.03	1.06	1.18	1.90	0.84	0.30	1.20	0.49	1.88	1.32	0.78	0.11	1.47	0.43	0.62	0.85	0.63
406	0.26	1.68	-0.57	0.42	-0.04	0.88	1.06	1.77	0.52	0.10	0.81	0.44	1.70	1.25	0.54	-0.04	1.26	0.30	0.31	0.67	0.65
414	0.08	1.64	-0.80	0.21	-0.09	0.74	0.97	1.68	0.26	-0.06	0.46	0.42	1.57	1.20	0.36	-0.15	1.08	0.21	0.04	0.52	0.68
422	-0.06	1.61	-0.99	0.04	-0.12	0.63	0.91	1.61	0.03	-0.18	0.15	0.40	1.46	1.17	0.21	-0.24	0.94	0.14	-0.19	0.40	0.72
429	-0.17	1.60	-1.14	-0.10	-0.14	0.55	0.86	1.56	-0.15	-0.28	-0.12	0.38	1.38	1.15	0.09	-0.30	0.83	0.09	-0.38	0.30	0.75
437	-0.26	1.59	-1.26	-0.20	-0.16	0.50	0.82	1.53	-0.31	-0.35	0.38	1.32	1.13	0.00	-0.35	0.74	0.06	-0.54	0.23	0.78	

Table 5. Weekly Chl_a (Log_{10} (mg m^{-3})), averages and standard deviations from SeaWiFS (1998-2006), MODIS (2007-2011), and VIIRS (2012-2015) data, between days of year (DoY) 44 and 441, and years 1998 to 2015, in the Northern region.

DoY	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Average	Stddev
44	-0.39	-0.41	-0.30	-0.34	-0.46	-0.42	-0.33	-0.28	-0.33	-0.36	-0.40	-0.37	-0.37	-0.18	-0.47	-0.48	-0.33	-0.45	-0.37	0.08
52	-0.30	-0.39	-0.26	-0.42	-0.43	-0.34	-0.30	-0.38	-0.32	-0.40	-0.51	-0.51	-0.13	-0.20	-0.41	-0.50	-0.36	-0.44	-0.37	0.10
60	-0.28	-0.36	-0.36	-0.30	-0.28	-0.29	-0.28	-0.39	-0.46	-0.54	-0.39	-0.41	-0.21	-0.15	-0.53	-0.42	-0.55	-0.32	-0.36	0.11
68	-0.31	-0.32	-0.37	-0.34	-0.32	-0.16	-0.22	-0.26	-0.34	-0.39	-0.34	-0.49	-0.56	-0.20	-0.39	-0.47	-0.39	-0.49	-0.35	0.11
76	-0.25	-0.31	-0.33	-0.50	-0.33	-0.30	-0.24	-0.35	-0.21	-0.33	-0.36	-0.32	-0.29	-0.15	-0.40	-0.38	-0.58	-0.45	-0.34	0.10
84	-0.18	0.13	-0.32	-0.34	-0.25	-0.31	-0.21	-0.21	-0.20	-0.35	-0.48	-0.35	-0.15	-0.21	-0.50	-0.32	-0.37	-0.42	-0.28	0.14
92	-0.09	0.11	-0.02	-0.26	-0.30	-0.35	-0.17	-0.06	0.12	-0.34	-0.45	-0.49	-0.08	-0.26	-0.40	-0.23	-0.44	-0.46	-0.23	0.19
100	0.08	0.09	0.14	-0.27	-0.21	-0.37	-0.03	0.20	0.50	-0.20	-0.44	-0.37	0.38	-0.16	-0.12	-0.14	-0.31	-0.47	-0.09	0.28
108	0.11	0.28	0.15	-0.05	-0.14	-0.31	0.08	0.41	0.59	-0.20	-0.57	-0.26	0.28	0.08	0.05	-0.08	-0.32	-0.36	-0.01	0.30
116	0.25	0.19	0.23	-0.12	-0.05	0.16	0.09	0.38	0.54	0.26	0.04	0.08	-0.09	0.66	0.45	0.25	0.29	-0.26	0.19	0.24
124	0.18	0.36	0.22	-0.02	0.22	0.19	0.28	0.12	0.26	0.23	0.19	0.38	0.16	0.53	0.29	0.36	-0.14	-0.01	0.21	0.16
132	0.22	0.01	0.40	0.00	0.28	0.14	0.28	-0.01	-0.22	0.28	0.44	0.38	-0.02	0.78	0.35	0.24	0.58	0.13	0.24	0.24
140	0.06	-0.09	0.18	0.13	0.29	0.34	0.29	-0.18	-0.40	0.32	0.01	0.41	0.10	0.41	0.14	0.52	0.49	0.39	0.19	0.24
148	0.09	-0.13	0.09	0.11	0.46	0.37	0.02	-0.34	-0.33	0.33	-0.22	0.27	0.02	0.04	0.05	0.31	-0.07	0.30	0.08	0.24
156	0.06	-0.15	0.00	0.08	0.12	0.08	-0.33	-0.33	-0.39	0.24	0.00	0.07	-0.13	-0.05	0.02	-0.25	-0.07	0.01	-0.06	0.17
164	-0.36	-0.23	-0.12	-0.28	-0.33	-0.08	-0.26	-0.27	-0.42	0.12	-0.09	0.09	-0.22	-0.22	0.00	-0.32	-0.15	-0.13	-0.18	0.15
172	-0.39	-0.35	-0.19	-0.11	-0.16	-0.36	-0.40	-0.35	-0.42	-0.21	-0.14	-0.20	-0.22	-0.21	0.45	-0.38	-0.39	-0.33	-0.24	0.20
180	-0.47	-0.37	-0.23	-0.25	-0.24	-0.38	-0.31	-0.38	-0.39	-0.25	-0.36	-0.33	-0.32	-0.46	-0.37	-0.30	-0.41	-0.24	-0.34	0.07
188	-0.49	-0.35	-0.31	-0.34	-0.41	-0.27	-0.38	-0.40	-0.37	-0.41	-0.34	-0.38	-0.34	-0.36	-0.28	-0.45	-0.30	-0.36	0.06	
196	-0.48	-0.38	-0.40	-0.27	-0.39	-0.43	-0.27	-0.44	-0.45	-0.43	-0.40	-0.36	-0.29	-0.31	-0.36	-0.27	-0.42	-0.33	-0.37	0.07
204	-0.46	-0.38	-0.44	-0.41	-0.37	-0.42	-0.34	-0.45	-0.48	-0.51	-0.42	-0.48	-0.41	-0.26	-0.39	-0.37	-0.41	-0.33	-0.41	0.06
212	-0.42	-0.27	-0.40	-0.45	-0.37	-0.39	-0.36	-0.43	-0.40	-0.54	-0.47	-0.49	-0.37	-0.35	-0.42	-0.42	-0.38	-0.41	0.06	
220	-0.35	-0.32	-0.39	-0.43	-0.45	-0.42	-0.38	-0.39	-0.40	-0.44	-0.42	-0.50	-0.29	-0.40	-0.37	-0.43	-0.37	-0.27	-0.39	0.06
228	-0.35	-0.22	-0.36	-0.44	-0.34	-0.41	-0.35	-0.37	-0.37	-0.36	-0.47	-0.45	-0.29	-0.37	-0.30	-0.36	-0.43	-0.34	-0.36	0.06
236	-0.33	-0.26	-0.31	-0.39	-0.34	-0.41	-0.30	-0.31	-0.32	-0.39	-0.43	-0.40	-0.18	-0.36	-0.29	-0.35	-0.32	-0.36	-0.34	0.06
244	-0.37	-0.25	-0.31	-0.38	-0.28	-0.36	-0.30	-0.34	-0.24	-0.38	-0.42	-0.37	-0.20	-0.30	-0.30	-0.34	-0.26	-0.28	-0.32	0.06
252	-0.12	-0.21	-0.31	-0.39	-0.22	-0.31	-0.26	-0.34	-0.20	-0.29	-0.30	-0.32	-0.17	-0.25	-0.25	-0.30	-0.26	-0.24	-0.26	0.06
260	-0.25	-0.20	-0.32	-0.33	-0.16	-0.34	-0.24	-0.25	-0.21	-0.20	-0.21	-0.30	-0.18	-0.19	-0.23	-0.34	-0.22	-0.27	-0.25	0.06
268	-0.12	-0.15	-0.28	-0.29	-0.10	-0.28	-0.09	-0.23	-0.30	-0.19	-0.18	-0.19	-0.08	-0.16	-0.27	-0.25	-0.24	-0.22	-0.20	0.07
276	-0.13	-0.18	-0.26	-0.26	-0.08	-0.21	0.00	-0.06	-0.24	-0.22	-0.12	-0.18	0.09	-0.11	-0.14	-0.30	-0.18	-0.25	-0.16	0.10
284	0.00	-0.13	-0.23	-0.18	0.01	-0.09	-0.06	-0.05	-0.16	-0.10	-0.17	-0.24	0.16	-0.06	-0.27	-0.19	-0.20	-0.15	-0.12	0.11
292	0.00	-0.11	-0.13	-0.04	-0.05	-0.02	-0.04	0.00	-0.12	-0.11	-0.04	-0.08	0.16	-0.11	0.06	-0.16	-0.19	-0.13	-0.06	0.09
300	0.04	-0.16	-0.15	-0.12	-0.03	0.06	0.03	-0.03	-0.17	-0.20	0.03	-0.10	0.03	-0.02	-0.02	-0.11	-0.12	-0.07	-0.06	0.08
308	-0.02	-0.15	-0.13	-0.06	-0.04	-0.05	-0.17	-0.11	0.00	-0.01	0.01	-0.04	0.27	-0.05	-0.19	-0.09	-0.12	-0.13	-0.06	0.10
316	-0.02	-0.18	0.00	-0.13	-0.21	-0.13	-0.17	-0.06	-0.03	-0.05	-0.05	0.00	-0.01	-0.36	-0.20	-0.04	-0.23	-0.21	-0.11	0.10
324	NA	-0.25	-0.15	-0.19	-0.18	-0.24	NA	-0.20	-0.13	-0.52	-0.15	-0.24	0.53	-0.14	-0.20	-0.19	-0.26	-0.25	-0.17	0.21
332	-0.32	-0.31	-0.34	-0.33	-0.49	NA	NA	NA	NA	-0.07	-0.07	0.29	0.14	-0.36	-0.28	-0.23	-0.34	-0.24	-0.21	0.21
340	NA	-0.32	-0.01	0.70	-0.43	-0.82	-0.34	-0.16	-0.39	-0.22	0.44									
348	NA																			
356	NA																			
364	NA																			
369	NA																			
377	-0.25	NA	NA	-0.32	NA	-0.22	NA	-0.26	0.05											
385	-0.42	-0.32	-0.48	-0.34	-0.38	-0.45	0.00	-0.23	NA	-0.27	NA	NA	-0.73	0.34	NA	-0.19	-0.27	0.49	-0.35	0.17
393	-0.44	-0.34	-0.39	-0.28	-0.35	-0.34	-0.41	-0.25	-0.42	-0.31	-0.41	-0.19	-0.18	-0.25	-0.47	-0.50	-0.41	-0.58	-0.36	0.11
401	-0.47	-0.40	-0.35	-0.27	-0.42	-0.34	-0.39	-0.40	-0.38	-0.38	-0.25	-0.24	-0.24	-0.27	-0.55	-0.51	-0.47	-0.46	-0.38	0.09
409	-0.41	-0.30	-0.34	-0.46	-0.42	-0.33	-0.28	-0.33	-0.25	-0.32	-0.47	-0.30	-0.04	-0.53	-0.45	-0.42	-0.44	-0.36	-0.36	0.11
417	-0.39	-0.26	-0.42	-0.43	-0.34	-0.30	-0.38	-0.32	-0.26	-0.40	-0.37	-0.37	-0.18	-0.33	-0.48	-0.33	-0.45	-0.49	-0.36	0.08
425	-0.36	-0.36	-0.30	-0.28	-0.29	-0.28	-0.39	-0.46	-0.34	-0.51	-0.51	-0.13	-0.20	-0.41	-0.50	-0.36	-0.44	-0.37	-0.36	0.11
433	-0.32	-0.37	-0.34	-0.32	-0.16	-0.22	-0.26	-0.34	-0.33	-0.39	-0.41	-0.21	-0.15	-0.50	-0.42	-0.55	-0.32	-0.28	-0.33	0.11
441	-0.31	-0.33	-0.50	-0.33	-0.30	-0.24	-0.35	-0.21	-0.30	-0.34	-0.49	-0.56	-0.20	-0.34	-0.47	-0.39	-0.49	-0.38	-0.36	0.10

Table 6. Weekly Chl_a (Log_{10} (mg m^{-3})), averages and standard deviations from satellite-fitted data, between days of year (DoY) 44 and 441, and years 1998 to 2015, in the Northern region.

DoY	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Average	Stdev	
44	-0.35	-0.43	-0.34	-0.38	-0.36	-0.33	-0.30	-0.34	-0.37	-0.42	-0.44	-0.43	-0.31	-0.22	-0.48	-0.47	-0.44	-0.44	-0.38	0.07	
52	-0.34	-0.40	-0.34	-0.38	-0.36	-0.33	-0.30	-0.34	-0.37	-0.42	-0.44	-0.43	-0.31	-0.22	-0.48	-0.46	-0.44	-0.44	-0.38	0.07	
60	-0.32	-0.34	-0.33	-0.38	-0.36	-0.33	-0.29	-0.34	-0.36	-0.42	-0.44	-0.43	-0.31	-0.22	-0.48	-0.46	-0.44	-0.44	-0.37	0.07	
68	-0.29	-0.26	-0.31	-0.37	-0.36	-0.33	-0.28	-0.33	-0.33	-0.41	-0.44	-0.43	-0.29	-0.22	-0.47	-0.44	-0.44	-0.44	-0.36	0.08	
76	-0.24	-0.15	-0.27	-0.36	-0.35	-0.33	-0.25	-0.30	-0.25	-0.39	-0.44	-0.43	-0.25	-0.21	-0.46	-0.41	-0.44	-0.44	-0.33	0.09	
84	-0.16	-0.02	-0.20	-0.34	-0.33	-0.33	-0.20	-0.20	-0.08	-0.35	-0.44	-0.42	-0.15	-0.19	-0.41	-0.35	-0.43	-0.44	-0.28	0.13	
92	-0.07	0.10	-0.10	-0.30	-0.29	-0.31	-0.13	-0.01	0.17	-0.29	-0.43	-0.40	0.00	-0.14	-0.31	-0.25	-0.40	-0.44	-0.20	0.18	
100	0.03	0.19	0.03	-0.24	-0.22	-0.26	-0.04	0.20	0.42	-0.19	-0.39	-0.33	0.14	-0.03	-0.14	-0.12	-0.33	-0.42	-0.09	0.23	
108	0.13	0.22	0.16	-0.16	-0.11	-0.18	0.06	0.30	0.53	-0.06	-0.29	-0.18	0.21	0.15	0.07	0.04	-0.19	-0.36	0.02	0.23	
116	0.20	0.25	0.26	-0.08	0.03	-0.04	0.17	0.31	0.47	0.08	-0.10	0.05	0.16	0.38	0.26	0.20	0.03	-0.23	0.13	0.18	
124	0.22	0.18	0.30	0.00	0.18	0.13	0.24	0.17	0.19	0.22	0.11	0.28	0.12	0.58	0.34	0.32	0.23	-0.02	0.21	0.13	
132	0.24	0.08	0.28	0.06	0.29	0.27	0.27	-0.01	-0.10	0.32	0.21	0.38	0.07	0.66	0.29	0.36	0.32	0.19	0.23	0.17	
140	0.13	-0.03	0.21	0.08	0.34	0.33	0.19	-0.17	-0.28	0.35	0.09	0.38	0.01	0.41	0.25	0.35	0.30	0.28	0.18	0.20	
148	0.00	-0.13	0.11	0.05	0.25	0.26	-0.01	-0.28	-0.37	0.33	0.03	0.28	-0.06	0.19	0.18	0.14	0.13	0.20	0.07	0.19	
156	-0.14	-0.20	0.00	0.00	0.10	0.09	-0.19	-0.34	-0.40	0.20	-0.05	0.14	-0.13	-0.05	0.09	-0.08	-0.07	0.06	-0.05	0.16	
164	-0.25	-0.26	-0.11	-0.08	-0.07	-0.10	-0.29	-0.37	-0.40	0.04	-0.15	-0.01	-0.19	-0.21	0.00	-0.24	-0.23	-0.10	-0.17	0.12	
172	-0.33	-0.29	-0.20	-0.17	-0.21	-0.26	-0.32	-0.38	-0.41	-0.13	-0.24	-0.15	-0.24	-0.30	-0.09	-0.32	-0.34	-0.22	-0.25	0.09	
180	-0.38	-0.31	-0.27	-0.25	-0.30	-0.35	-0.33	-0.38	-0.41	-0.26	-0.31	-0.27	-0.27	-0.34	-0.17	-0.35	-0.39	-0.30	-0.31	0.06	
188	-0.41	-0.32	-0.32	-0.31	-0.35	-0.40	-0.33	-0.38	-0.41	-0.36	-0.37	-0.36	-0.30	-0.35	-0.24	-0.36	-0.41	-0.33	-0.35	0.04	
196	-0.42	-0.32	-0.35	-0.36	-0.37	-0.42	-0.33	-0.38	-0.41	-0.42	-0.41	-0.42	-0.42	-0.32	-0.35	-0.30	-0.36	-0.42	-0.35	-0.37	0.04
204	-0.43	-0.32	-0.37	-0.39	-0.37	-0.42	-0.33	-0.38	-0.41	-0.45	-0.43	-0.46	-0.34	-0.35	-0.34	-0.36	-0.42	-0.35	-0.38	0.04	
212	-0.42	-0.32	-0.40	-0.43	-0.39	-0.40	-0.36	-0.41	-0.42	-0.48	-0.45	-0.46	-0.35	-0.35	-0.37	-0.38	-0.39	-0.37	-0.40	0.04	
220	-0.40	-0.30	-0.39	-0.42	-0.38	-0.40	-0.36	-0.40	-0.39	-0.45	-0.44	-0.45	-0.32	-0.34	-0.36	-0.38	-0.37	-0.36	-0.38	0.04	
228	-0.37	-0.27	-0.37	-0.42	-0.35	-0.40	-0.35	-0.39	-0.35	-0.42	-0.42	-0.44	-0.29	-0.34	-0.35	-0.35	-0.35	-0.34	-0.37	0.04	
236	-0.33	-0.25	-0.36	-0.41	-0.32	-0.40	-0.33	-0.38	-0.32	-0.38	-0.39	-0.43	-0.25	-0.32	-0.32	-0.37	-0.33	-0.33	-0.35	0.05	
244	-0.29	-0.23	-0.33	-0.40	-0.28	-0.38	-0.29	-0.34	-0.28	-0.34	-0.36	-0.40	-0.21	-0.30	-0.30	-0.36	-0.30	-0.30	-0.32	0.05	
252	-0.24	-0.20	-0.31	-0.37	-0.23	-0.36	-0.25	-0.30	-0.25	-0.29	-0.32	-0.38	-0.15	-0.26	-0.26	-0.34	-0.27	-0.27	-0.28	0.06	
260	-0.18	-0.18	-0.28	-0.33	-0.17	-0.32	-0.19	-0.24	-0.22	-0.24	-0.27	-0.34	-0.09	-0.22	-0.23	-0.31	-0.24	-0.24	-0.24	0.06	
268	-0.13	-0.17	-0.25	-0.28	-0.11	-0.26	-0.13	-0.17	-0.20	-0.19	-0.21	-0.29	-0.03	-0.16	-0.19	-0.28	-0.21	-0.21	-0.19	0.07	
276	-0.07	-0.15	-0.22	-0.22	-0.06	-0.18	-0.06	-0.10	-0.17	-0.16	-0.15	-0.24	0.04	-0.11	-0.16	-0.23	-0.19	-0.18	-0.15	0.07	
284	-0.03	-0.14	-0.20	-0.16	-0.03	-0.10	-0.02	-0.05	-0.15	-0.14	-0.10	-0.18	0.09	-0.07	-0.13	-0.19	-0.17	-0.16	-0.11	0.08	
292	-0.01	-0.14	-0.18	-0.11	-0.01	-0.04	0.00	-0.04	-0.14	-0.13	-0.05	-0.11	0.14	-0.06	-0.11	-0.15	-0.16	-0.14	-0.08	0.08	
300	0.00	-0.14	-0.18	-0.10	-0.02	-0.02	-0.08	-0.05	-0.12	-0.15	-0.02	-0.04	0.16	-0.04	-0.10	-0.12	-0.16	-0.14	-0.07	0.08	
308	-0.02	-0.16	-0.15	-0.11	-0.09	-0.05	-0.09	-0.06	-0.12	-0.16	-0.01	0.03	0.17	-0.13	-0.12	-0.11	-0.20	-0.12	-0.08	0.09	
316	-0.06	-0.19	-0.17	-0.14	-0.18	-0.10	-0.10	-0.09	-0.11	-0.17	-0.02	0.09	0.21	-0.24	-0.15	-0.12	-0.22	-0.17	-0.11	0.11	
324	-0.12	-0.22	-0.20	-0.18	-0.25	-0.15	-0.11	-0.11	-0.07	-0.18	-0.04	0.15	0.12	-0.33	-0.19	-0.13	-0.23	-0.23	-0.14	0.12	
332	-0.18	-0.25	-0.24	-0.22	-0.30	-0.21	-0.12	-0.14	-0.10	-0.20	-0.05	0.19	0.01	-0.38	-0.25	-0.15	-0.25	-0.29	-0.17	0.13	
340	-0.23	-0.28	-0.27	-0.25	-0.33	-0.25	-0.14	-0.17	-0.13	-0.22	-0.08	0.22	-0.10	-0.40	-0.30	-0.18	-0.27	-0.35	-0.21	0.14	
348	-0.27	-0.30	-0.30	-0.28	-0.35	-0.28	-0.16	-0.20	-0.18	-0.24	-0.11	0.23	-0.18	-0.41	-0.35	-0.21	-0.30	-0.39	-0.24	0.14	
356	-0.29	-0.31	-0.33	-0.30	-0.35	-0.30	-0.18	-0.23	-0.22	-0.26	-0.15	0.25	-0.23	-0.41	-0.39	-0.24	-0.32	-0.41	-0.26	0.15	
364	-0.31	-0.32	-0.35	-0.31	-0.36	-0.31	-0.20	-0.25	-0.25	-0.28	-0.18	0.20	-0.26	-0.41	-0.42	-0.27	-0.34	-0.43	-0.28	0.14	
369	-0.32	-0.33	-0.36	-0.32	-0.36	-0.31	-0.22	-0.26	-0.28	-0.30	-0.22	0.12	-0.27	-0.41	-0.44	-0.30	-0.36	-0.44	-0.30	0.12	
377	-0.32	-0.33	-0.37	-0.32	-0.36	-0.32	-0.24	-0.28	-0.30	-0.32	-0.26	0.03	-0.27	-0.41	-0.46	-0.33	-0.38	-0.44	-0.32	0.11	
385	-0.32	-0.33	-0.38	-0.32	-0.36	-0.32	-0.25	-0.29	-0.31	-0.33	-0.30	-0.06	-0.27	-0.41	-0.47	-0.36	-0.39	-0.44	-0.33	0.09	
393	-0.32	-0.33	-0.38	-0.32	-0.36	-0.32	-0.27	-0.30	-0.32	-0.35	-0.33	-0.15	-0.27	-0.41	-0.47	-0.38	-0.40	-0.44	-0.34	0.07	
401	-0.32	-0.33	-0.38	-0.32	-0.36	-0.32	-0.28	-0.30	-0.32	-0.36	-0.37	-0.22	-0.27	-0.41	-0.48	-0.40	-0.41	-0.44	-0.35	0.06	
409	-0.32	-0.33	-0.38	-0.32	-0.36	-0.32	-0.29	-0.30	-0.32	-0.37	-0.40	-0.27	-0.27	-0.41	-0.48	-0.41	-0.41	-0.44	-0.36	0.06	
417	-0.32	-0.33	-0.38	-0.32	-0.36	-0.32	-0.30	-0.31	-0.32	-0.37	-0.42	-0.31	-0.27	-0.41	-0.48	-0.42	-0.42	-0.44	-0.36	0.06	
425	-0.32	-0.33	-0.38	-0.32	-0.36	-0.32	-0.31	-0.31	-0.32	-0.38	-0.44	-0.34	-0.27	-0.41	-0.48	-0.43	-0.42	-0.44	-0.37	0.06	
433	-0.32	-0.33	-0.38	-0.32	-0.36	-0.32	-0.32	-0.31	-0.32	-0.38	-0.46	-0.35	-0.27	-0.41	-0.48	-0.43	-0.42	-0.44	-0.37	0.06	
441	-0.32	-0.33	-0.38	-0.32	-0.36	-0.32	-0.32	-0.31	-0.32	-0.39	-0.48	-0.36	-0.27	-0.41	-0.48	-0.44	-0.42	-0.44	-0.37	0.06	

Table 7. Weekly Chl_a (Log_{10} (mg m^{-3})), averages and standard deviations from SeaWiFS (1998-2006), MODIS (2007-2011), and VIIRS (2012-2015) data, between days of year (DoY) 34 and 414, and years 1998 to 2015, in the Southern region.

DoY	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Average	Stdev	
34	-0.29	-0.34	-0.30	-0.37	-0.23	-0.29	-0.24	-0.28	-0.28	-0.26	-0.30	-0.23	-0.22	-0.17	-0.33	-0.36	-0.26	-0.28	-0.28	0.05	
42	-0.31	-0.27	-0.27	-0.25	-0.24	-0.28	-0.28	-0.25	-0.24	-0.22	-0.27	-0.31	-0.20	0.04	-0.28	-0.30	-0.30	-0.25	-0.25	0.08	
49	-0.29	-0.21	-0.28	-0.30	-0.23	-0.23	-0.25	-0.28	-0.24	-0.24	-0.25	-0.24	-0.23	-0.13	0.04	-0.36	-0.26	-0.19	-0.23	-0.23	0.08
57	-0.31	-0.24	-0.27	-0.26	-0.23	-0.31	-0.24	-0.25	-0.27	-0.30	-0.34	-0.30	-0.11	-0.10	-0.10	-0.32	-0.29	-0.22	-0.33	-0.25	0.08
64	-0.26	-0.17	-0.16	-0.21	-0.23	-0.29	-0.25	-0.25	-0.27	-0.30	-0.24	0.17	0.08	0.03	-0.23	-0.24	-0.27	-0.21	-0.18	0.14	
72	-0.25	-0.08	-0.14	-0.23	-0.14	-0.28	-0.23	-0.29	-0.25	-0.29	-0.26	0.17	0.08	0.14	-0.16	-0.21	-0.23	-0.25	-0.16	0.15	
80	-0.18	0.47	-0.04	-0.21	-0.15	-0.34	-0.16	-0.05	0.02	-0.19	-0.19	0.05	0.39	-0.01	-0.02	-0.12	-0.03	-0.19	-0.05	0.20	
87	-0.02	0.23	0.01	-0.20	-0.10	-0.16	0.08	0.03	0.19	-0.14	0.01	0.11	0.70	0.05	0.00	-0.07	0.16	-0.26	0.03	0.21	
95	0.17	0.55	0.05	0.10	0.24	-0.10	0.20	0.18	0.42	-0.01	0.02	0.43	0.24	0.00	0.41	0.24	0.40	-0.26	0.18	0.21	
102	0.14	0.28	0.15	0.46	0.47	0.08	0.26	0.47	0.49	0.07	-0.08	0.12	0.37	0.28	0.59	0.53	0.36	-0.19	0.27	0.22	
110	0.39	0.10	0.08	0.10	0.29	0.23	0.43	0.20	0.66	0.46	0.51	0.21	0.01	0.64	0.46	0.81	0.53	-0.12	0.33	0.25	
118	0.27	0.06	-0.20	0.20	0.25	0.30	0.19	-0.30	0.00	0.31	-0.05	0.09	0.07	0.58	-0.04	0.31	0.22	0.00	0.13	0.21	
125	-0.22	-0.40	-0.27	0.02	0.17	0.08	0.09	-0.37	-0.44	0.08	0.39	0.09	-0.14	0.20	0.06	-0.08	0.77	0.37	0.02	0.31	
133	-0.39	-0.45	-0.30	-0.16	-0.09	-0.06	-0.14	-0.41	-0.48	-0.13	-0.02	-0.13	-0.23	-0.27	-0.33	-0.39	0.34	0.33	-0.18	0.24	
140	-0.39	-0.48	-0.34	-0.29	-0.08	-0.17	-0.33	-0.45	-0.46	-0.41	-0.25	-0.40	-0.21	-0.35	-0.47	-0.47	-0.16	-0.09	-0.32	0.13	
148	-0.49	-0.49	-0.40	-0.38	-0.34	-0.36	-0.41	-0.48	-0.54	-0.50	-0.36	-0.49	-0.34	-0.26	-0.46	-0.49	-0.44	-0.23	-0.42	0.09	
156	-0.55	-0.49	-0.42	-0.49	-0.47	-0.37	-0.39	-0.46	-0.50	-0.46	-0.43	-0.50	-0.30	-0.36	-0.49	-0.46	-0.46	-0.43	-0.45	0.06	
163	-0.59	-0.50	-0.45	-0.54	-0.54	-0.45	-0.41	-0.44	-0.48	-0.54	-0.42	-0.55	-0.29	-0.38	0.46	-0.46	-0.45	-0.50	-0.42	0.23	
171	-0.52	-0.45	-0.50	-0.48	-0.45	-0.52	-0.41	-0.48	-0.55	-0.53	-0.54	-0.54	-0.32	-0.33	-0.54	-0.50	-0.49	-0.51	-0.48	0.07	
178	-0.55	-0.42	-0.47	-0.48	-0.43	-0.52	-0.42	-0.47	-0.52	-0.57	-0.52	-0.64	-0.43	-0.35	-0.53	-0.46	-0.49	-0.51	-0.49	0.07	
186	-0.48	-0.39	-0.43	-0.45	-0.44	-0.52	-0.43	-0.45	-0.48	-0.57	-0.56	-0.54	-0.37	-0.35	-0.40	-0.47	-0.57	-0.50	-0.47	0.07	
194	-0.45	-0.38	-0.37	-0.47	-0.47	-0.55	-0.41	-0.44	-0.47	-0.68	-0.53	-0.61	-0.39	-0.29	-0.47	-0.48	-0.36	-0.46	-0.46	0.09	
201	-0.51	-0.38	-0.29	-0.50	-0.46	-0.58	-0.42	-0.44	-0.45	-0.53	-0.54	-0.57	-0.33	-0.23	-0.46	-0.44	-0.44	-0.47	-0.45	0.09	
209	-0.52	-0.38	-0.33	-0.46	-0.36	-0.49	-0.46	-0.44	-0.43	-0.58	-0.52	-0.57	-0.27	-0.24	-0.49	-0.48	-0.41	-0.46	-0.44	0.09	
216	-0.47	-0.34	-0.21	-0.30	-0.42	-0.53	-0.33	-0.43	-0.41	-0.44	-0.49	-0.53	-0.24	-0.21	-0.46	-0.41	-0.51	-0.42	-0.40	0.10	
224	-0.42	-0.37	-0.26	-0.40	-0.34	-0.42	-0.28	-0.41	-0.43	-0.43	-0.52	-0.47	-0.28	-0.28	-0.45	-0.38	-0.40	-0.36	-0.38	0.07	
232	-0.43	-0.33	-0.30	-0.29	-0.36	-0.45	-0.18	-0.35	-0.35	-0.40	-0.40	-0.44	-0.20	-0.31	-0.36	-0.37	-0.39	-0.42	-0.35	0.07	
239	-0.34	-0.21	-0.24	-0.33	-0.32	-0.38	-0.23	-0.34	-0.27	-0.41	-0.33	-0.32	-0.23	-0.32	-0.36	-0.32	-0.33	-0.36	-0.31	0.05	
247	-0.08	-0.26	-0.24	-0.33	-0.17	-0.29	-0.21	-0.26	-0.18	-0.35	-0.30	-0.31	-0.23	-0.30	-0.26	-0.28	-0.32	-0.40	-0.26	0.07	
254	-0.11	-0.29	-0.26	-0.20	-0.15	-0.30	-0.17	-0.21	-0.14	-0.33	-0.24	-0.28	-0.31	-0.22	-0.26	-0.32	-0.31	-0.43	-0.25	0.08	
262	-0.20	-0.11	-0.22	-0.19	-0.21	-0.34	-0.15	-0.15	-0.20	-0.35	-0.22	-0.25	-0.15	-0.18	-0.26	-0.30	-0.32	-0.32	-0.23	0.07	
270	-0.20	-0.17	-0.21	-0.25	-0.14	-0.31	-0.11	-0.13	-0.12	-0.33	-0.22	-0.18	0.09	-0.19	-0.23	-0.31	-0.29	-0.34	-0.20	0.10	
277	-0.12	-0.15	-0.15	-0.23	-0.16	-0.26	-0.19	-0.10	-0.18	-0.28	-0.28	-0.25	0.07	-0.21	-0.25	-0.22	-0.29	-0.30	-0.20	0.09	
285	-0.12	-0.07	-0.16	-0.24	-0.17	-0.23	-0.19	-0.07	-0.14	-0.25	-0.23	-0.09	-0.02	0.00	-0.29	-0.14	-0.35	-0.28	-0.17	0.10	
292	-0.09	-0.09	-0.08	-0.14	-0.07	-0.20	-0.18	0.02	-0.14	-0.18	-0.04	0.00	-0.08	-0.15	-0.14	-0.06	-0.27	-0.29	-0.12	0.08	
300	-0.10	-0.09	-0.26	-0.16	-0.17	-0.05	-0.08	-0.11	-0.14	-0.19	-0.18	-0.05	-0.14	-0.26	-0.16	0.43	-0.34	-0.20	-0.12	0.16	
308	-0.13	-0.10	-0.28	-0.13	-0.10	-0.18	-0.09	0.07	-0.08	-0.12	-0.17	-0.01	-0.10	-0.06	-0.15	0.12	-0.30	-0.24	-0.11	0.11	
315	-0.16	-0.04	-0.20	-0.16	-0.16	-0.15	-0.12	-0.13	-0.09	-0.30	0.08	0.04	-0.04	-0.20	-0.12	-0.21	-0.20	-0.13	0.09		
323	-0.21	0.03	-0.21	-0.16	-0.23	0.19	-0.09	-0.03	-0.19	-0.12	-0.25	0.37	-0.15	-0.11	-0.12	-0.13	-0.35	-0.27	-0.11	0.17	
330	-0.22	-0.02	-0.16	-0.21	-0.21	-0.31	-0.04	-0.18	-0.34	-0.02	-0.24	0.18	-0.28	0.19	-0.20	0.00	-0.29	-0.20	-0.14	0.16	
338	-0.15	-0.03	-0.07	-0.16	-0.08	-0.20	-0.18	-0.12	-0.39	-0.15	-0.02	0.41	0.10	0.11	-0.18	0.04	-0.29	-0.26	-0.09	0.18	
346	-0.12	-0.07	-0.16	-0.23	-0.34	0.06	-0.17	-0.07	-0.41	-0.61	-0.28	0.09	0.09	-0.01	-0.16	-0.33	-0.33	-0.34	-0.19	0.19	
353	0.10	-0.14	-0.24	-0.18	-0.31	-0.23	-0.14	-0.15	-0.31	-0.13	-0.11	-0.05	0.27	-0.10	-0.15	-0.02	-0.29	-0.52	-0.15	0.17	
361	0.22	-0.15	0.27	-0.24	-0.29	0.13	0.18	-0.35	-0.18	-0.35	-0.22	0.05	-0.12	-0.02	-0.20	-0.19	-0.30	-0.24	-0.18	0.14	
368	-0.21	-0.23	-0.25	-0.19	-0.19	-0.17	-0.23	-0.04	-0.17	-0.26	-0.25	-0.15	-0.08	0.07	-0.42	-0.09	-0.14	-0.32	-0.18	0.11	
376	-0.29	-0.18	-0.32	-0.15	-0.15	-0.30	-0.17	-0.11	-0.20	-0.21	-0.24	-0.11	-0.06	-0.26	-0.33	-0.25	-0.08	-0.33	-0.21	0.09	
384	-0.30	-0.33	-0.31	-0.06	-0.11	-0.37	-0.29	-0.25	-0.29	-0.17	-0.32	-0.07	-0.11	-0.32	-0.36	-0.33	-0.36	-0.38	-0.26	0.11	
391	-0.34	-0.30	-0.37	-0.23	-0.29	-0.24	-0.28	-0.28	-0.34	-0.26	-0.20	-0.14	-0.03	-0.17	-0.33	-0.28	-0.27	-0.36	-0.26	0.09	
399	-0.27	-0.27	-0.25	-0.24	-0.28	-0.25	-0.24	-0.31	-0.30	-0.23	-0.22	-0.17	-0.30	-0.30	-0.36	-0.26	-0.28	-0.33	-0.27	0.04	
406	-0.21	-0.28	-0.30	-0.23	-0.23	-0.25	-0.28	-0.24	-0.21	-0.27	-0.31	-0.20	0.04	-0.24	-0.30	-0.30	-0.25	-0.24	-0.24	0.08	
414	-0.24	-0.27	-0.26	-0.23	-0.31	-0.24	-0.24	-0.35	-0.35	NA	-0.23	-0.27	0.04								

Table 8. Weekly Chl_a (Log_{10} (mg m^{-3})), averages and standard deviations from satellite-fitted data, between days of year (DoY) 34 and 414, and years 1998 to 2015, in the Southern region.

DoY	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Average	Stdev
34	-0.31	-0.31	-0.29	-0.29	-0.24	-0.29	-0.27	-0.29	-0.28	-0.28	-0.29	-0.23	-0.21	-0.01	-0.33	-0.31	-0.29	-0.25	-0.27	0.07
42	-0.31	-0.30	-0.29	-0.29	-0.24	-0.29	-0.27	-0.29	-0.28	-0.28	-0.29	-0.18	-0.20	-0.01	-0.32	-0.31	-0.29	-0.25	-0.26	0.07
49	-0.31	-0.27	-0.27	-0.29	-0.24	-0.29	-0.27	-0.29	-0.28	-0.28	-0.29	-0.12	-0.16	-0.01	-0.32	-0.31	-0.27	-0.25	-0.25	0.08
57	-0.30	-0.21	-0.25	-0.29	-0.23	-0.29	-0.26	-0.28	-0.27	-0.28	-0.28	-0.06	-0.08	-0.01	-0.30	-0.30	-0.24	-0.25	-0.23	0.09
64	-0.28	-0.11	-0.20	-0.27	-0.22	-0.29	-0.24	-0.27	-0.23	-0.28	-0.26	0.02	0.05	-0.01	-0.26	-0.28	-0.20	-0.25	-0.20	0.11
72	-0.23	0.05	-0.12	-0.24	-0.18	-0.28	-0.18	-0.22	-0.15	-0.27	-0.22	0.09	0.22	-0.01	-0.17	-0.22	-0.12	-0.25	-0.14	0.14
80	-0.14	0.22	-0.03	-0.16	-0.10	-0.27	-0.09	-0.08	0.00	-0.23	-0.16	0.15	0.37	-0.01	-0.01	-0.11	-0.01	-0.25	-0.05	0.17
87	-0.02	0.37	0.04	-0.05	0.03	-0.20	0.03	0.12	0.21	-0.14	-0.08	0.20	0.44	0.03	0.18	0.07	0.12	-0.25	0.06	0.18
95	0.12	0.42	0.07	0.09	0.18	-0.07	0.17	0.23	0.40	0.02	0.02	0.24	0.39	0.15	0.35	0.28	0.26	-0.24	0.17	0.17
102	0.23	0.33	0.08	0.21	0.31	0.10	0.29	0.26	0.49	0.20	0.12	0.25	0.29	0.35	0.42	0.47	0.40	-0.19	0.26	0.16
110	0.27	0.13	-0.01	0.25	0.36	0.19	0.33	0.07	0.38	0.27	0.19	0.22	0.16	0.47	0.40	0.54	0.49	-0.06	0.26	0.17
118	0.12	-0.10	-0.13	0.15	0.28	0.20	0.22	-0.14	0.04	0.25	0.22	0.12	0.02	0.40	0.14	0.32	0.53	0.11	0.15	0.18
125	-0.09	-0.28	-0.24	0.02	0.14	0.10	0.05	-0.30	-0.26	0.08	0.15	-0.02	-0.11	0.16	-0.11	-0.01	0.48	0.20	0.00	0.20
133	-0.30	-0.38	-0.33	-0.15	-0.03	-0.03	-0.13	-0.40	-0.42	-0.12	0.01	-0.18	-0.21	-0.08	-0.26	-0.29	0.21	0.20	-0.16	0.19
140	-0.43	-0.43	-0.40	-0.29	-0.20	-0.17	-0.28	-0.45	-0.49	-0.31	-0.17	-0.32	-0.27	-0.24	-0.33	-0.43	-0.08	-0.01	-0.29	0.13
148	-0.50	-0.45	-0.41	-0.40	-0.32	-0.30	-0.37	-0.46	-0.50	-0.45	-0.33	-0.43	-0.31	-0.32	-0.35	-0.48	-0.39	-0.23	-0.39	0.08
156	-0.52	-0.45	-0.42	-0.46	-0.41	-0.40	-0.41	-0.47	-0.51	-0.53	-0.48	-0.50	-0.34	-0.34	-0.35	-0.49	-0.45	-0.39	-0.44	0.06
163	-0.52	-0.46	-0.41	-0.48	-0.45	-0.47	-0.44	-0.47	-0.51	-0.57	-0.51	-0.55	-0.35	-0.35	-0.35	-0.49	-0.48	-0.47	-0.46	0.06
171	-0.52	-0.46	-0.41	-0.49	-0.47	-0.51	-0.43	-0.47	-0.51	-0.58	-0.52	-0.58	-0.38	-0.33	-0.44	-0.47	-0.48	-0.50	-0.47	0.06
178	-0.53	-0.44	-0.40	-0.50	-0.47	-0.54	-0.42	-0.47	-0.52	-0.58	-0.51	-0.59	-0.37	-0.33	-0.43	-0.47	-0.48	-0.50	-0.47	0.07
186	-0.52	-0.44	-0.40	-0.49	-0.47	-0.54	-0.41	-0.47	-0.51	-0.58	-0.51	-0.59	-0.36	-0.32	-0.42	-0.47	-0.47	-0.50	-0.47	0.07
194	-0.52	-0.43	-0.39	-0.48	-0.46	-0.54	-0.40	-0.47	-0.50	-0.57	-0.50	-0.58	-0.35	-0.32	-0.42	-0.47	-0.47	-0.50	-0.46	0.07
201	-0.49	-0.39	-0.34	-0.44	-0.42	-0.51	-0.35	-0.45	-0.46	-0.53	-0.46	-0.55	-0.31	-0.30	-0.46	-0.44	-0.43	-0.47	-0.43	0.07
209	-0.46	-0.37	-0.32	-0.41	-0.40	-0.50	-0.33	-0.44	-0.43	-0.52	-0.44	-0.53	-0.29	-0.30	-0.44	-0.44	-0.42	-0.46	-0.42	0.07
216	-0.43	-0.35	-0.31	-0.39	-0.37	-0.48	-0.31	-0.41	-0.40	-0.50	-0.42	-0.51	-0.27	-0.29	-0.42	-0.42	-0.44	-0.40	-0.44	0.07
224	-0.39	-0.33	-0.30	-0.36	-0.35	-0.45	-0.29	-0.39	-0.36	-0.47	-0.40	-0.49	-0.24	-0.29	-0.40	-0.43	-0.43	-0.38	-0.38	0.07
232	-0.34	-0.31	-0.28	-0.33	-0.32	-0.43	-0.27	-0.35	-0.32	-0.44	-0.38	-0.45	-0.22	-0.28	-0.38	-0.42	-0.38	-0.41	-0.35	0.07
239	-0.30	-0.28	-0.27	-0.31	-0.28	-0.40	-0.25	-0.31	-0.28	-0.41	-0.36	-0.41	-0.20	-0.27	-0.35	-0.39	-0.37	-0.39	-0.33	0.06
247	-0.25	-0.25	-0.26	-0.28	-0.25	-0.37	-0.23	-0.27	-0.24	-0.38	-0.34	-0.37	-0.18	-0.26	-0.32	-0.36	-0.36	-0.37	-0.30	0.06
254	-0.20	-0.22	-0.24	-0.26	-0.21	-0.34	-0.21	-0.22	-0.21	-0.34	-0.32	-0.31	-0.16	-0.25	-0.30	-0.32	-0.35	-0.35	-0.27	0.06
262	-0.16	-0.19	-0.23	-0.24	-0.18	-0.30	-0.19	-0.17	-0.18	-0.31	-0.30	-0.26	-0.14	-0.23	-0.27	-0.26	-0.34	-0.33	-0.24	0.06
270	-0.13	-0.16	-0.22	-0.22	-0.16	-0.26	-0.18	-0.13	-0.15	-0.27	-0.28	-0.19	-0.12	-0.20	-0.25	-0.20	-0.33	-0.31	-0.21	0.06
277	-0.11	-0.13	-0.21	-0.20	-0.14	-0.23	-0.16	-0.09	-0.13	-0.24	-0.26	-0.13	-0.10	-0.18	-0.23	-0.13	-0.32	-0.29	-0.18	0.07
285	-0.10	-0.10	-0.20	-0.18	-0.12	-0.19	-0.15	-0.05	-0.12	-0.21	-0.24	-0.07	-0.08	-0.15	-0.21	-0.06	-0.31	-0.27	-0.16	0.08
292	-0.12	-0.08	-0.19	-0.17	-0.12	-0.17	-0.13	-0.03	-0.11	-0.18	-0.22	0.00	-0.07	-0.12	-0.19	0.00	-0.30	-0.26	-0.14	0.08
300	-0.12	-0.06	-0.18	-0.17	-0.13	-0.14	-0.12	-0.03	-0.10	-0.16	-0.20	0.05	-0.05	-0.08	-0.17	0.04	-0.30	-0.25	-0.12	0.09
308	-0.13	-0.05	-0.17	-0.17	-0.14	-0.12	-0.11	-0.05	-0.15	-0.15	-0.19	0.10	-0.04	-0.05	-0.16	0.05	-0.29	-0.24	-0.12	0.10
315	-0.13	-0.04	-0.17	-0.15	-0.16	-0.11	-0.10	-0.06	-0.20	-0.15	-0.17	0.13	-0.03	-0.03	-0.16	0.00	-0.28	-0.24	-0.11	0.10
323	-0.14	-0.04	-0.16	-0.17	-0.19	-0.11	-0.10	-0.07	-0.24	-0.12	-0.16	0.16	-0.03	-0.01	-0.15	-0.01	-0.28	-0.23	-0.11	0.10
330	-0.15	-0.02	-0.16	-0.18	-0.21	-0.09	-0.09	-0.27	-0.17	-0.16	0.16	-0.02	0.01	-0.15	-0.03	-0.27	-0.27	-0.12	0.11	
338	-0.16	-0.04	-0.16	-0.19	-0.22	-0.10	-0.09	-0.11	-0.28	-0.22	-0.15	0.20	-0.02	0.01	-0.17	-0.06	-0.27	-0.30	-0.13	0.12
346	-0.17	-0.08	-0.18	-0.20	-0.23	-0.13	-0.09	-0.13	-0.28	-0.25	-0.15	0.15	-0.02	0.03	-0.19	-0.10	-0.26	-0.32	-0.14	0.12
353	-0.18	-0.12	-0.20	-0.20	-0.24	-0.16	-0.10	-0.15	-0.28	-0.26	-0.19	0.09	0.03	0.01	-0.22	-0.13	-0.26	-0.33	-0.16	0.11
361	-0.19	-0.17	-0.23	-0.20	-0.24	-0.19	-0.11	-0.17	-0.28	-0.27	-0.20	0.02	0.01	-0.04	-0.25	-0.17	-0.26	-0.33	-0.18	0.10
368	-0.19	-0.20	-0.26	-0.20	-0.24	-0.22	-0.14	-0.19	-0.28	-0.27	-0.21	-0.05	0.00	-0.09	-0.28	-0.20	-0.25	-0.33	-0.20	0.09
376	-0.20	-0.23	-0.27	-0.20	-0.24	-0.24	-0.17	-0.20	-0.28	-0.27	-0.22	-0.10	-0.02	-0.14	-0.30	-0.23	-0.25	-0.33	-0.22	0.08
384	-0.21	-0.26	-0.28	-0.20	-0.25	-0.25	-0.20	-0.21	-0.28	-0.27	-0.24	-0.14	-0.04	-0.19	-0.32	-0.25	-0.23	-0.33	-0.23	0.07
391	-0.22	-0.27	-0.29	-0.20	-0.25	-0.26	-0.23	-0.22	-0.28	-0.27	-0.26	-0.17	-0.05	-0.23	-0.33	-0.27	-0.24	-0.33	-0.24	0.06
399	-0.23	-0.28	-0.29	-0.20	-0.25	-0.26	-0.25	-0.23	-0.28	-0.27	-0.27	-0.18	-0.06	-0.26	-0.34	-0.29	-0.25	-0.33	-0.25	0.06
406	-0.23	-0.29	-0.29	-0.20	-0.25	-0.27	-0.27	-0.24	-0.28	-0.27	-0.29	-0.19	-0.07	-0.29	-0.34	-0.30	-0.25	-0.33	-0.26	0.06
414	-0.24	-0.29	-0.29	-0.20	-0.25	-0.27	-0.28	-0.24	-0.28	NA	-0.26									

Table 9. North and south regions' Sea Surface Temperature indices: Initiation, Maximum, End, Duration, Rates of Warming and Cooling of the annual cycle, derived from AVHRR between 1998 and 2016. See methods for the indices' definitions.

SST	NORTH										SOUTH									
	Year	Initiation ("C)	Maximum ("C)	End ("C)	Initiation (doy)	Maximum (doy)	End (doy)	Duration (days)	WarmRate ("C*100/day)	CoolRate ("C*100/day)	Initiation ("C)	Maximum ("C)	End ("C)	Initiation (doy)	Maximum (doy)	End (doy)	Duration (days)	WarmRate ("C*100/day)	CoolRate ("C*100/day)	
1998	0.30	13.03	0.23	125	224	353	228	12.86	9.92	1.06	16.01	1.45	102	232	376	274	11.50	10.11		
1999	0.07	12.21	0.21	118	224	353	235	11.46	9.31	1.87	17.13	3.01	102	232	353	251	11.74	11.67		
2000	0.39	13.83	0.24	140	224	346	206	15.99	11.14	2.33	16.69	0.48	118	232	384	266	12.60	10.67		
2001	-0.29	11.03	-0.19	118	232	368	250	9.93	8.25	0.86	16.79	1.37	118	239	384	266	13.17	10.64		
2002	0.15	11.34	0.32	133	224	338	205	12.29	9.67	1.81	15.63	1.43	133	232	353	220	13.96	11.74		
2003	-0.12	12.31	0.94	125	239	346	221	10.90	10.62	1.27	16.31	1.91	133	239	376	243	14.19	10.51		
2004	1.00	13.85	0.79	148	224	346	198	16.91	10.71	2.72	16.39	2.47	140	224	361	221	16.27	10.16		
2005	0.33	13.13	0.62	118	232	353	235	11.22	10.34	2.44	16.78	2.88	125	239	368	243	12.58	10.77		
2006	0.01	13.32	0.10	102	232	361	259	10.24	10.25	2.23	16.33	1.20	110	224	391	281	12.37	9.05		
2007	0.28	10.82	0.18	133	224	353	220	11.58	8.25	1.63	15.83	1.25	125	239	376	251	12.46	10.65		
2008	0.16	14.13	0.12	125	232	361	236	13.05	10.86	2.11	15.66	1.20	133	216	399	266	16.33	7.90		
2009	-0.38	11.46	0.33	125	224	338	213	11.96	9.77	2.22	16.24	1.81	125	224	346	221	14.15	11.82		
2010	0.42	13.01	1.30	133	239	346	213	11.88	10.94	2.34	16.37	2.68	133	239	376	243	13.23	9.99		
2011	0.67	11.66	0.35	133	239	353	220	10.37	9.93	1.89	14.85	2.34	110	239	361	251	10.05	10.26		
2012	0.20	13.96	0.34	125	232	353	228	12.86	11.25	2.59	17.91	1.88	118	232	376	258	13.44	11.14		
2013	0.15	10.88	-0.31	125	232	361	236	10.03	8.68	1.97	17.34	1.31	118	239	368	250	12.70	12.43		
2014	0.03	14.31	-0.01	140	224	353	213	17.00	11.10	1.44	17.35	2.44	133	224	376	243	17.49	9.81		
2015	-0.73	10.62	-0.24	118	232	353	235	9.95	8.97	1.79	15.00	1.47	125	247	368	243	10.82	11.18		
2016	-0.16	11.30	-0.17	133	224	361	228	12.59	8.37	2.04	15.45	0.99	133	224	391	258	14.74	8.66		

Table 10. North and south regions' CHL indices: Initiation, Maximum, End and Duration of the spring cycle remotely-sensed-derived between 1998 and 2015. See methods for the indices' definitions.

CHL - SPR	NORTH							SOUTH						
	Year	Initiation $\text{Log}_{10}(\text{mg} \cdot \text{m}^{-3})$	Maximum $\text{Log}_{10}(\text{mg} \cdot \text{m}^{-3})$	End $\text{Log}_{10}(\text{mg} \cdot \text{m}^{-3})$	Initiation (doy)	Maximum (doy)	End (doy)	Duration (days)	Initiation $\text{Log}_{10}(\text{mg} \cdot \text{m}^{-3})$	Maximum $\text{Log}_{10}(\text{mg} \cdot \text{m}^{-3})$	End $\text{Log}_{10}(\text{mg} \cdot \text{m}^{-3})$	Initiation (doy)	Maximum (doy)	End (doy)
1998	-0.29	0.24	-0.38	68	132	180	112	-0.28	0.27	-0.43	68	116	148	80
1999	-0.34	0.25	-0.26	60	116	164	104	-0.21	0.42	-0.38	60	100	140	80
2000	-0.27	0.30	-0.32	76	124	188	112	-0.25	0.08	-0.38	60	108	148	88
2001	-0.34	0.08	-0.39	84	140	204	120	-0.24	0.25	-0.46	76	116	164	88
2002	-0.29	0.34	-0.30	92	140	180	88	-0.18	0.36	-0.41	76	116	164	88
2003	-0.26	0.33	-0.35	100	140	180	80	-0.27	0.20	-0.47	84	124	172	88
2004	-0.25	0.27	-0.29	76	132	164	88	-0.24	0.33	-0.37	68	116	156	88
2005	-0.30	0.31	-0.34	76	116	156	80	-0.22	0.26	-0.40	76	108	140	64
2006	-0.25	0.53	-0.28	76	108	140	64	-0.23	0.49	-0.42	68	108	140	72
2007	-0.35	0.35	-0.42	80	133	186	106	-0.23	0.27	-0.53	80	110	156	76
2008	-0.39	0.21	-0.41	95	125	186	91	-0.26	0.22	-0.49	64	118	163	99
2009	-0.33	0.38	-0.42	95	125	186	91	-0.23	0.25	-0.50	34	102	156	122
2010	-0.25	0.21	-0.30	72	102	178	106	-0.16	0.44	-0.27	49	87	140	91
2011	-0.14	0.66	-0.30	87	125	163	76	0.03	0.47	-0.24	87	110	140	53
2012	-0.41	0.34	-0.34	80	118	194	114	-0.26	0.42	-0.26	64	102	133	69
2013	-0.41	0.36	-0.32	72	125	163	91	-0.22	0.54	-0.43	72	110	140	68
2014	-0.33	0.32	-0.34	95	125	163	68	-0.20	0.53	-0.42	64	118	156	92
2015	-0.36	0.28	-0.30	102	133	171	69	-0.19	0.20	-0.47	102	133	163	61

Table 11. North and south regions' CHL indices: Initiation, Maximum, End and Duration of the autumn cycle remotely-sensed-derived between 1998 and 2015. See methods for the indices' definitions.

CHL - AUT	NORTH							SOUTH						
	Year	Initiation $\text{Log}_{10}(\text{mg} \cdot \text{m}^{-3})$	Maximum $\text{Log}_{10}(\text{mg} \cdot \text{m}^{-3})$	End $\text{Log}_{10}(\text{mg} \cdot \text{m}^{-3})$	Initiation (doy)	Maximum (doy)	End (doy)	Duration (days)	Initiation $\text{Log}_{10}(\text{mg} \cdot \text{m}^{-3})$	Maximum $\text{Log}_{10}(\text{mg} \cdot \text{m}^{-3})$	End $\text{Log}_{10}(\text{mg} \cdot \text{m}^{-3})$	Initiation (doy)	Maximum (doy)	End (doy)
1998	-0.40	0.00	-0.29	220	300	356	136	-0.49	-0.10	-0.23	204	292	417	213
1999	-0.32	-0.14	-0.31	212	292	356	144	-0.39	-0.02	-0.26	204	340	393	189
2000	-0.39	-0.15	-0.36	220	308	369	149	-0.40	-0.16	-0.27	164	348	385	221
2001	-0.40	-0.10	-0.30	244	300	356	112	-0.46	-0.15	-0.19	196	324	348	152
2002	-0.35	-0.01	-0.33	228	292	340	112	-0.42	-0.12	-0.23	204	300	356	152
2003	-0.36	-0.02	-0.28	252	300	348	96	-0.50	-0.09	-0.25	212	340	393	181
2004	-0.33	0.00	-0.30	236	292	417	181	-0.41	-0.09	-0.27	180	356	417	237
2005	-0.38	-0.04	-0.28	236	292	377	141	-0.44	-0.03	-0.22	212	308	401	189
2006	-0.42	-0.07	-0.30	212	324	377	165	-0.49	-0.10	-0.27	196	308	340	144
2007	-0.48	-0.13	-0.37	209	285	399	190	-0.53	-0.12	-0.25	201	323	346	145
2008	-0.42	-0.01	-0.42	224	300	406	182	-0.50	-0.15	-0.27	178	346	399	221
2009	-0.40	0.25	-0.31	239	346	406	167	-0.51	0.20	-0.14	216	338	384	168
2010	-0.32	0.21	-0.23	216	308	346	130	-0.36	0.03	-0.06	186	353	399	213
2011	-0.32	-0.04	-0.38	232	292	323	91	-0.27	0.03	-0.26	239	346	399	160
2012	-0.36	-0.10	-0.44	216	292	361	145	-0.48	-0.15	-0.32	194	330	384	190
2013	-0.36	-0.11	-0.41	239	300	399	160	-0.39	0.05	-0.27	239	308	391	152
2014	-0.39	-0.16	-0.40	209	292	384	175	-0.46	-0.23	-0.26	171	384	422	251
2015	-0.36	-0.12	-0.41	216	300	346	130	-0.47	-0.23	-0.32	201	323	346	145

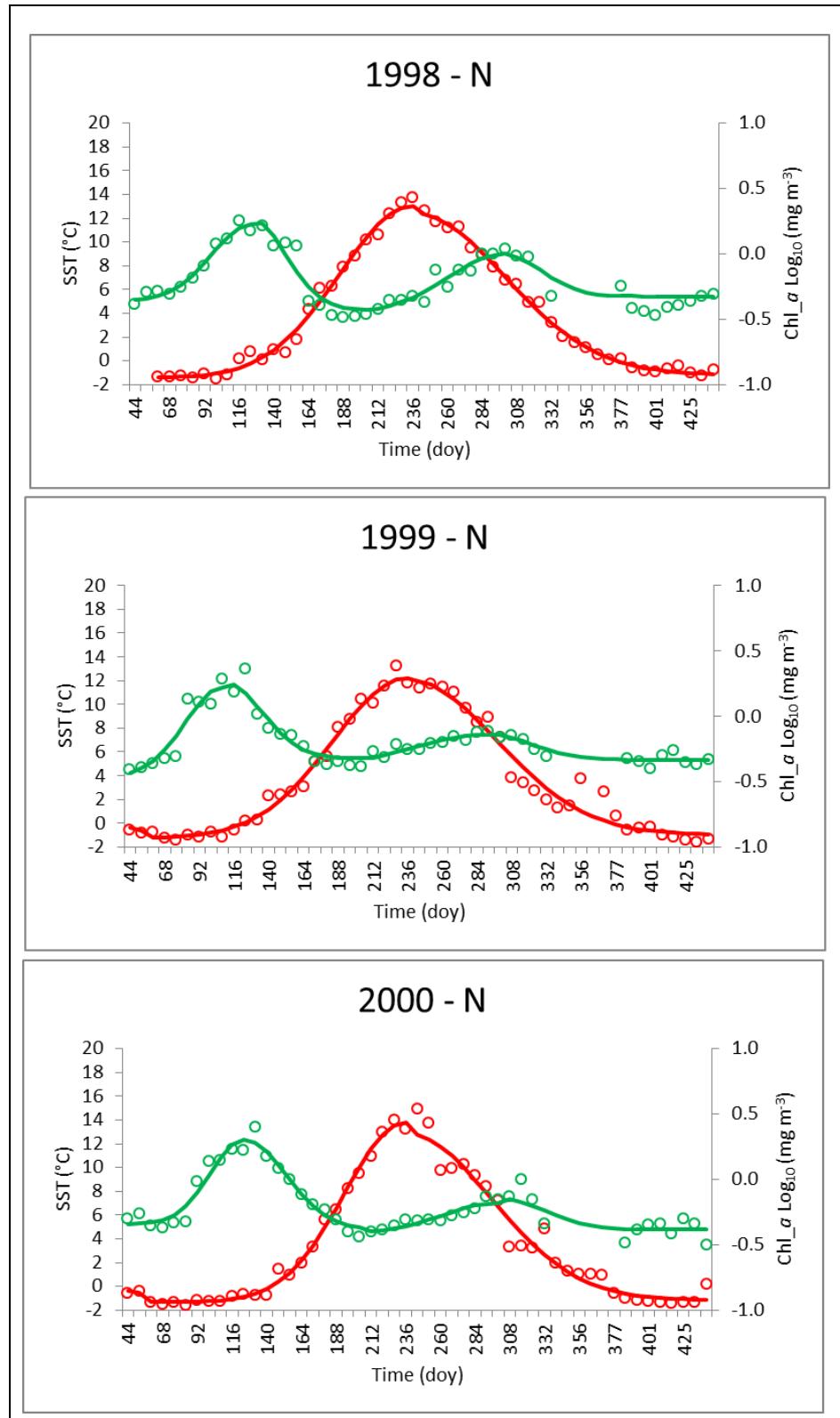
Table 12. Population Development Index of Calanus finmarchicus in the northern and southern areas, for the spring (1999 - 2015) and autumn (1999 - 2014) seasons.

Year	NORTH		SOUTH	
	SPRING	AUTUMN	SPRING	AUTUMN
1999	57.42	13.62	67.49	52.16
2000	42.51	15.99	47.63	28.58
2001	44.61	3.21	43.17	12.23
2002	37.02	5.32	47.48	16.90
2003	27.66	25.17	41.64	27.36
2004	47.28	5.62	51.56	19.08
2005	49.70	9.74	68.75	25.07
2006	56.09	18.57	65.98	18.28
2007	34.54	14.44	44.19	33.10
2008	44.18	12.94	37.89	26.59
2009	49.29	23.59	46.02	30.57
2010	21.13	8.85	53.22	35.20
2011	38.20	8.76	60.29	21.93
2012	51.51	9.22	52.95	24.75
2013	45.45	20.02	53.11	24.86
2014	48.41	11.72	44.45	11.25
2015	55.20		43.71	

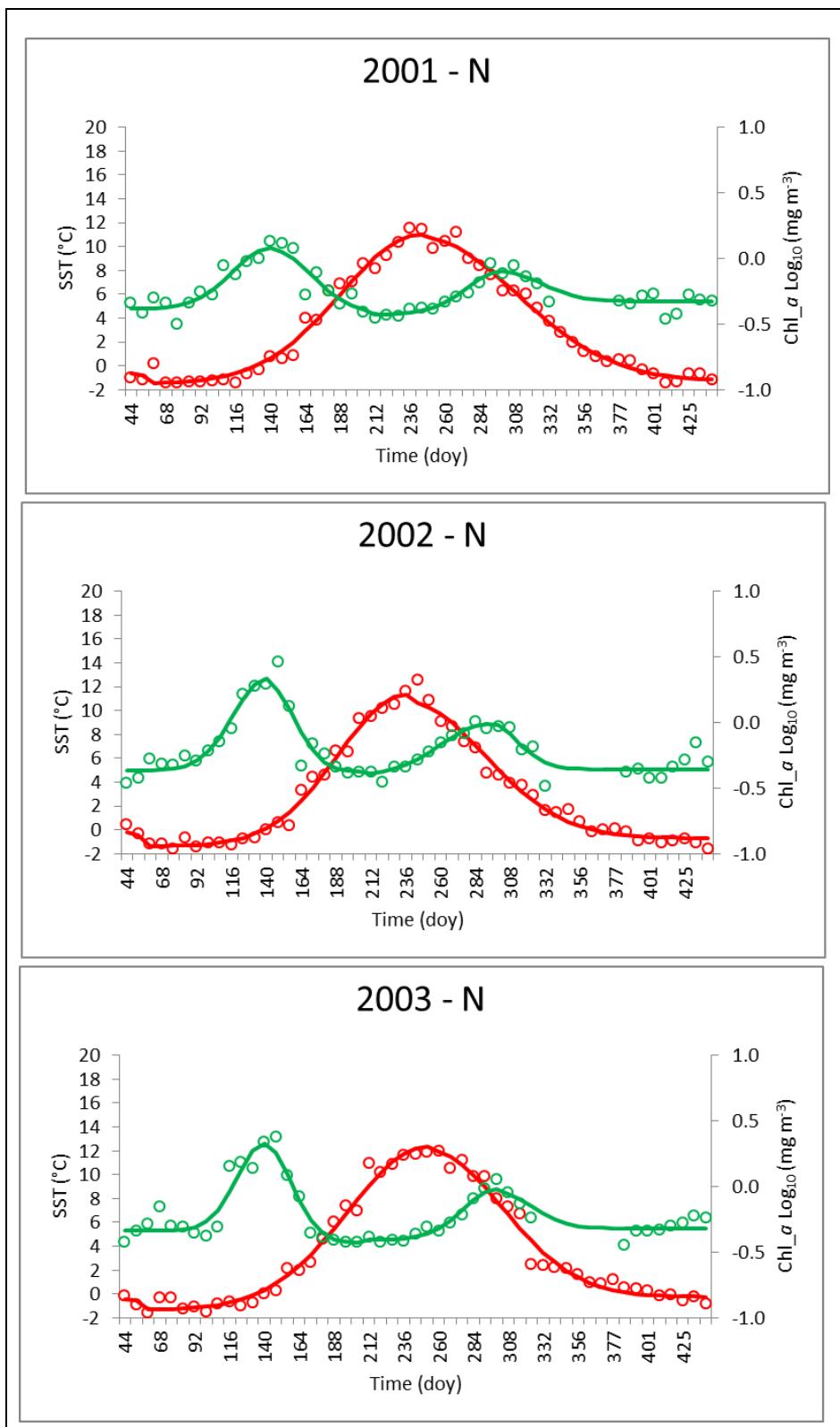
APPENDICES

APPENDIX 1.

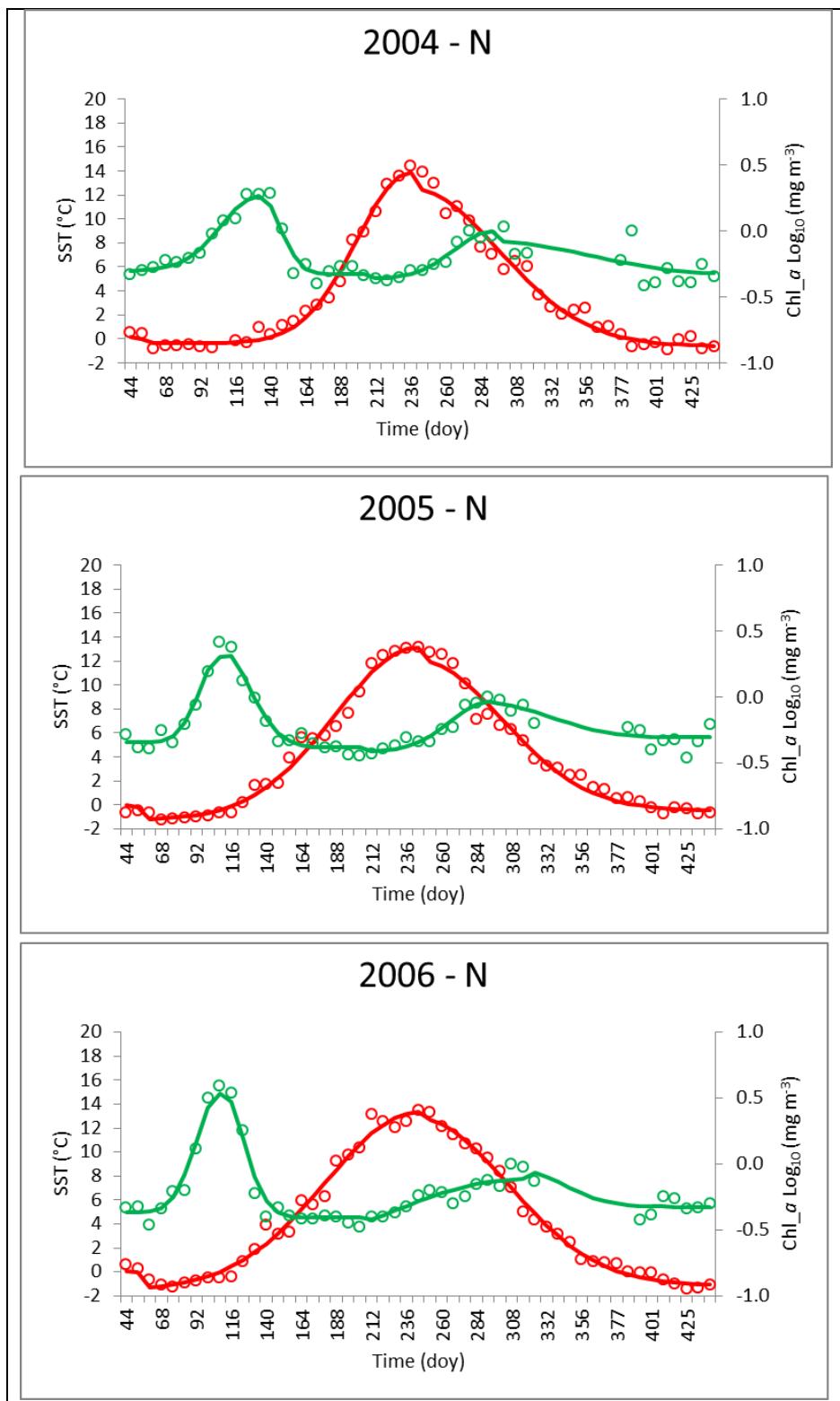
Northern and southern region weekly values (1998 to 2015) of satellite-derived Chlorophyll_a and AVHRR derived SST and their corresponding fitted curves.



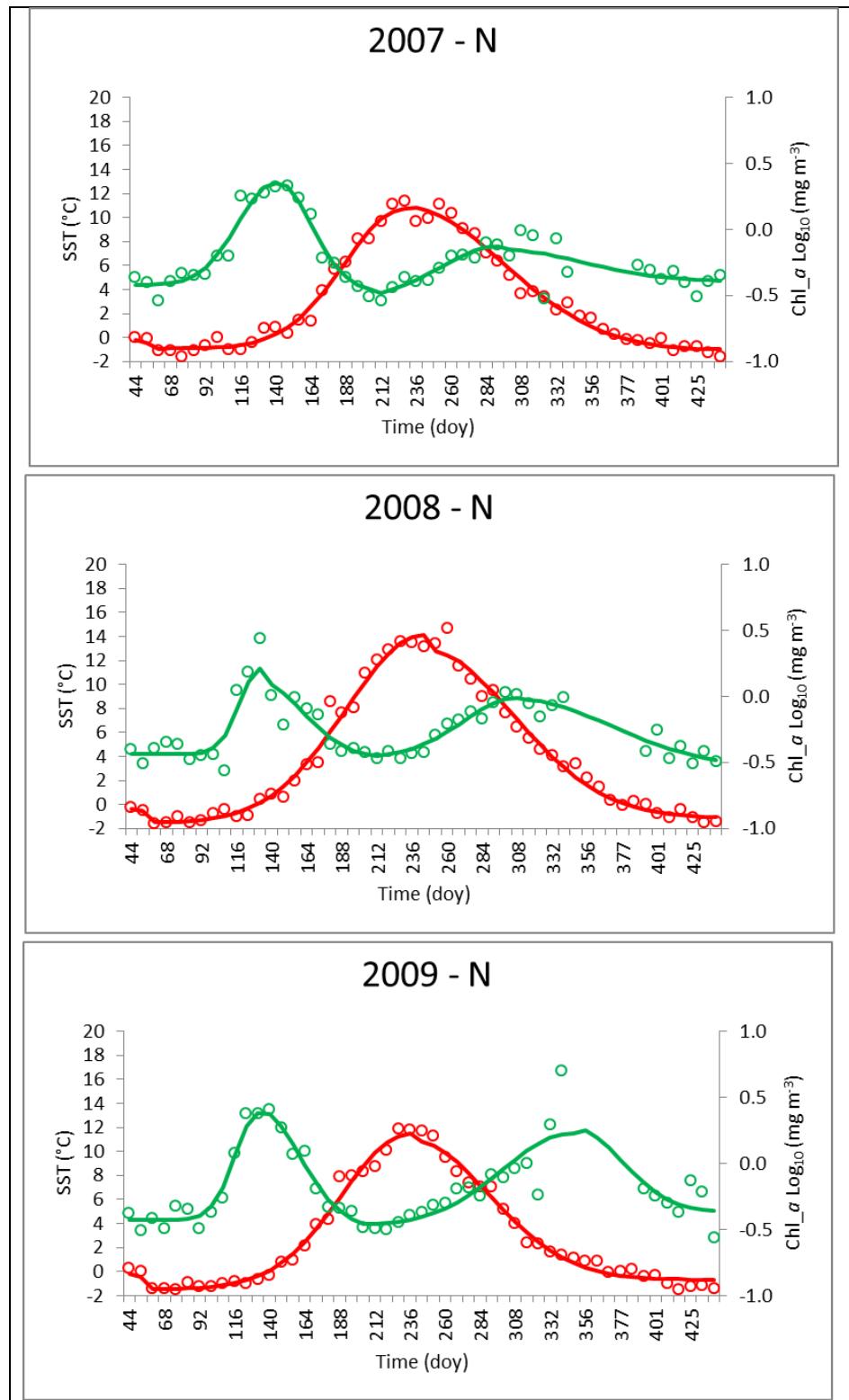
Figures APX1-1. Northern region weekly values (1998 to 2000) of satellite-derived Chlorophyll_a (\log_{10} (mg m^{-3})) in green colour, and AVHRR derived SST ($^{\circ}\text{C}$) in red colour; they are referred to the right and left axes, respectively. Open symbols represent satellite-data and solid lines fitted data. The abscissa axes (day of year) extends beyond the year 365 days to show the cycle conclusions.



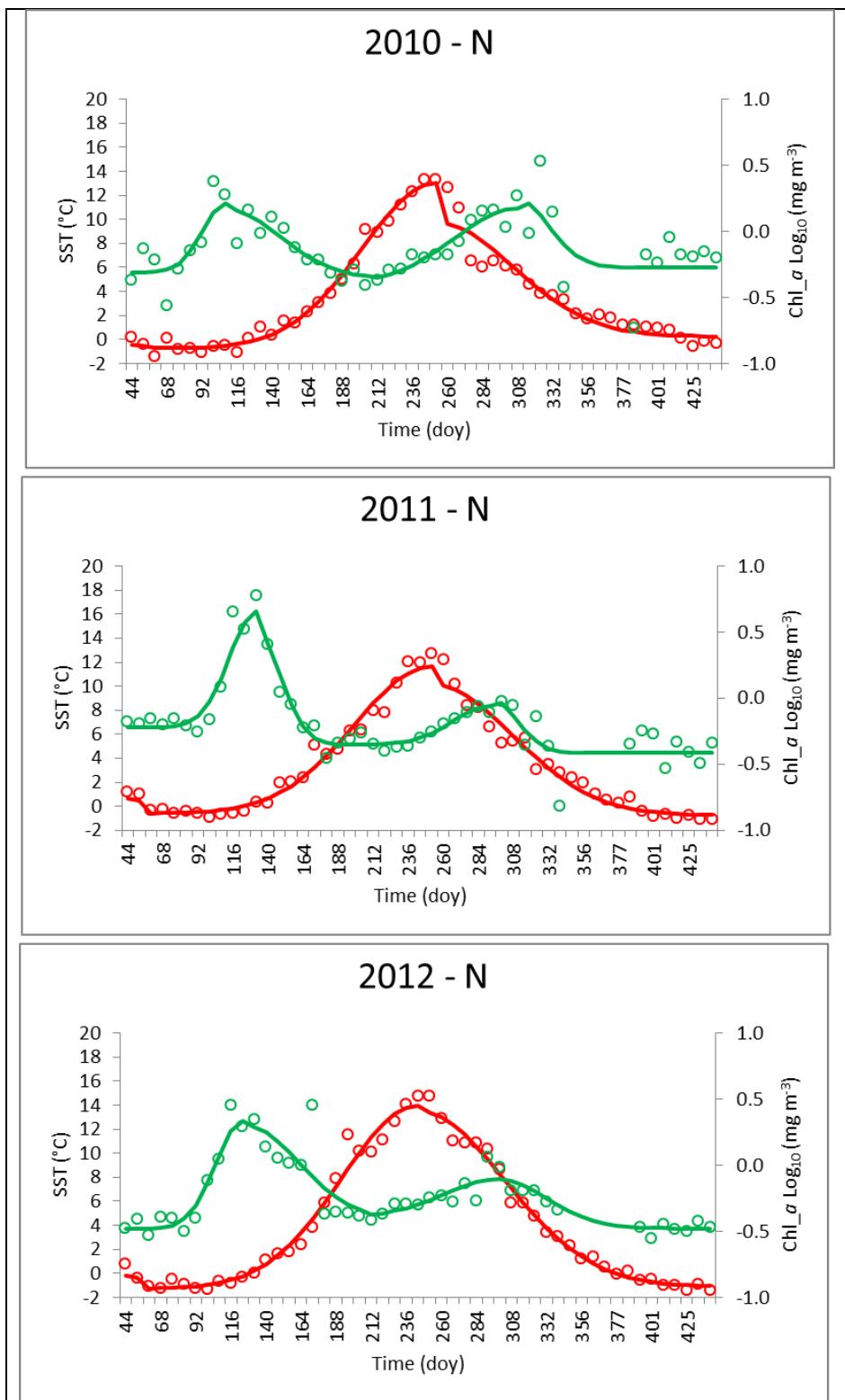
Figures APX1-2. Northern region weekly values (2001 to 2003) of satellite-derived Chlorophyll_a (\log_{10} (mg m^{-3})) in green colour, and AVHRR derived SST ($^{\circ}\text{C}$) in red colour; they are referred to the right and left axes, respectively. Open symbols represent satellite-data and solid lines fitted data. The abscissa axes (day of year) extends beyond the year 365 days to show the cycle conclusions.



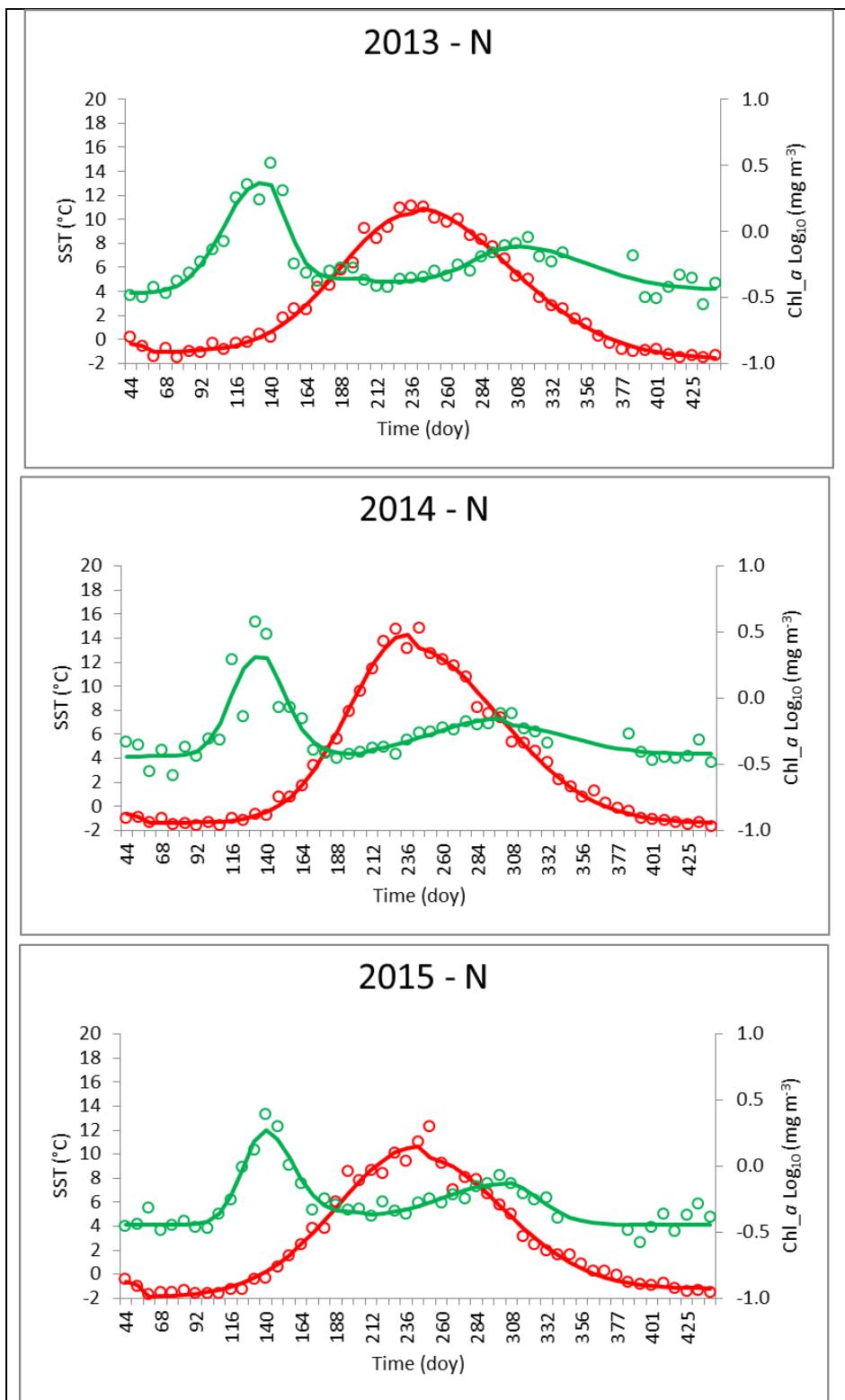
Figures APX1-3. Northern region weekly values (2004 to 2006) of satellite-derived Chlorophyll_a ($\text{Log}_{10}(\text{mg m}^{-3})$) in green colour, and AVHRR derived SST ($^{\circ}\text{C}$) in red colour; they are referred to the right and left axes, respectively. Open symbols represent satellite-data and solid lines fitted data. The abscissa axes (day of year) extends beyond the year 365 days to show the cycle conclusions.



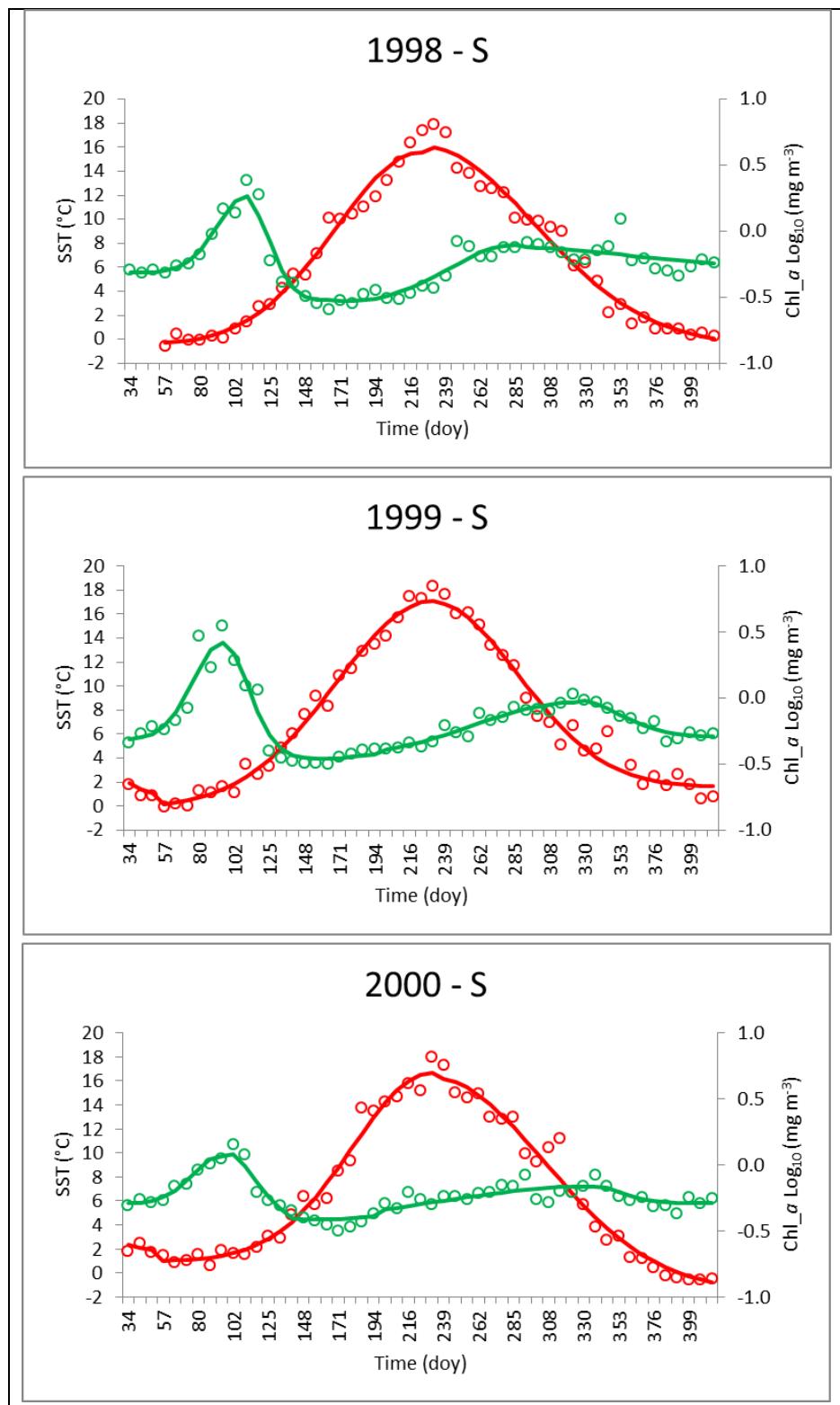
Figures APX1-4. Northern region weekly values (2007 to 2009) of satellite-derived Chlorophyll α ($\text{Log}_{10} (\text{mg m}^{-3})$) in green colour, and AVHRR derived SST ($^{\circ}\text{C}$) in red colour; they are referred to the right and left axes, respectively. Open symbols represent satellite-data and solid lines fitted data. The abscissa axes (day of year) extends beyond the year 365 days to show the cycle conclusions.



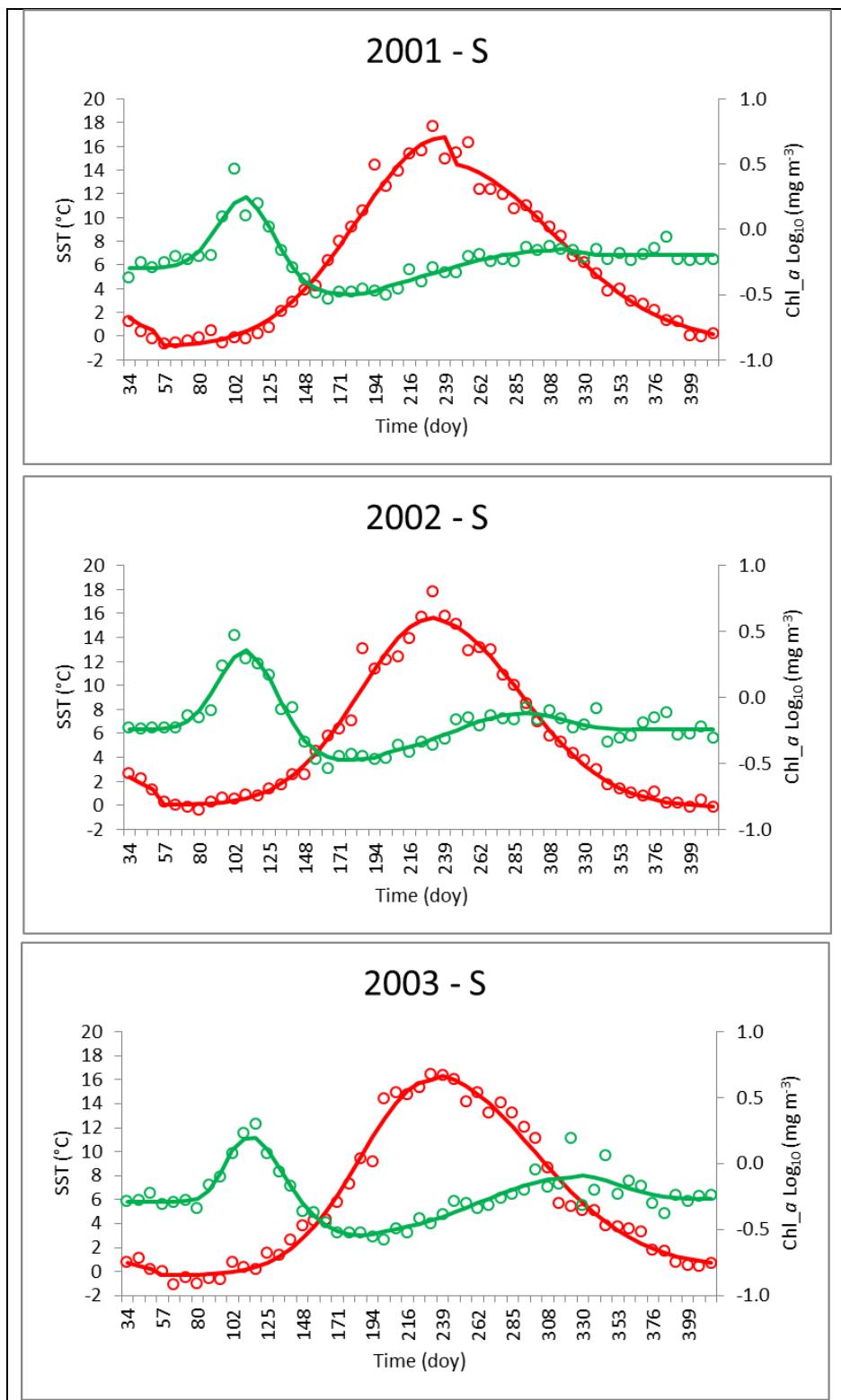
Figures APX1-5. Northern region weekly values (2010 to 2012) of satellite-derived Chlorophyll_a ($\text{Log}_{10}(\text{mg m}^{-3})$) in green colours, and AVHRR derived SST ($^{\circ}\text{C}$) in red colour; they are referred to the right and left axes, respectively. Open symbols represent satellite-data and solid lines fitted data. The abscissa axes (day of year) extends beyond the year 365 days to show the cycle conclusions.



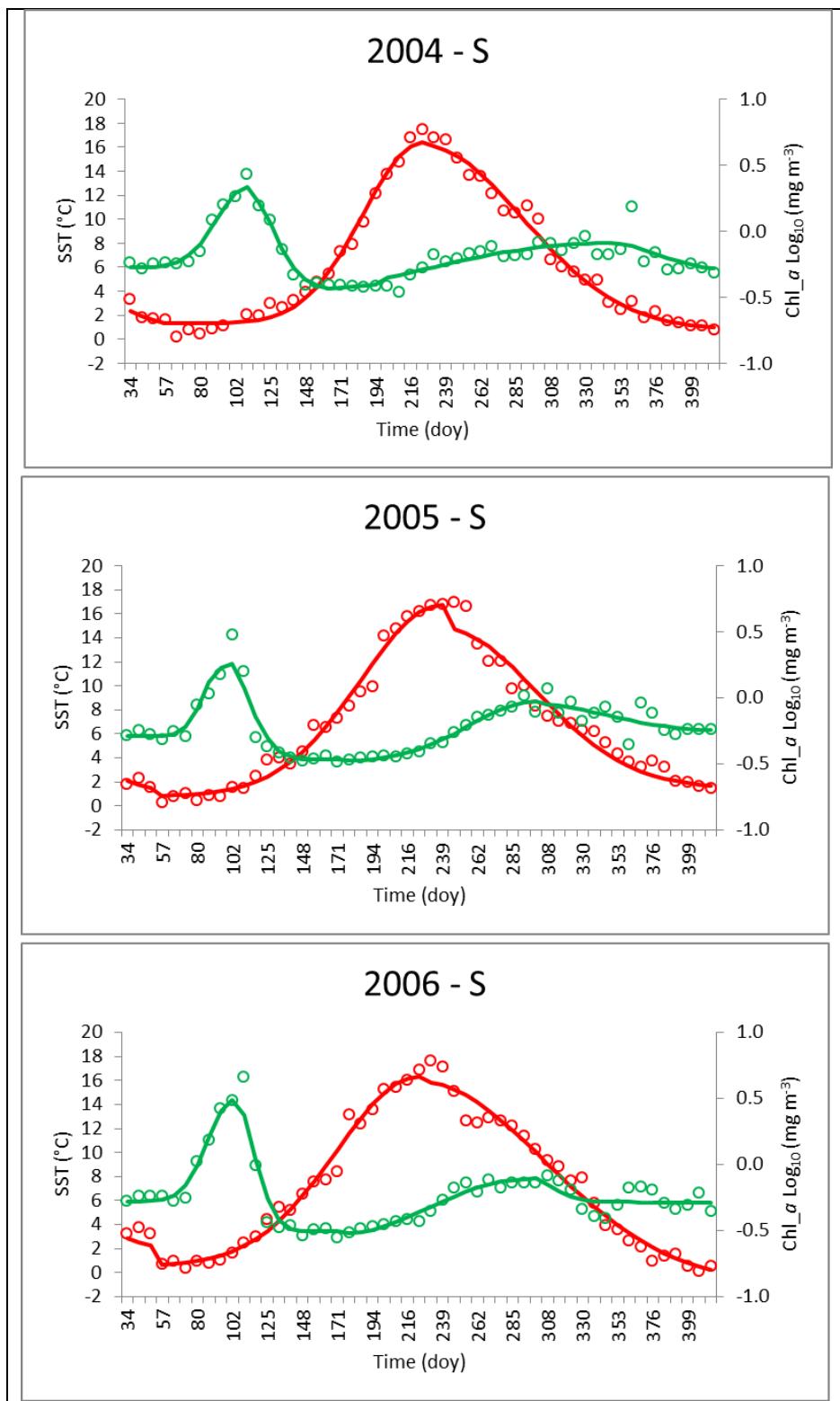
Figures APX1-6. Northern region weekly values (2013 to 2015) of satellite-derived Chlorophyll_a ($\text{Log}_{10}(\text{mg m}^{-3})$) in green colour, and AVHRR derived SST ($^{\circ}\text{C}$) in red colour; they are referred to the right and left axes, respectively. Open symbols represent satellite-data and solid lines fitted data. The abscissa axes (day of year) extends beyond the year 365 days to show the cycle conclusions.



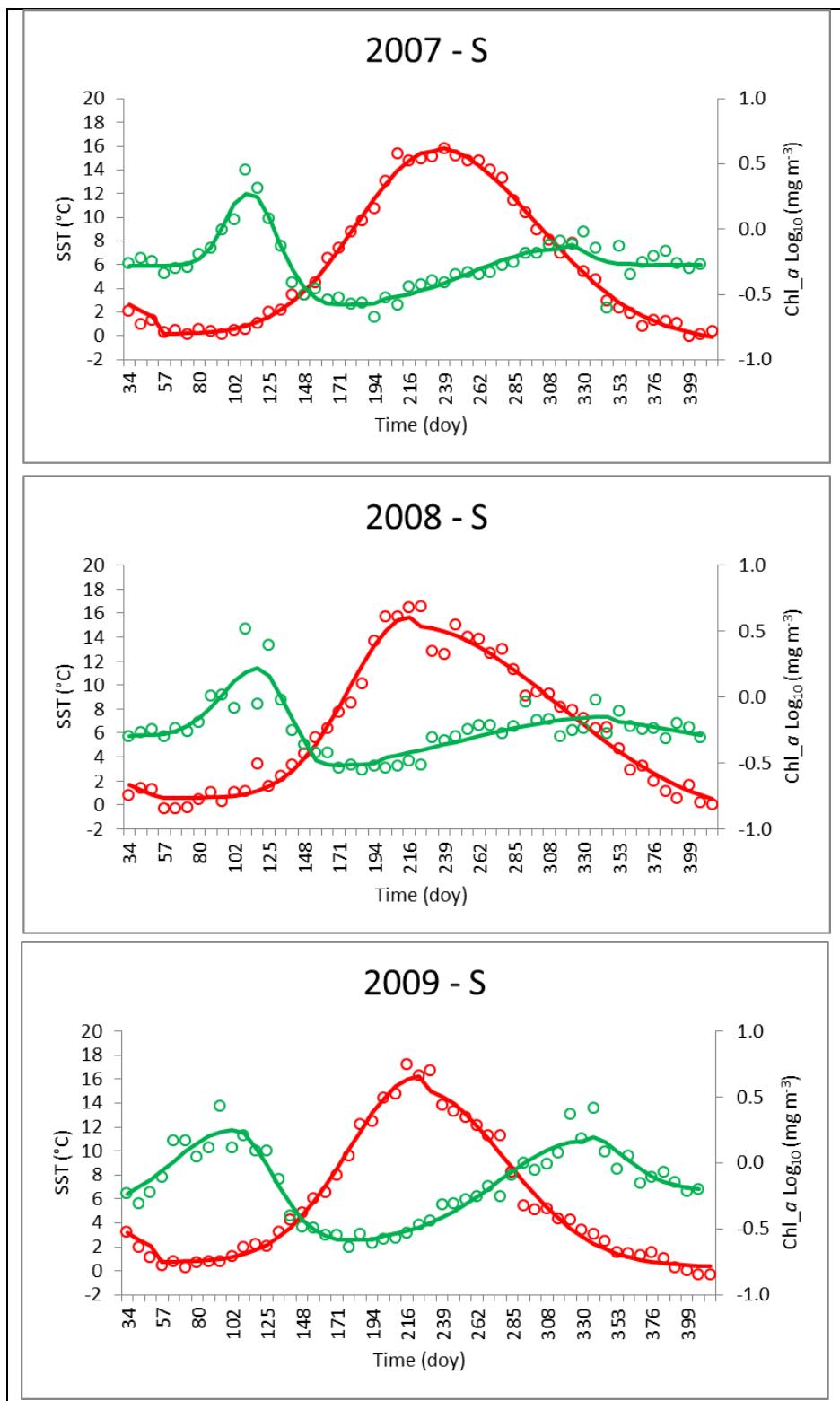
Figures APX1-7. Southern region weekly values (1998 to 2000) of satellite-derived Chlorophyll α (Log $_{10}$ (mg m^{-3})) in green colour, and AVHRR derived SST ($^{\circ}\text{C}$) in red colour; they are referred to the right and left axes, respectively. Open symbols represent satellite-data and solid lines fitted data. The abscissa axes (day of year) extends beyond the year 365 days to show the cycle conclusions.



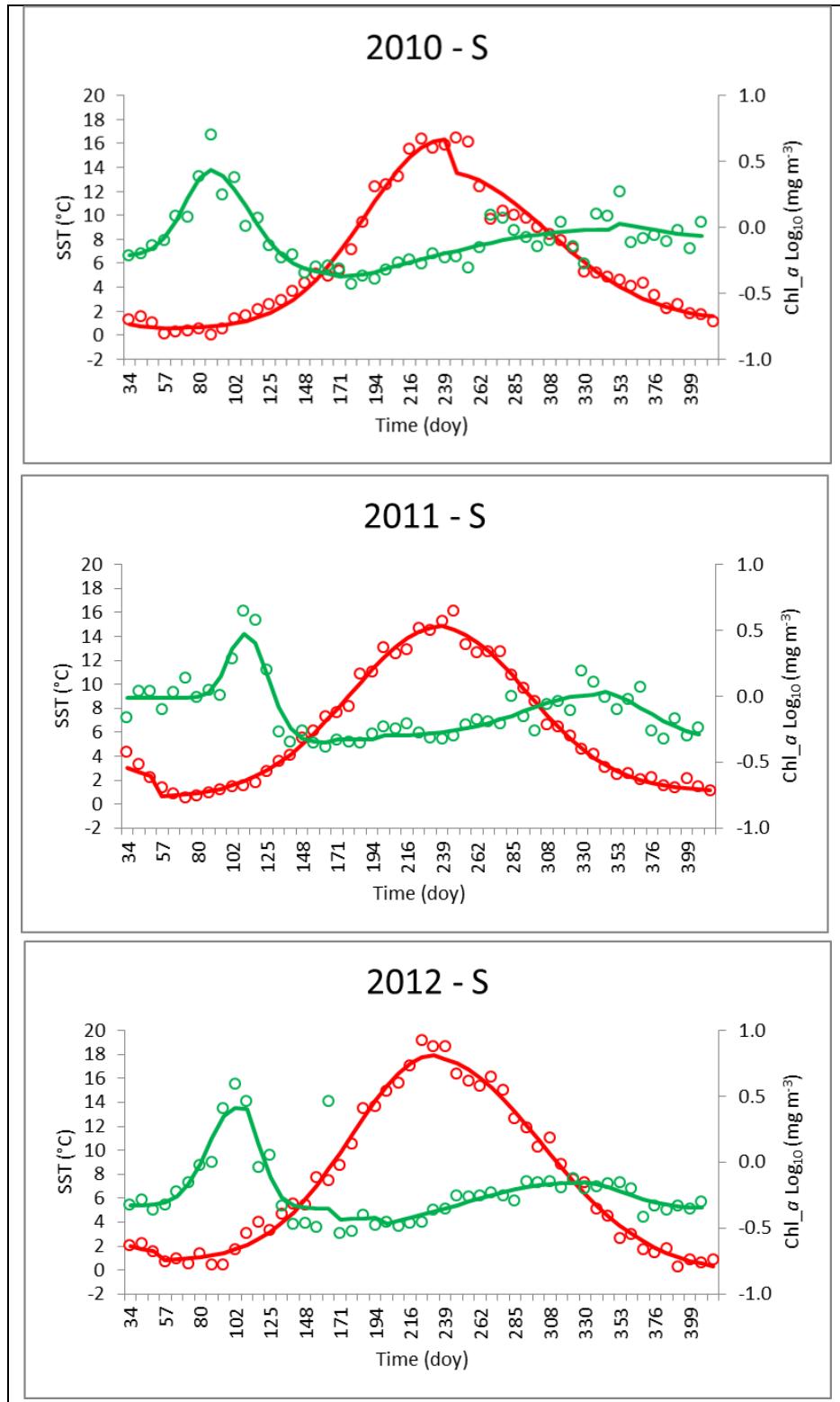
Figures APX1-8. Southern region weekly values (2001 to 2003) of satellite-derived Chlorophyll_a ($\text{Log}_{10}(\text{mg m}^{-3})$) in green colour, and AVHRR derived SST ($^{\circ}\text{C}$) in red colour; they are referred to the right and left axes, respectively. Open symbols represent satellite-data and solid lines fitted data. The abscissa axes (day of year) extends beyond the year 365 days to show the cycle conclusions.



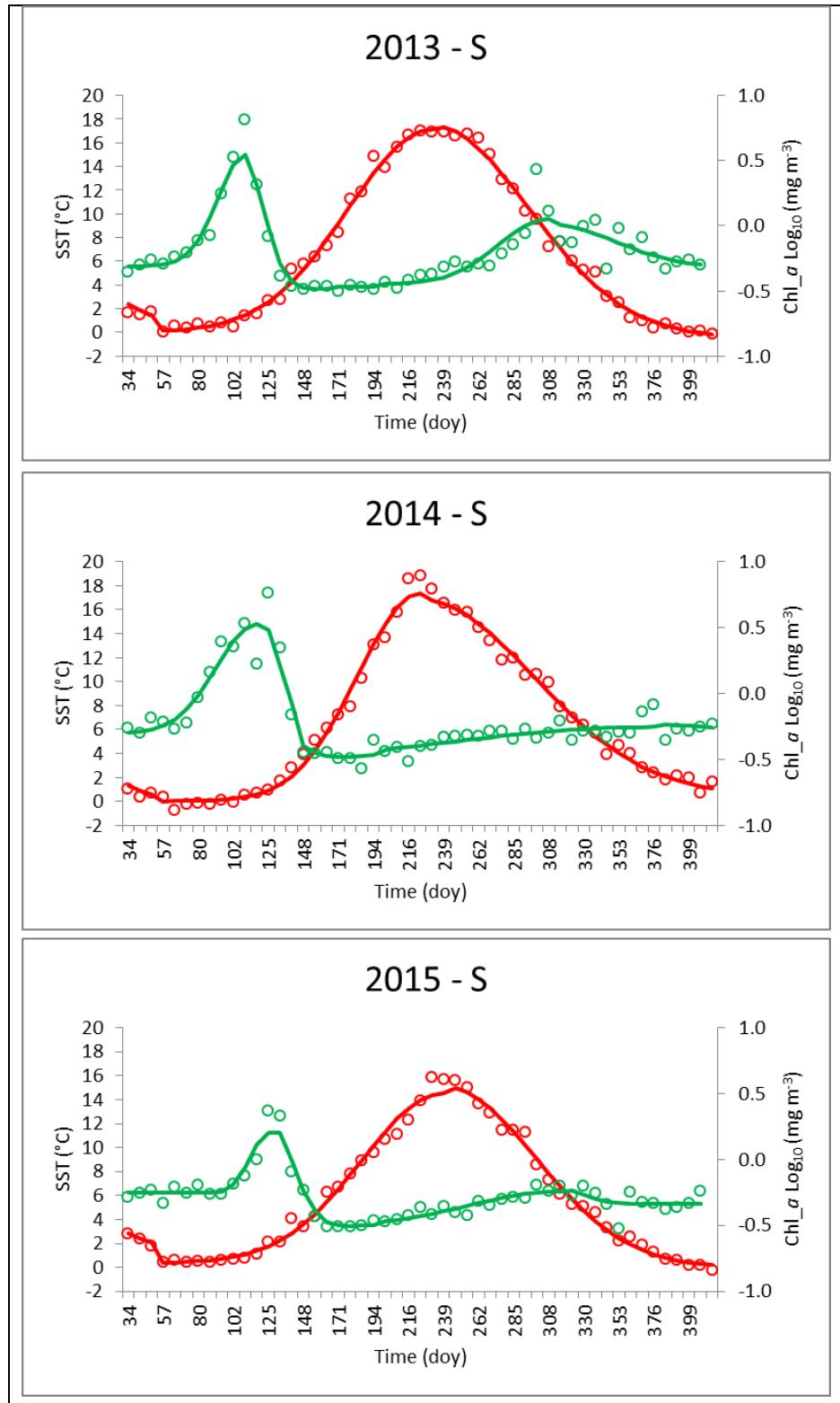
Figures APX1-9. Southern region weekly values (2004 to 2006) of satellite-derived Chlorophyll_a ($\text{Log}_{10}(\text{mg m}^{-3})$) in green colour, and AVHRR derived SST ($^{\circ}\text{C}$) in red colour; they are referred to the right and left axes, respectively. Open symbols represent satellite-data and solid lines fitted data. The abscissa axes (day of year) extends beyond the year 365 days to show the cycle conclusions.



Figures APX1-10. Southern region weekly values (2007 to 2009) of satellite-derived Chlorophyll $_{\alpha}$ (Log $_{10}$ (mg m^{-3})) in green colour, and AVHRR derived SST ($^{\circ}\text{C}$) in red colour; they are referred to the right and left axes, respectively. Open symbols represent satellite-data and solid lines fitted data. The abscissa axes (day of year) extends beyond the year 365 days to show the cycle conclusions.



Figures APX1-11. Southern region weekly values (2010 to 2012) of satellite-derived Chlorophyll α (Log $_{10}$ (mg m^{-3})) in green colour, and AVHRR derived SST ($^{\circ}\text{C}$) in red colour; they are referred to the right and left axes, respectively. Open symbols represent satellite-data and solid lines fitted data. The abscissa axes (day of year) extends beyond the year 365 days to show the cycle conclusions.



Figures APX1-12. Southern region weekly values (2013 to 2015) of satellite-derived Chlorophyll α (Log $_{10}$ (mg m^{-3})) in green colour, and AVHRR derived SST ($^{\circ}\text{C}$) in red colour; they are referred to the right and left axes, respectively. Open symbols represent satellite-data and solid lines fitted data. The abscissa axes (day of year) extends beyond the year 365 days to show the cycle conclusions.

APPENDIX 2

Graphs of thermal indices: annual normalized anomalies of ecological indices of SST in the northern and southern areas between 1998 and 2016. The yearly anomaly was computed by subtracting each annual value from the long term average and dividing by its standard deviation ($x - \mu/\sigma$).

Analogous time series of normalized anomalies of seasonal (spring and autumn) phytoplankton bloom indices, for the northern and southern regions for the period between 1998 and 2015.

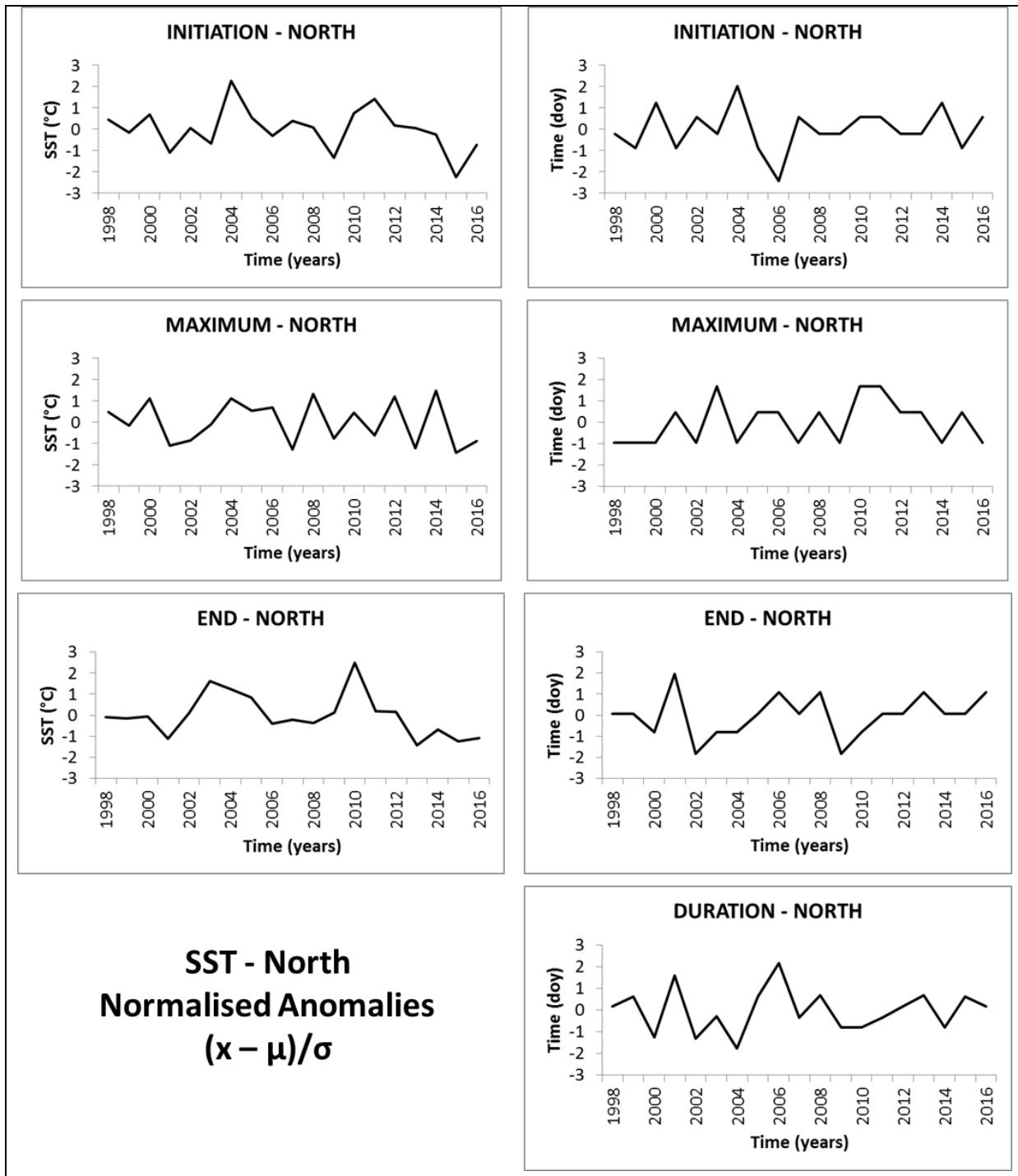


Figure APX2-1. Northern region normalized anomalies of SST indices: values of initiation, maximum, and end are on the left side. The time to reach these values, as well as the duration are on the right side.

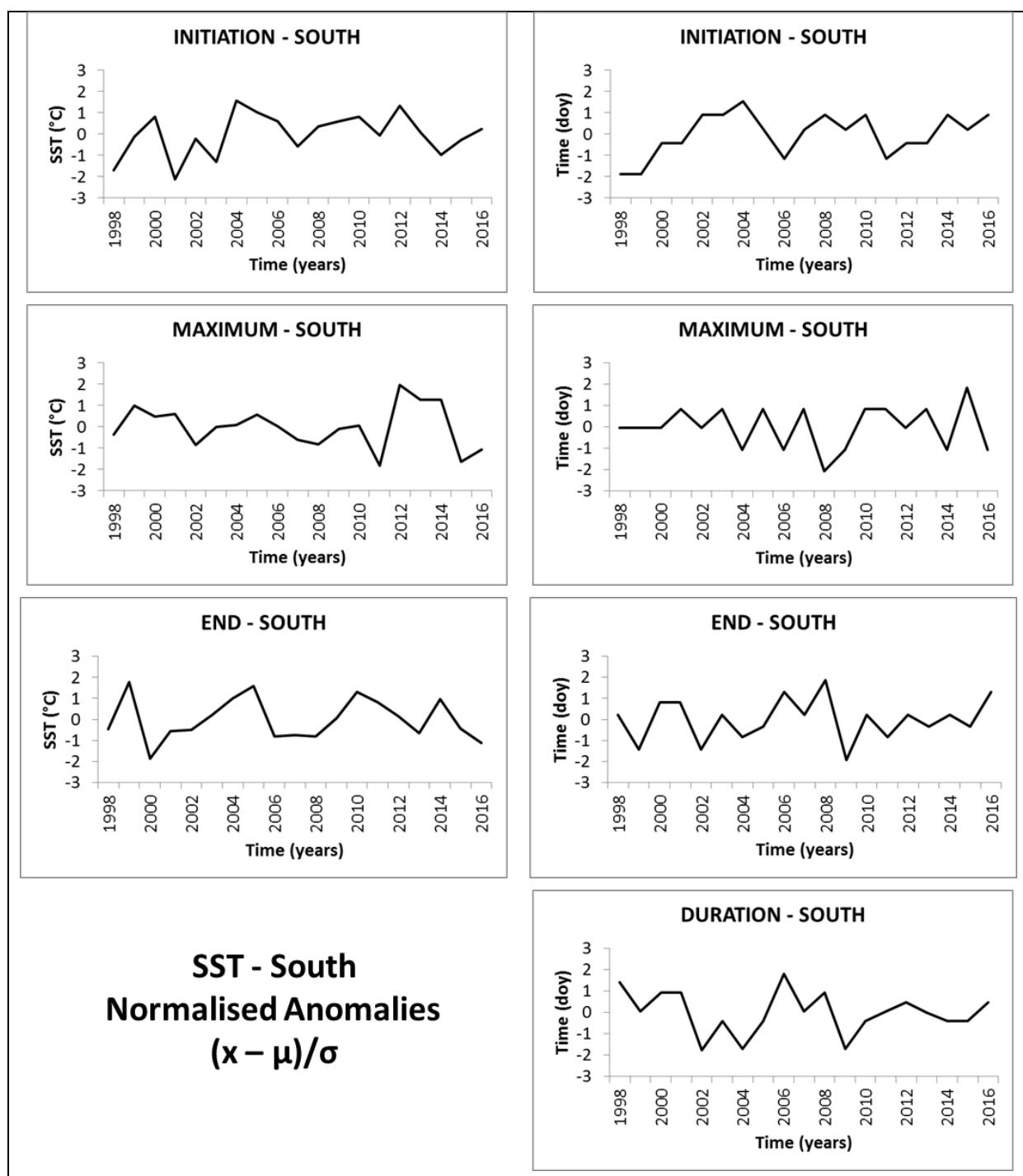


Figure APX2-2. Southern region normalized anomalies of SST indices: values of initiation, maximum, and end are on the left side. The time to reach these values, as well as the duration are on the right side.

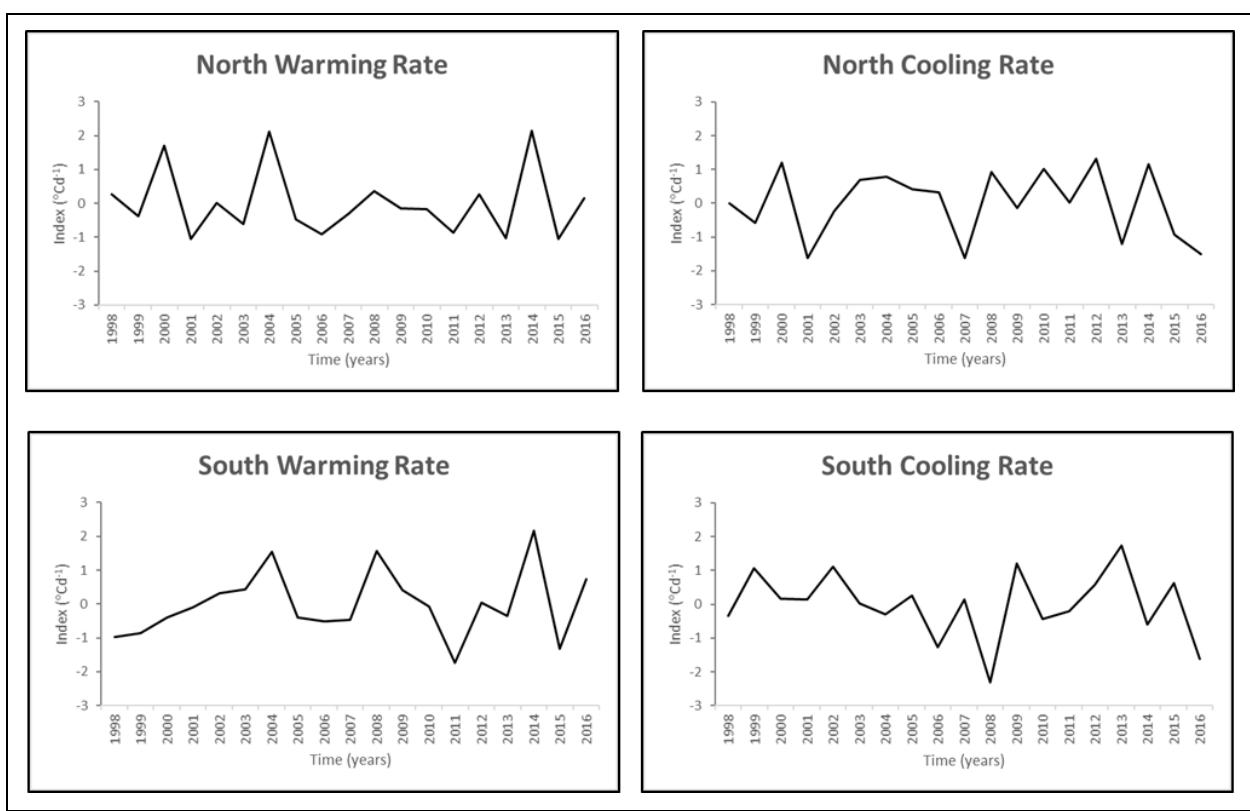


Figure APX2-3. Satellite-derived SST indices. Warming (left) and Cooling (right) Rates, for the North region (top) and South (bottom) regions. Values are annual normalized anomalies [year data (x) minus average (μ), normalized by standard deviation (σ)], between 1998 and 2016.

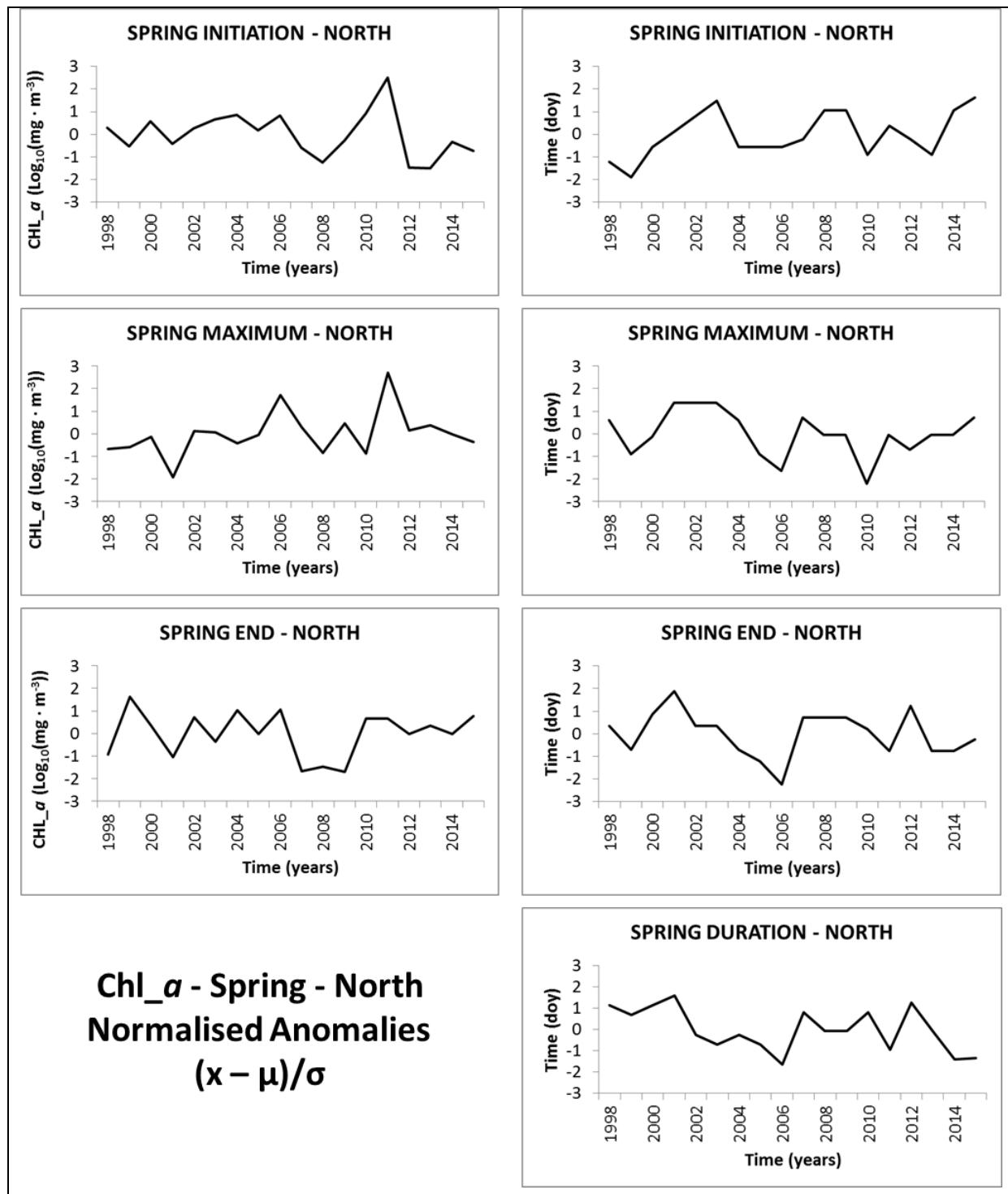


Figure APX2-4. Normalized anomalies of the spring phytoplankton bloom indices in the northern region: values of initiation, maximum, and end are on the left side. The time to reach these values, as well as the duration are on the right side.

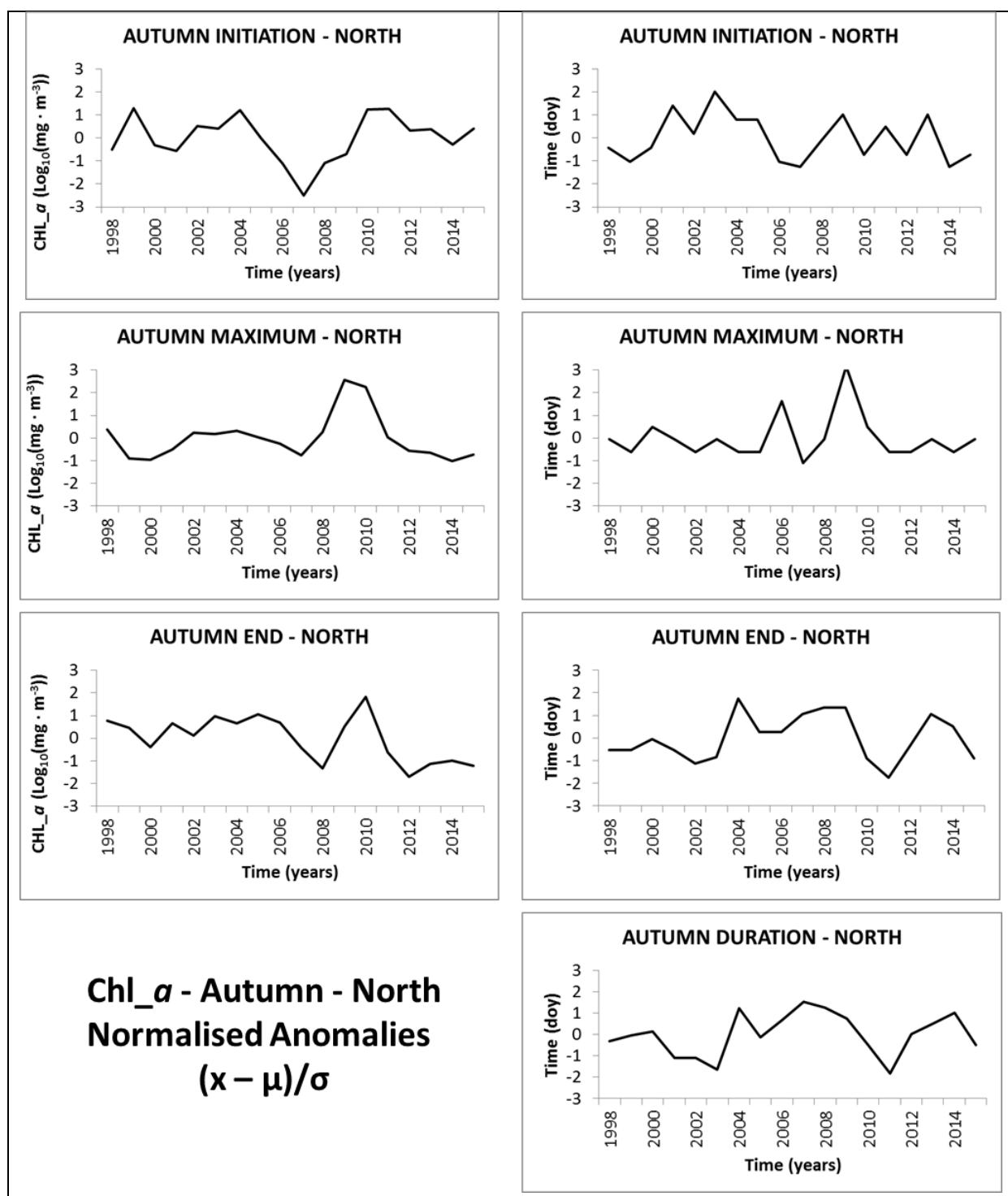


Figure APX2-5. Normalized anomalies of the autumn phytoplankton bloom indices in the northern region: values of initiation, maximum, and end are on the left side. The time to reach these values, as well as the duration are on the right side.

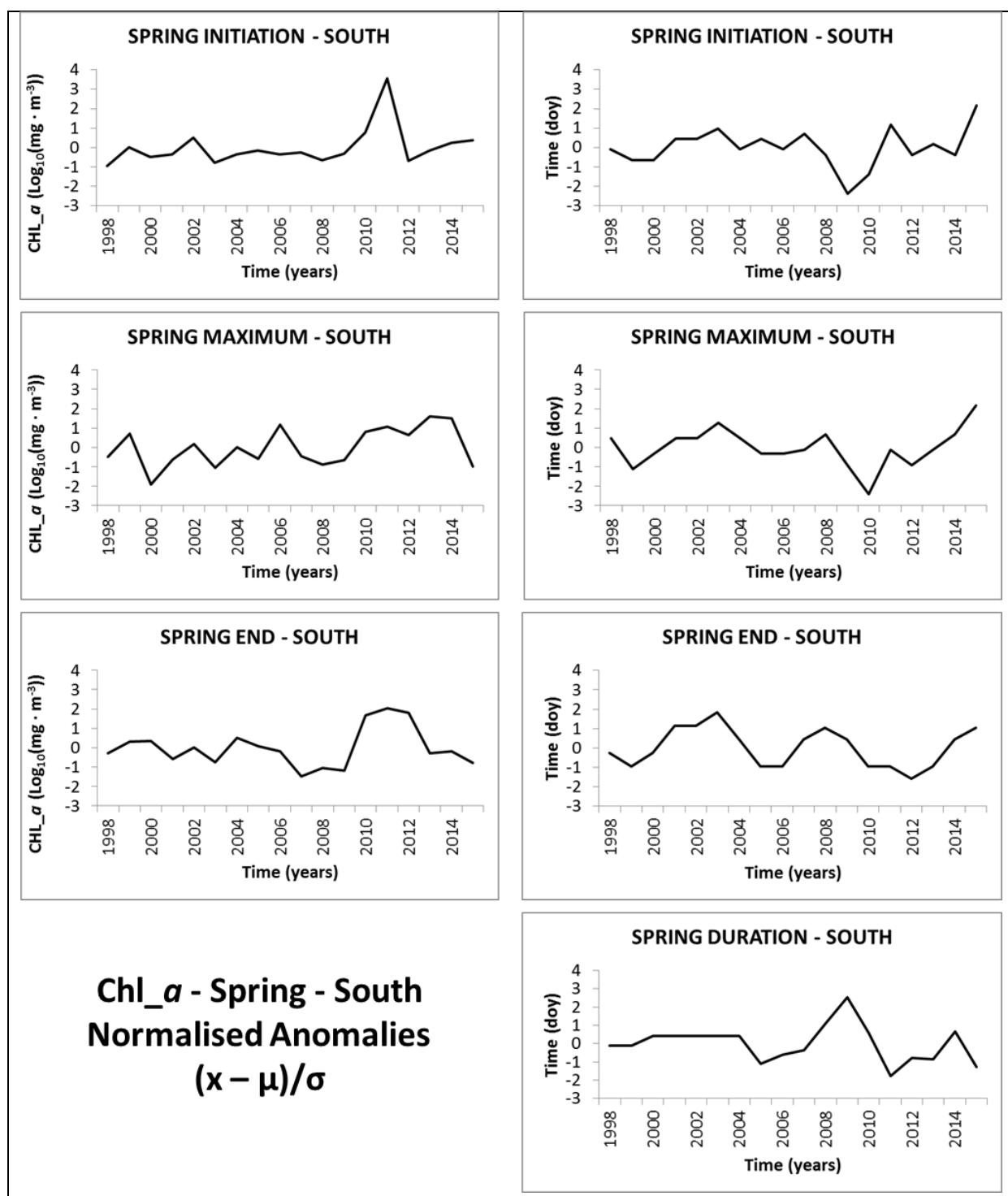


Figure APX2-6. Normalized anomalies of the spring phytoplankton bloom indices in the southern region: values of initiation, maximum, and end are on the left side. The time to reach these values, as well as the duration are on the right side.

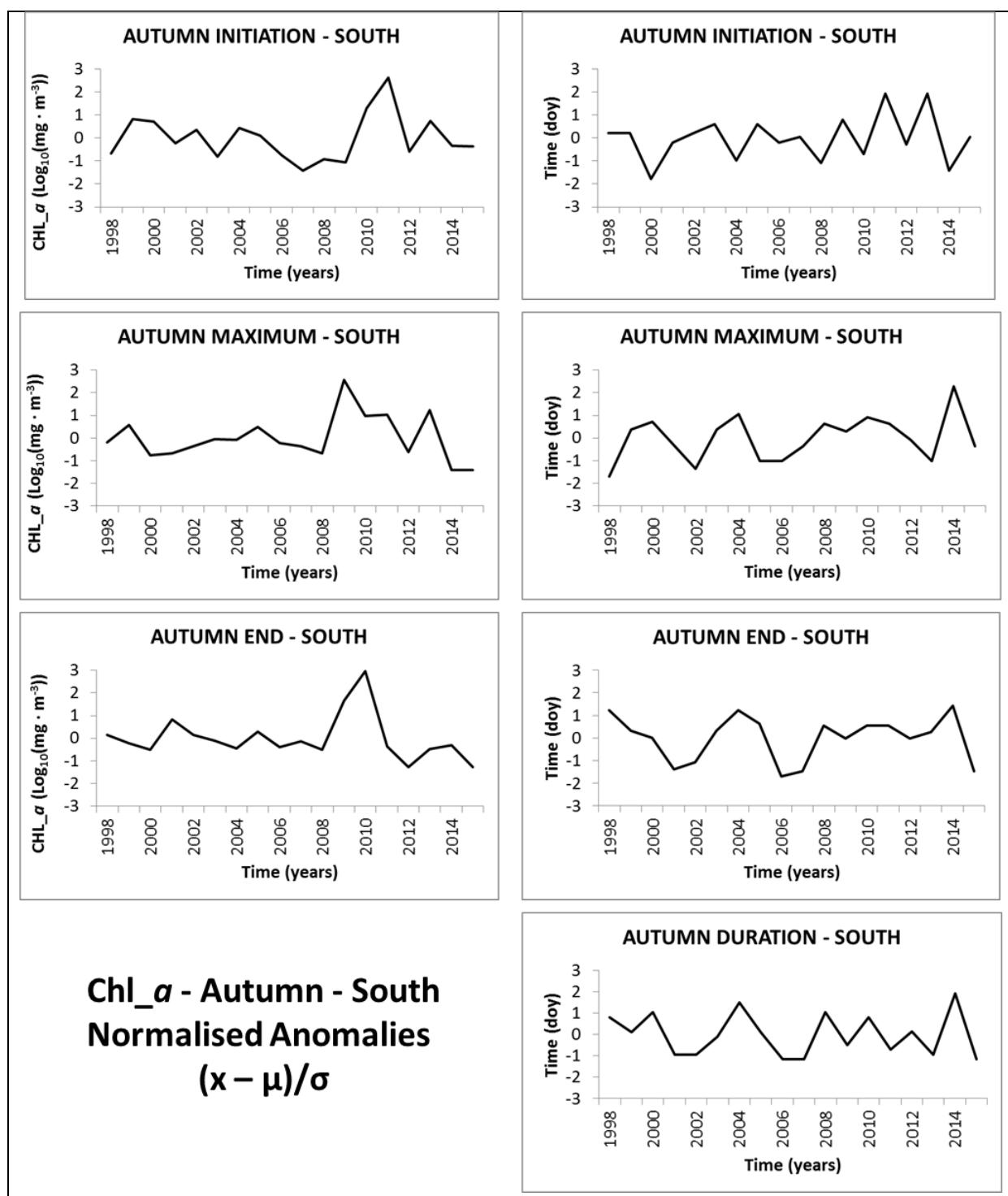


Figure APX2-7. Normalized anomalies of the autumn phytoplankton bloom indices in the southern region: values of initiation, maximum, and end are on the left side. The time to reach these values, as well as the duration are on the right side.

APPENDIX 3.

Statistical reports of the Generalized Additive Models applied in this study.

```

GAM lo.wam loop 1: deviance = 11.3389

*** Generalized Additive Model ***
Call:
gam(formula = CALFINPDI ~ lo(WARMRATE), family = gaussian, data = SDF121,
     na.action = na.exclude, control = list(epsilon = 0.001, bf.epsilon =
     0.001, maxit = 50, bf.maxit = 10, trace = TRUE))

Degrees of Freedom: 16 total; 11.13136 Residual
Residual Deviance: 11.33885

Call: gam(formula = CALFINPDI ~ lo(WARMRATE), family = gaussian, data = SDF121,
     na.action = na.exclude, control = list(epsilon = 0.001, bf.epsilon =
     0.001, maxit = 50, bf.maxit = 10, trace = TRUE))
Deviance Residuals:
    Min      1Q      Median      3Q      Max
-1.770095 -0.3628127 -0.2121118  0.6297863  1.677683
(Dispersion Parameter for Gaussian family taken to be 1.01864 )

Null Deviance: 14.44539 on 15 degrees of freedom
Residual Deviance: 11.33885 on 11.13136 degrees of freedom
Number of Local Scoring Iterations: 1

DF for Terms and F-values for Nonparametric Effects

          Df Npar Df   Npar F     Pr(F)
(Intercept)  1
lo(WARMRATE)  1     2.9 1.010478 0.4213355

```

Figure APX3-1. GAM for Calanus finmarchicus PDI during the spring in the northern region (CALFINPDI), with the Loess smoothed independent variable SST warming rate (WARMRATE).

```

GAM lo.wam loop 1: deviance = 4.8561

*** Generalized Additive Model ***
Call:
gam(formula = CALFINPDI ~ lo(CHLMAXDOY), family = gaussian, data = SDF121,
na.action = na.exclude, control = list(epsilon = 0.001, bf.epsilon =
0.001, maxit = 50, bf.maxit = 10, trace = TRUE))

Degrees of Freedom: 16 total; 10.30777 Residual
Residual Deviance: 4.85614

Call: gam(formula = CALFINPDI ~ lo(CHLMAXDOY), family = gaussian, data = SDF121,
na.action = na.exclude, control = list(epsilon = 0.001, bf.epsilon =
0.001, maxit = 50, bf.maxit = 10, trace = TRUE))
Deviance Residuals:
    Min      1Q  Median      3Q     Max
-1.076609 -0.2960656  0.04785721  0.3617018  1.012544

(Dispersion Parameter for Gaussian family taken to be 0.4711148 )

Null Deviance: 14.44539 on 15 degrees of freedom
Residual Deviance: 4.856145 on 10.30777 degrees of freedom
Number of Local Scoring Iterations: 1

DF for Terms and F-values for Nonparametric Effects

      Df Npar Df   Npar F      Pr(F)
(Intercept) 1
lo(CHLMAXDOY) 1      3.7 5.512331 0.01338071

```

Figure APX3-2. GAM for Calanus finmarchicus PDI during the spring in the northern region (CALFINPDI), with the Loess smoothed independent variable timing at the maximum concentration of phytoplankton biomass (CHMAXDOY).

```

GAM lo.wam loop 1: deviance = 2.0912

*** Generalized Additive Model ***
Call:
gam(formula = CALFINPDI ~ lo(WARMRATE) + lo(CHLMAXDOY), family = gaussian,
      data = SDF107, na.action = na.exclude, control = list(epsilon = 0.001,
      bf.epsilon = 0.001, maxit = 50, bf.maxit = 10, trace = TRUE))

Degrees of Freedom: 17 total; 6.76991 Residual
Residual Deviance: 2.09122

Call: gam(formula = CALFINPDI ~ lo(WARMRATE) + lo(CHLMAXDOY), family = gaussian,
      data = SDF107, na.action = na.exclude, control = list(epsilon = 0.001,
      bf.epsilon = 0.001, maxit = 50, bf.maxit = 10, trace = TRUE))
Deviance Residuals:
    Min        1Q    Median        3Q        Max
-0.5353476 -0.3075984  0.06158205  0.1783794  0.7067614

(Dispersion Parameter for Gaussian family taken to be 0.3088998 )

Null Deviance: 16 on 16 degrees of freedom
Residual Deviance: 2.091225 on 6.769913 degrees of freedom
Number of Local Scoring Iterations: 1

DF for Terms and F-values for Nonparametric Effects

      Df Npar Df      Npar F      Pr(F)
(Intercept) 1
lo(WARMRATE) 1      2.9 5.280927 0.03426712
lo(CHLMAXDOY) 1      4.3 9.519346 0.00614429

```

Figure APX3-3. GAM for Calanus finmarchicus PDI during the spring in the northern region (CALFINPDI). Independent variables are Loess smoothed: SST warming rate (WARMRATE), and timing at the maximum concentration of phytoplankton biomass (CHMAXDOY).

```

GAM lo.wam loop 1: deviance = 14.5882

*** Generalized Additive Model ***
Call:
gam(formula = CALFINPDI ~ lo(COOLRATE), family = gaussian, data = SDF110,
     na.action = na.exclude, control = list(epsilon = 0.001, bf.epsilon =
     0.001, maxit = 50, bf.maxit = 10, trace = TRUE))

Degrees of Freedom: 16 total; 11.4319 Residual
Residual Deviance: 14.58818

Call: gam(formula = CALFINPDI ~ lo(COOLRATE), family = gaussian, data = SDF110,
     na.action = na.exclude, control = list(epsilon = 0.001, bf.epsilon =
     0.001, maxit = 50, bf.maxit = 10, trace = TRUE))
Deviance Residuals:
    Min      1Q  Median      3Q      Max
-1.379397 -0.731536 -0.0991063  0.6566085  1.741267
(Dispersion Parameter for Gaussian family taken to be 1.276094 )

Null Deviance: 15 on 15 degrees of freedom
Residual Deviance: 14.58818 on 11.4319 degrees of freedom
Number of Local Scoring Iterations: 1

DF for Terms and F-values for Nonparametric Effects

          Df Npar Df      Npar F      Pr(F)
(Intercept)  1
lo(COOLRATE)  1      2.6 0.1248105 0.923699

```

Figure APX3-4. GAM for Calanus finmarchicus PDI during the autumn in the northern region (CALFINPDI), with the Loess smoothed independent variable SST cooling rate (COOLRATE).

```

GAM lo.wam loop 1: deviance = 8.4589

*** Generalized Additive Model ***
Call:
gam(formula = CALFINPDI ~ lo(CHLMAXDOY), family = gaussian, data = SDF110,
na.action = na.exclude, control = list(epsilon = 0.001, bf.epsilon =
0.001, maxit = 50, bf.maxit = 10, trace = TRUE))

Degrees of Freedom: 16 total; 10 Residual
Residual Deviance: 8.45895

Call: gam(formula = CALFINPDI ~ lo(CHLMAXDOY), family = gaussian, data = SDF110,
na.action = na.exclude, control = list(epsilon = 0.001, bf.epsilon =
0.001, maxit = 50, bf.maxit = 10, trace = TRUE))
Deviance Residuals:
    Min          1Q      Median          3Q          Max
-1.882066 -0.4152194 -3.330669e-016  0.438929  1.525803
(Dispersion Parameter for Gaussian family taken to be 0.8458947 )

Null Deviance: 15 on 15 degrees of freedom
Residual Deviance: 8.458947 on 10 degrees of freedom
Number of Local Scoring Iterations: 1
DF for Terms and F-values for Nonparametric Effects

      Df Npar Df      Npar F      Pr(F)
(Intercept) 1
lo(CHLMAXDOY) 1        4 0.6014701 0.6702732

```

Figure APX3-5. GAM for Calanus finmarchicus PDI during the autumn in the northern region (CALFINPDI), with the Loess smoothed independent variable timing at the maximum concentration of phytoplankton biomass (CHMAXDOY).

```

GAM lo.wam loop 1: deviance = 4.8595

*** Generalized Additive Model ***
Call:
gam(formula = CALFINPDI ~ lo(COOLRATE) + lo(CHLMAXDOY), family = gaussian,
      data = SDF110, na.action = na.exclude, control = list(epsilon = 0.001,
      bf.epsilon = 0.001, maxit = 50, bf.maxit = 10, trace = TRUE))

Degrees of Freedom: 16 total; 6.4319 Residual
Residual Deviance: 4.8595

Call: gam(formula = CALFINPDI ~ lo(COOLRATE) + lo(CHLMAXDOY), family = gaussian,
      data = SDF110, na.action = na.exclude, control = list(epsilon = 0.001,
      bf.epsilon = 0.001, maxit = 50, bf.maxit = 10, trace = TRUE))
Deviance Residuals:
    Min          1Q      Median          3Q          Max
 -0.9194216 -0.3509444 -0.0004956846  0.4532427  0.9576599

(Dispersion Parameter for Gaussian family taken to be 0.7555303 )

Null Deviance: 15 on 15 degrees of freedom
Residual Deviance: 4.859496 on 6.431901 degrees of freedom
Number of Local Scoring Iterations: 1

DF for Terms and F-values for Nonparametric Effects

      Df Npar Df      Npar F      Pr(F)
(Intercept) 1
lo(COOLRATE) 1      2.6 2.120822 0.1944783
lo(CHLMAXDOY) 1      4.0 2.520904 0.1427924

```

Figure APX3-6. GAM for Calanus finmarchicus PDI during the autumn in the northern region (CALFINPDI). Independent variables are Loess smoothed: SST cooling rate (COOLRATE), and timing at the maximum concentration of phytoplankton biomass (CHLMAXDOY).

```

GAM lo.wam loop 1: deviance = 10.3625

*** Generalized Additive Model ***
Call:
gam(formula = CALFINPDI ~ lo(WARMRATE), family = gaussian, data = SDF5,
     na.action = na.exclude, control = list(epsilon = 0.001, bf.epsilon =
     0.001, maxit = 50, bf.maxit = 10, trace = TRUE))

Degrees of Freedom: 17 total; 11.13729 Residual
Residual Deviance: 10.36249

Call: gam(formula = CALFINPDI ~ lo(WARMRATE), family = gaussian, data = SDF5,
     na.action = na.exclude, control = list(epsilon = 0.001, bf.epsilon =
     0.001, maxit = 50, bf.maxit = 10, trace = TRUE))
Deviance Residuals:
    Min      1Q  Median      3Q     Max
-1.419986 -0.7047705  0.1152242  0.5733799  1.401153
(Dispersion Parameter for Gaussian family taken to be 0.9304319 )

Null Deviance: 16 on 16 degrees of freedom
Residual Deviance: 10.36249 on 11.13729 degrees of freedom
Number of Local Scoring Iterations: 1

DF for Terms and F-values for Nonparametric Effects

      Df Npar Df      Npar F      Pr(F)
(Intercept)  1
lo(WARMRATE)  1      3.9 0.5778572 0.6796068

```

Figure APX3-7. GAM for Calanus finmarchicus PDI during the spring in the southern region (CALFINPDI), with the Loess smoothed independent variable SST warming rate (WARMRATE).

```

GAM lo.wam loop 1: deviance = 9.2606

*** Generalized Additive Model ***
Call:
gam(formula = CALFINPDI ~ lo(CHLMAXMAG), family = gaussian, data = SDF5,
     na.action = na.exclude, control = list(epsilon = 0.001, bf.epsilon =
     0.001, maxit = 50, bf.maxit = 10, trace = TRUE))

Degrees of Freedom: 17 total; 11.34643 Residual
Residual Deviance: 9.2606

Call: gam(formula = CALFINPDI ~ lo(CHLMAXMAG), family = gaussian, data = SDF5,
     na.action = na.exclude, control = list(epsilon = 0.001, bf.epsilon =
     0.001, maxit = 50, bf.maxit = 10, trace = TRUE))
Deviance Residuals:
    Min          1Q      Median          3Q          Max
-0.9601461 -0.6372208  0.008917106  0.2189085  1.969745

(Dispersion Parameter for Gaussian family taken to be 0.8161685 )

Null Deviance: 16 on 16 degrees of freedom
Residual Deviance: 9.260597 on 11.34643 degrees of freedom
Number of Local Scoring Iterations: 1

DF for Terms and F-values for Nonparametric Effects

      Df Npar Df      Npar F      Pr(F)
(Intercept) 1
lo(CHLMAXMAG) 1      3.7 1.135579 0.3845703

```

Figure APX3-8. GAM for Calanus finmarchicus PDI during the spring in the southern region (CALFINPDI), with the Loess smoothed independent variable magnitude of the maximum concentration of phytoplankton biomass (CHMAXMAG).

```

GAM lo.wam loop 1: deviance = 4.6731

*** Generalized Additive Model ***
Call:
gam(formula = CALFINPDI ~ lo(WARMRATE) + lo(CHLMAXMAG), family = gaussian,
      data = SDF5, na.action = na.exclude, control = list(epsilon = 0.001,
      bf.epsilon = 0.001, maxit = 50, bf.maxit = 10, trace = TRUE))

Degrees of Freedom: 17 total; 6.48372 Residual
Residual Deviance: 4.6731

Call: gam(formula = CALFINPDI ~ lo(WARMRATE) + lo(CHLMAXMAG), family = gaussian,
      data = SDF5, na.action = na.exclude, control = list(epsilon = 0.001,
      bf.epsilon = 0.001, maxit = 50, bf.maxit = 10, trace = TRUE))
Deviance Residuals:
    Min          1Q      Median          3Q          Max
 -1.188366 -0.240608 -0.02319241  0.1723137  1.523437

(Dispersion Parameter for Gaussian family taken to be 0.7207428 )

Null Deviance: 16 on 16 degrees of freedom
Residual Deviance: 4.673095 on 6.483721 degrees of freedom
Number of Local Scoring Iterations: 1

DF for Terms and F-values for Nonparametric Effects

      Df Npar Df      Npar F      Pr(F)
(Intercept) 1
lo(WARMRATE) 1      3.9 1.123441 0.4203965
lo(CHLMAXMAG) 1      3.7 1.003061 0.4636926

```

Figure APX3-9. GAM for Calanus finmarchicus PDI during the spring in the southern region (CALFINPDI). Independent variables are Loess smoothed: SST warming rate (WARMRATE), and magnitude of the maximum concentration of phytoplankton biomass (CHMAXMAG).

```

GAM lo.wam loop 1: deviance = 12.593

*** Generalized Additive Model ***
Call:
gam(formula = CALFINPDI ~ lo(COOLRATE), family = gaussian, data = SDF4,
na.action = na.exclude, control = list(epsilon = 0.001, bf.epsilon =
0.001, maxit = 50, bf.maxit = 10, trace = TRUE))

Degrees of Freedom: 17 total; 10.52644 Residual
Residual Deviance: 12.59302

Call: gam(formula = CALFINPDI ~ lo(COOLRATE), family = gaussian, data = SDF4,
na.action = na.exclude, control = list(epsilon = 0.001, bf.epsilon =
0.001, maxit = 50, bf.maxit = 10, trace = TRUE))
Deviance Residuals:
    Min          1Q      Median          3Q          Max
-1.368118 -0.5103715  0.008076848  0.3020448  2.184941

(Dispersion Parameter for Gaussian family taken to be 1.196323 )

Null Deviance: 15.5866 on 16 degrees of freedom
Residual Deviance: 12.59302 on 10.52644 degrees of freedom
Number of Local Scoring Iterations: 1

DF for Terms and F-values for Nonparametric Effects

      Df Npar Df      Npar F      Pr(F)
(Intercept)  1
lo(COOLRATE)  1      4.5 0.4252889 0.8049187

```

*Figure APX3-10. GAM for *Calanus finmarchicus* PDI during the autumn in the southern region (CALFINPDI), with the Loess smoothed independent variable SST cooling rate (COOLRATE).*

```

GAM lo.wam loop 1: deviance = 8.6098

*** Generalized Additive Model ***
Call:
gam(formula = CALFINPDI ~ lo(CHLMAXMAG), family = gaussian, data = SDF4,
na.action = na.exclude, control = list(epsilon = 0.001, bf.epsilon =
0.001, maxit = 50, bf.maxit = 10, trace = TRUE))

Degrees of Freedom: 17 total; 10.4302 Residual
Residual Deviance: 8.6098

Call: gam(formula = CALFINPDI ~ lo(CHLMAXMAG), family = gaussian, data = SDF4,
na.action = na.exclude, control = list(epsilon = 0.001, bf.epsilon =
0.001, maxit = 50, bf.maxit = 10, trace = TRUE))
Deviance Residuals:
    Min          1Q      Median          3Q          Max
-1.128588 -0.4778529 -0.00924342  0.4494094  1.702914

(Dispersion Parameter for Gaussian family taken to be 0.825468 )

Null Deviance: 15.5866 on 16 degrees of freedom
Residual Deviance: 8.609798 on 10.4302 degrees of freedom
Number of Local Scoring Iterations: 1

DF for Terms and F-values for Nonparametric Effects

      Df Npar Df      Npar F      Pr(F)
(Intercept) 1
lo(CHLMAXMAG) 1      4.6 0.9938505 0.4611168

```

Figure APX3-11. GAM for Calanus finmarchicus PDI during the autumn in the southern region (CALFINPDI), with the Loess smoothed independent variable magnitude of the maximum concentration of phytoplankton biomass (CHMAXMAG).

```

GAM lo.wam loop 1: deviance = 7.1217

*** Generalized Additive Model ***
Call:
gam(formula = CALFINPDI ~ lo(COOLRATE) + lo(CHLMAXMAG), family = gaussian,
      data = SDF4, na.action = na.exclude, control = list(epsilon = 0.001,
      bf.epsilon = 0.001, maxit = 50, bf.maxit = 10, trace = TRUE))

Degrees of Freedom: 17 total; 4.95664 Residual
Residual Deviance: 7.12166

Call: gam(formula = CALFINPDI ~ lo(COOLRATE) + lo(CHLMAXMAG), family = gaussian,
      data = SDF4, na.action = na.exclude, control = list(epsilon = 0.001,
      bf.epsilon = 0.001, maxit = 50, bf.maxit = 10, trace = TRUE))
Deviance Residuals:
   3          4          5          6          7          8          10 
 1.34061  0.7033752 -0.9492175 -0.9288544  0.3706524 -0.2560545 -0.9534233 

   11         12         13         14         15         16         17 
-0.3384874  1.107175  0.2049408 -0.01871229  0.4830578 -0.5340619 -0.1285912 

   18         171        182 
-0.1339286 -0.07815436  0.1096741 

(Dispersion Parameter for Gaussian family taken to be 1.436791 )

Null Deviance: 15.5866 on 16 degrees of freedom
Residual Deviance: 7.121657 on 4.956641 degrees of freedom
Number of Local Scoring Iterations: 1

DF for Terms and F-values for Nonparametric Effects

      Df Npar Df      Npar F      Pr(F)
(Intercept) 1
lo(COOLRATE) 1      4.5 0.3585998 0.8437613
lo(CHLMAXMAG) 1      4.6 0.5617794 0.7183947

```

*Figure APX3-12. GAM for *Calanus finmarchicus* PDI during the autumn in the southern region (CALFINPDI). Independent variables are Loess smoothed: SST cooling rate (COOLRATE), and magnitude of the maximum concentration of phytoplankton biomass (CHMAXMAG).*

```

GAM lo.wam loop 1: deviance = 0.0142

*** Generalized Additive Model ***
Call:
gam(formula = LWRSPRNOR ~ lo(CALFINPDI), family = gaussian, data = SDF121,
na.action = na.exclude, control = list(epsilon = 0.001, bf.epsilon =
0.001, maxit = 50, bf.maxit = 10, trace = TRUE))

Degrees of Freedom: 16 total; 10.71268 Residual
Residual Deviance: 0.01417

Call: gam(formula = LWRSPRNOR ~ lo(CALFINPDI), family = gaussian, data = SDF121,
na.action = na.exclude, control = list(epsilon = 0.001, bf.epsilon =
0.001, maxit = 50, bf.maxit = 10, trace = TRUE))
Deviance Residuals:
    Min          1Q      Median          3Q          Max
-0.04027255 -0.02183927 -0.006962394 0.01921585 0.06148665

(Dispersion Parameter for Gaussian family taken to be 0.0013224 )

Null Deviance: 0.015341 on 15 degrees of freedom
Residual Deviance: 0.0141666 on 10.71268 degrees of freedom
Number of Local Scoring Iterations: 1

DF for Terms and F-values for Nonparametric Effects

      Df Npar Df      Npar F      Pr(F)
(Intercept) 1
lo(CALFINPDI) 1      3.3 0.2643575 0.8649058

```

*Figure APX3-13. GAM for somatic condition of capelin (*Mallotus villosus*) male age 2 during the spring in the northern region (LWRSPRNOR), with the Loess smoothed independent variable *Calanus finmarchicus PDI*.*

```

GAM lo.wam loop 1: deviance = 0.0104

*** Generalized Additive Model ***
Call:
gam(formula = LWRSPRNOR ~ lo(CHLMAXMAG), family = gaussian, data = SDF121,
na.action = na.exclude, control = list(epsilon = 0.001, bf.epsilon =
0.001, maxit = 50, bf.maxit = 10, trace = TRUE))

Degrees of Freedom: 16 total; 9.60222 Residual
Residual Deviance: 0.01036

Call: gam(formula = LWRSPRNOR ~ lo(CHLMAXMAG), family = gaussian, data = SDF121,
na.action = na.exclude, control = list(epsilon = 0.001, bf.epsilon =
0.001, maxit = 50, bf.maxit = 10, trace = TRUE))
Deviance Residuals:
    Min          1Q      Median          3Q         Max
-0.03399815 -0.01705678 -0.005950191  0.006466679  0.05992978

(Dispersion Parameter for Gaussian family taken to be 0.0010793 )

Null Deviance: 0.015341 on 15 degrees of freedom
Residual Deviance: 0.010364 on 9.602224 degrees of freedom
Number of Local Scoring Iterations: 1

DF for Terms and F-values for Nonparametric Effects

      Df Npar Df      Npar F      Pr(F)
(Intercept) 1
lo(CHLMAXMAG) 1     4.4 0.9145489 0.5009184

```

*Figure APX3-14. GAM for somatic condition of capelin (*Mallotus villosus*) male age 2 during the spring in the northern region (LWRSPRNOR), with the Loess smoothed independent variable maximum concentration of phytoplankton biomass (CHMAXMAG).*

```

GAM lo.wam loop 1: deviance = 0.0066

*** Generalized Additive Model ***
Call:
gam(formula = LWRSPRNOR ~ lo(CALFINPDI) + lo(CHLMAXMAG), family = gaussian,
      data = SDF121, na.action = na.exclude, control = list(epsilon = 0.001,
      bf.epsilon = 0.001, maxit = 50, bf.maxit = 10, trace = TRUE))

Degrees of Freedom: 16 total; 5.31491 Residual
Residual Deviance: 0.00663

Call: gam(formula = LWRSPRNOR ~ lo(CALFINPDI) + lo(CHLMAXMAG), family = gaussian,
      data = SDF121, na.action = na.exclude, control = list(epsilon = 0.001,
      bf.epsilon = 0.001, maxit = 50, bf.maxit = 10, trace = TRUE))
Deviance Residuals:
    Min          1Q      Median          3Q          Max
-0.04549292 -0.008323338 -0.000780371  0.004138671  0.04889771

(Dispersion Parameter for Gaussian family taken to be 0.0012479 )

Null Deviance: 0.015341 on 15 degrees of freedom
Residual Deviance: 0.0066327 on 5.314906 degrees of freedom
Number of Local Scoring Iterations: 1

DF for Terms and F-values for Nonparametric Effects

      Df Npar Df      Npar F      Pr(F)
(Intercept) 1
lo(CALFINPDI) 1      3.3 0.881432 0.5157427
lo(CHLMAXMAG) 1      4.4 1.304111 0.3795076

```

*Figure APX3-15. GAM for somatic condition of capelin (*Mallotus villosus*) male age 2 during the spring in the northern region (LWRSPRNOR). Independent variables are Loess smoothed: Calanus finmarchicus PDI, and the maximum concentration of phytoplankton biomass (CHMAXMAG).*

```

GAM lo.wam loop 1: deviance = 0.0083

*** Generalized Additive Model ***
Call:
gam(formula = LWRFALNOR ~ lo(CALFINPDI), family = gaussian, data = SDF110,
na.action = na.exclude, control = list(epsilon = 0.001, bf.epsilon =
0.001, maxit = 50, bf.maxit = 10, trace = TRUE))

Degrees of Freedom: 16 total; 11.04793 Residual
Residual Deviance: 0.0083

Call: gam(formula = LWRFALNOR ~ lo(CALFINPDI), family = gaussian, data = SDF110,
na.action = na.exclude, control = list(epsilon = 0.001, bf.epsilon =
0.001, maxit = 50, bf.maxit = 10, trace = TRUE))
Deviance Residuals:
    Min          1Q      Median          3Q      Max
-0.04372581 -0.007561905 0.002326734 0.01270674 0.0439

(Dispersion Parameter for Gaussian family taken to be 0.0007511 )

Null Deviance: 0.0136171 on 15 degrees of freedom
Residual Deviance: 0.008298 on 11.04793 degrees of freedom
Number of Local Scoring Iterations: 1

DF for Terms and F-values for Nonparametric Effects

      Df Npar Df   Npar F     Pr(F)
(Intercept) 1
lo(CALFINPDI) 1       3 1.727013 0.2190607

```

*Figure APX3-16. GAM for somatic condition of capelin (*Mallotus villosus*) male age 2 during the autumn in the northern region (LWRFALNOR), with the Loess smoothed independent variable *Calanus finmarchicus PDI*.*

```

GAM lo.wam loop 1: deviance = 0.0065

*** Generalized Additive Model ***
Call:
gam(formula = LWRFALNOR ~ lo(CHLMAXMAG), family = gaussian, data = SDF110,
na.action = na.exclude, control = list(epsilon = 0.001, bf.epsilon =
0.001, maxit = 50, bf.maxit = 10, trace = TRUE))

Degrees of Freedom: 16 total; 11.26501 Residual
Residual Deviance: 0.0065

Call: gam(formula = LWRFALNOR ~ lo(CHLMAXMAG), family = gaussian, data = SDF110,
na.action = na.exclude, control = list(epsilon = 0.001, bf.epsilon =
0.001, maxit = 50, bf.maxit = 10, trace = TRUE))
Deviance Residuals:
    Min          1Q      Median          3Q          Max
-0.04284513 -0.01331968  0.003181464  0.0174916  0.02883082

(Dispersion Parameter for Gaussian family taken to be 0.0005771 )

Null Deviance: 0.0136171 on 15 degrees of freedom
Residual Deviance: 0.0065005 on 11.26501 degrees of freedom
Number of Local Scoring Iterations: 1

DF for Terms and F-values for Nonparametric Effects

      Df Npar Df      Npar F      Pr(F)
(Intercept) 1
lo(CHLMAXMAG) 1      2.7 0.6893016 0.564548

```

*Figure APX3-17. GAM for somatic condition of capelin (*Mallotus villosus*) male age 2 during the autumn in the northern region (LWRFALNOR), with the Loess smoothed independent variable maximum concentration of phytoplankton biomass (CHMAXMAG).*

```

GAM lo.wam loop 1: deviance = 0.003

*** Generalized Additive Model ***
Call:
gam(formula = LWRFALNOR ~ lo(CALFINPDI) + lo(CHLMAXMAG), family = gaussian,
      data = SDF110, na.action = na.exclude, control = list(epsilon = 0.001,
      bf.epsilon = 0.001, maxit = 50, bf.maxit = 10, trace = TRUE))

Degrees of Freedom: 16 total; 7.31295 Residual
Residual Deviance: 0.00305

Call: gam(formula = LWRFALNOR ~ lo(CALFINPDI) + lo(CHLMAXMAG), family = gaussian,
      data = SDF110, na.action = na.exclude, control = list(epsilon = 0.001,
      bf.epsilon = 0.001, maxit = 50, bf.maxit = 10, trace = TRUE))
Deviance Residuals:
    Min          1Q      Median          3Q          Max
-0.019443 -0.01138897 -0.004280981 0.0119208 0.02339707

(Dispersion Parameter for Gaussian family taken to be 0.000417 )

Null Deviance: 0.0136171 on 15 degrees of freedom
Residual Deviance: 0.0030496 on 7.312946 degrees of freedom
Number of Local Scoring Iterations: 1

DF for Terms and F-values for Nonparametric Effects

      Df Npar Df   Npar F     Pr(F)
(Intercept) 1
lo(CALFINPDI) 1     3.0 2.044220 0.1931644
lo(CHLMAXMAG) 1     2.7 1.047048 0.4210322

```

*Figure APX3-18. GAM for somatic condition of capelin (*Mallotus villosus*) male age 2 during the autumn in the northern region (LWRFALNOR). Independent variables are Loess smoothed: Calanus finmarchicus PDI, and the maximum concentration of phytoplankton biomass (CHMAXMAG).*

```

GAM lo.wam loop 1: deviance = 0.0154

*** Generalized Additive Model ***
Call:
gam(formula = LWRSPRSUR ~ lo(CALFINPDI), family = gaussian, data = SDF5,
na.action = na.exclude, control = list(epsilon = 0.001, bf.epsilon =
0.001, maxit = 50, bf.maxit = 10, trace = TRUE))

Degrees of Freedom: 17 total; 11.11395 Residual
Residual Deviance: 0.01544

Call: gam(formula = LWRSPRSUR ~ lo(CALFINPDI), family = gaussian, data = SDF5,
na.action = na.exclude, control = list(epsilon = 0.001, bf.epsilon =
0.001, maxit = 50, bf.maxit = 10, trace = TRUE))
Deviance Residuals:
    Min          1Q      Median          3Q          Max
-0.03596982 -0.02439476 -0.009709054 0.01528548 0.09285393

(Dispersion Parameter for Gaussian family taken to be 0.0013893 )

Null Deviance: 0.0287003 on 16 degrees of freedom
Residual Deviance: 0.0154404 on 11.11395 degrees of freedom
Number of Local Scoring Iterations: 1

DF for Terms and F-values for Nonparametric Effects

      Df Npar Df      Npar F      Pr(F)
(Intercept) 1
lo(CALFINPDI) 1      3.9 0.9133241 0.487153

```

*Figure APX3-19. GAM for somatic condition of capelin (*Mallotus villosus*) male age 2 during the spring in the southern region (LWRSPRSUR), with the Loess smoothed independent variable *Calanus finmarchicus PDI*.*

```

GAM lo.wam loop 1: deviance = 0.0219

*** Generalized Additive Model ***
Call:
gam(formula = LWRSPRSUR ~ lo(CHLINIDOY), family = gaussian, data = SDF5,
na.action = na.exclude, control = list(epsilon = 0.001, bf.epsilon =
0.001, maxit = 50, bf.maxit = 10, trace = TRUE))

Degrees of Freedom: 17 total; 10.46532 Residual
Residual Deviance: 0.02187

Call: gam(formula = LWRSPRSUR ~ lo(CHLINIDOY), family = gaussian, data = SDF5,
na.action = na.exclude, control = list(epsilon = 0.001, bf.epsilon =
0.001, maxit = 50, bf.maxit = 10, trace = TRUE))
Deviance Residuals:
    Min          1Q      Median          3Q          Max
-0.04152958 -0.02526572 0.0007182363 0.0100228 0.1123177

(Dispersion Parameter for Gaussian family taken to be 0.0020902 )

Null Deviance: 0.0287003 on 16 degrees of freedom
Residual Deviance: 0.0218744 on 10.46532 degrees of freedom
Number of Local Scoring Iterations: 1

DF for Terms and F-values for Nonparametric Effects

      Df Npar Df      Npar F      Pr(F)
(Intercept) 1
lo(CHLINIDOY) 1      4.5 0.5379917 0.7299579

```

*Figure APX3-20. GAM for somatic condition of capelin (*Mallotus villosus*) male age 2 during the spring in the southern region (LWRSPRSUR), with the Loess smoothed independent variable initiation of the spring phytoplankton bloom (CHLINIDOY).*

```

GAM lo.wam loop 1: deviance = 0.0083

*** Generalized Additive Model ***
Call:
gam(formula = LWRSPRSUR ~ lo(CALFINPDI) + lo(CHLINIDOY), family = gaussian,
      data = SDF3, na.action = na.exclude, control = list(epsilon = 0.001,
      bf.epsilon = 0.001, maxit = 50, bf.maxit = 10, trace = TRUE))

Degrees of Freedom: 17 total; 5.57927 Residual
Residual Deviance: 0.00833

Call: gam(formula = LWRSPRSUR ~ lo(CALFINPDI) + lo(CHLINIDOY), family = gaussian,
      data = SDF3, na.action = na.exclude, control = list(epsilon = 0.001,
      bf.epsilon = 0.001, maxit = 50, bf.maxit = 10, trace = TRUE))
Deviance Residuals:
    Min          1Q      Median          3Q          Max
-0.03067521 -0.01216458 -0.007297763 0.01287248 0.06104692
(Dispersion Parameter for Gaussian family taken to be 0.0014927 )

Null Deviance: 0.0287003 on 16 degrees of freedom
Residual Deviance: 0.0083281 on 5.57927 degrees of freedom
Number of Local Scoring Iterations: 1

DF for Terms and F-values for Nonparametric Effects

      Df Npar Df   Npar F     Pr(F)
(Intercept) 1
lo(CALFINPDI) 1     3.9 0.851021 0.5421641
lo(CHLINIDOY) 1     4.5 1.282204 0.3832844

```

*Figure APX3-21. GAM for somatic condition of capelin (*Mallotus villosus*) male age 2 during the spring in the southern region (LWRSPRSUR). Independent variables are Loess smoothed: Calanus finmarchicus PDI, and the time at the initiation of the spring phytoplankton bloom (CHLINIDOY).*

```

GAM lo.wam loop 1: deviance = 0.0111

*** Generalized Additive Model ***
Call:
gam(formula = LWRFALSUR ~ lo(CALFINPDI), family = gaussian, data = SDF4,
     na.action = na.exclude, control = list(epsilon = 0.001, bf.epsilon =
0.001, maxit = 50, bf.maxit = 10, trace = TRUE))

Degrees of Freedom: 17 total; 11.19586 Residual
Residual Deviance: 0.01113

Call: gam(formula = LWRFALSUR ~ lo(CALFINPDI), family = gaussian, data = SDF4,
     na.action = na.exclude, control = list(epsilon = 0.001, bf.epsilon =
0.001, maxit = 50, bf.maxit = 10, trace = TRUE))
Deviance Residuals:
    Min          1Q      Median          3Q          Max
-0.04239862 -0.0186237 -0.002871428  0.0232654  0.04031472

(Dispersion Parameter for Gaussian family taken to be 0.0009944 )

Null Deviance: 0.0152748 on 16 degrees of freedom
Residual Deviance: 0.0111328 on 11.19586 degrees of freedom
Number of Local Scoring Iterations: 1

DF for Terms and F-values for Nonparametric Effects

      Df Npar Df      Npar F      Pr(F)
(Intercept) 1
lo(CALFINPDI) 1      3.8 0.8663161 0.5089523

```

*Figure APX3-22. GAM for somatic condition of capelin (*Mallotus villosus*) male age 2 during the autumn in the southern region (LWRFALSUR), with the Loess smoothed independent variable *Calanus finmarchicus PDI*.*

```

GAM lo.wam loop 1: deviance = 0.0083

*** Generalized Additive Model ***
Call:
gam(formula = LWRFALSUR ~ lo(CHLINIDOV), family = gaussian, data = SDF4,
     na.action = na.exclude, control = list(epsilon = 0.001, bf.epsilon =
0.001, maxit = 50, bf.maxit = 10, trace = TRUE))

Degrees of Freedom: 17 total; 11.78076 Residual
Residual Deviance: 0.00826

Call: gam(formula = LWRFALSUR ~ lo(CHLINIDOV), family = gaussian, data = SDF4,
     na.action = na.exclude, control = list(epsilon = 0.001, bf.epsilon =
0.001, maxit = 50, bf.maxit = 10, trace = TRUE))
Deviance Residuals:
    Min          1Q      Median          3Q          Max
-0.04611818 -0.01470045  0.01143608  0.01475361  0.03459595

(Dispersion Parameter for Gaussian family taken to be 0.0007011 )

Null Deviance: 0.0152748 on 16 degrees of freedom
Residual Deviance: 0.0082599 on 11.78076 degrees of freedom
Number of Local Scoring Iterations: 1

DF for Terms and F-values for Nonparametric Effects

      Df Npar Df   Npar F      Pr(F)
(Intercept) 1
lo(CHLINIDOV) 1     3.2 3.105903 0.06528749

```

*Figure APX3-23. GAM for somatic condition of capelin (*Mallotus villosus*) male age 2 during the autumn in the southern region (LWRFALSUR), with the Loess smoothed independent variable time at the initiation of the autumn phytoplankton bloom (CHLINIDOV).*

```

GAM lo.wam loop 1: deviance = 0.0033

*** Generalized Additive Model ***
Call:
gam(formula = LWRFALSUR ~ lo(CALFINPDI) + lo(CHLINIDOY), family = gaussian,
      data = SDF4, na.action = na.exclude, control = list(epsilon = 0.001,
      bf.epsilon = 0.001, maxit = 50, bf.maxit = 10, trace = TRUE))

Degrees of Freedom: 17 total; 6.97662 Residual
Residual Deviance: 0.00325

Call: gam(formula = LWRFALSUR ~ lo(CALFINPDI) + lo(CHLINIDOY), family = gaussian,
      data = SDF4, na.action = na.exclude, control = list(epsilon = 0.001,
      bf.epsilon = 0.001, maxit = 50, bf.maxit = 10, trace = TRUE))
Deviance Residuals:
    Min          1Q      Median          3Q         Max
-0.02700823 -0.007819966 0.0002638026 0.00875884 0.02232598

(Dispersion Parameter for Gaussian family taken to be 0.0004663 )

Null Deviance: 0.0152748 on 16 degrees of freedom
Residual Deviance: 0.0032532 on 6.976621 degrees of freedom
Number of Local Scoring Iterations: 1

DF for Terms and F-values for Nonparametric Effects

      Df Npar Df   Npar F     Pr(F)
(Intercept) 1
lo(CALFINPDI) 1     3.8 2.015314 0.1976820
lo(CHLINIDOY) 1     3.2 6.687634 0.0176244

```

*Figure APX3-24. GAM for somatic condition of capelin (*Mallotus villosus*) male age 2 during the autumn in the southern region (LWRFALSUR). Independent variables are Loess smoothed: Calanus finmarchicus PDI, and the time at the initiation of the autumn phytoplankton bloom (CHLINIDOY).*

```

GAM lo.wam loop 1: deviance = 5.8999

*** Generalized Additive Model ***
Call:
gam(formula = ABUSPRSUR ~ lo(WARMRATE), family = gaussian, data = SDF1,
na.action = na.exclude, control = list(epsilon = 0.001, bf.epsilon =
0.001, maxit = 50, bf.maxit = 10, trace = TRUE))

Degrees of Freedom: 16 total; 10.4686 Residual
Residual Deviance: 5.89987

Call: gam(formula = ABUSPRSUR ~ lo(WARMRATE), family = gaussian, data = SDF1,
na.action = na.exclude, control = list(epsilon = 0.001, bf.epsilon =
0.001, maxit = 50, bf.maxit = 10, trace = TRUE))
Deviance Residuals:
    Min          1Q      Median          3Q          Max
-0.9404316 -0.3858633 -0.1594966  0.4939058  1.339795

(Dispersion Parameter for Gaussian family taken to be 0.5635777 )

Null Deviance: 15 on 15 degrees of freedom
Residual Deviance: 5.89987 on 10.4686 degrees of freedom
Number of Local Scoring Iterations: 1
DF for Terms and F-values for Nonparametric Effects

      Df Npar Df      Npar F      Pr(F)
(Intercept) 1
lo(WARMRATE) 1      3.5 3.444009 0.05259567

```

*Figure APX3-25. GAM for abundance of capelin (*Mallotus villosus*) age 2 during the spring in the southern region (ABUSPRSUR), with the Loess smoothed independent variable SST warming rate (WARMRATE).*

```

GAM lo.wam loop 1: deviance = 8.8739

*** Generalized Additive Model ***
Call:
gam(formula = ABUSPRSUR ~ lo(CALFINPDI), family = gaussian, data = SDF1,
     na.action = na.exclude, control = list(epsilon = 0.001, bf.epsilon =
0.001, maxit = 50, bf.maxit = 10, trace = TRUE))

Degrees of Freedom: 16 total; 10.54568 Residual
Residual Deviance: 8.87391

Call: gam(formula = ABUSPRSUR ~ lo(CALFINPDI), family = gaussian, data = SDF1,
     na.action = na.exclude, control = list(epsilon = 0.001, bf.epsilon =
0.001, maxit = 50, bf.maxit = 10, trace = TRUE))
Deviance Residuals:
    Min      1Q      Median      3Q      Max
-0.9341094 -0.3350681 -0.04129724 0.1700739 2.44433

(Dispersion Parameter for Gaussian family taken to be 0.8414733 )

Null Deviance: 15 on 15 degrees of freedom
Residual Deviance: 8.873906 on 10.54568 degrees of freedom
Number of Local Scoring Iterations: 1

DF for Terms and F-values for Nonparametric Effects

      Df Npar Df   Npar F    Pr(F)
(Intercept) 1
lo(CALFINPDI) 1     3.5 1.793491 0.206252

```

*Figure APX3-26. GAM for abundance of capelin (*Mallotus villosus*) age 2 during the spring in the southern region (ABUSPRSUR), with the Loess smoothed independent variable Calanus PDI (CALFINPDI).*

```

GAM lo.wam loop 1: deviance = 3.0649

*** Generalized Additive Model ***
Call:
gam(formula = ABUSPRSUR ~ lo(WARMRATE) + lo(CALFINPDI), family = gaussian,
      data = SDF1, na.action = na.exclude, control = list(epsilon = 0.001,
      bf.epsilon = 0.001, maxit = 50, bf.maxit = 10, trace = TRUE))

Degrees of Freedom: 16 total; 6.01428 Residual
Residual Deviance: 3.06493

Call: gam(formula = ABUSPRSUR ~ lo(WARMRATE) + lo(CALFINPDI), family = gaussian,
      data = SDF1, na.action = na.exclude, control = list(epsilon = 0.001,
      bf.epsilon = 0.001, maxit = 50, bf.maxit = 10, trace = TRUE))
Deviance Residuals:
    Min          1Q      Median          3Q          Max
 -1.109974 -0.2232561  0.01160554  0.2117044  0.7895973

(Dispersion Parameter for Gaussian family taken to be 0.5096087 )

Null Deviance: 15 on 15 degrees of freedom
Residual Deviance: 3.064929 on 6.014278 degrees of freedom
Number of Local Scoring Iterations: 1

DF for Terms and F-values for Nonparametric Effects

      Df Npar Df      Npar F      Pr(F)
(Intercept) 1
lo(WARMRATE) 1      3.5 3.099491 0.1071212
lo(CALFINPDI) 1      3.5 1.986588 0.2165443

```

*Figure APX3-27. GAM for abundance of capelin (*Mallotus villosus*) age 2 during the spring in the southern region (ABUSPRSUR). Independent variables are Loess smoothed: SST warming rate (WARMRATE), and Calanus PDI (CALFINPDI).*