Northwest Atlantic Fisheries Organization

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# Environmental indices for NAFO subareas 0 to 4 in support of the Standing Committee on Fisheries Science (STACFIS) – 2023 update

by

Frédéric Cyr and David Bélanger

Northwest Atlantic Fisheries Centre, Fisheries and Oceans Canada, St. John's (NL)

## Abstract

This document present composite physical and biological indices in NAFO subareas 0-4 in support of the Standing Committee on Fisheries Science (STACFIS). The information is organized in 4 sub-regions: Greenland and Davis Strait (NAFO subareas 0 and 1), Flemish Cap (NAFO division 3M), Grand Banks (NAFO divisions 3LNO) and the northwest Atlantic as a whole (NAFO subareas 2, 3 and 4) for widely distributed stocks. When put in context with their long-term average, the large majority of ocean indicators were above normal in 2023, although the year was characterized by a relatively cold spring. The year 2023 was especially warm in NAFO Div. 3M (Flemish Cap), where the index, was at its warmest value since the time series started in 1985. The composite climate indices for subareas 2, 3 and 4 altogether was at its 5th warmest value, but four of the five warmest years all occurred in the last five years (including the record warm in 2021). The timing of the spring phytoplankton bloom was later than normal on average, likely due to the cooler temperatures observed on the Grand Bank and the Scotian Shelf (subareas 3-4) in 2023. A decline in the abundance of copepod in subareas 2 and 4 resulted in an overall lower-than-normal zooplankton biomass zooplankton biomass for the first time in nine years.

## Introduction

This report presents environmental indices that aim to provide a synthetic overview of physical and biogeochemical conditions in the northwest Atlantic (NAFO subareas 0 to 4; see **Figure 1**) in support of the different NAFO fish stock assessments. Over the recent years, this information was provided annually as part of the report of the NAFO Science Council Meeting (e.g., NAFO, 2020), in the report of the Standing Committee on Fisheries Science – STACFIS (see Appendix IV of the Science Council Meeting report). Since year 2021, this information has been formalized and presented as part of a distinct Science Council Research (SCR) multidisciplinary document (see Cyr & Bélanger, 2021, for the first report of this series).

The information provided here is partly extracted from individual SCR Documents on environmental and physical oceanographic conditions on the eastern Canadian shelves Cyr et al. (2024) and on biogeochemical oceanographic conditions in the Northwest Atlantic Bélanger et al. (2024). Following the STACFIS report, the information is organized in 4 sub-regions: Greenland and Davis Strait (NAFO subareas 0 and 1), Flemish Cap (NAFO division 3M), Grand Banks (NAFO divisions 3LNO) and the Northwest Atlantic as a whole (NAFO subareas 2, 3 and 4) for widely distributed stocks. Each of these sub-region is discussed separately below.

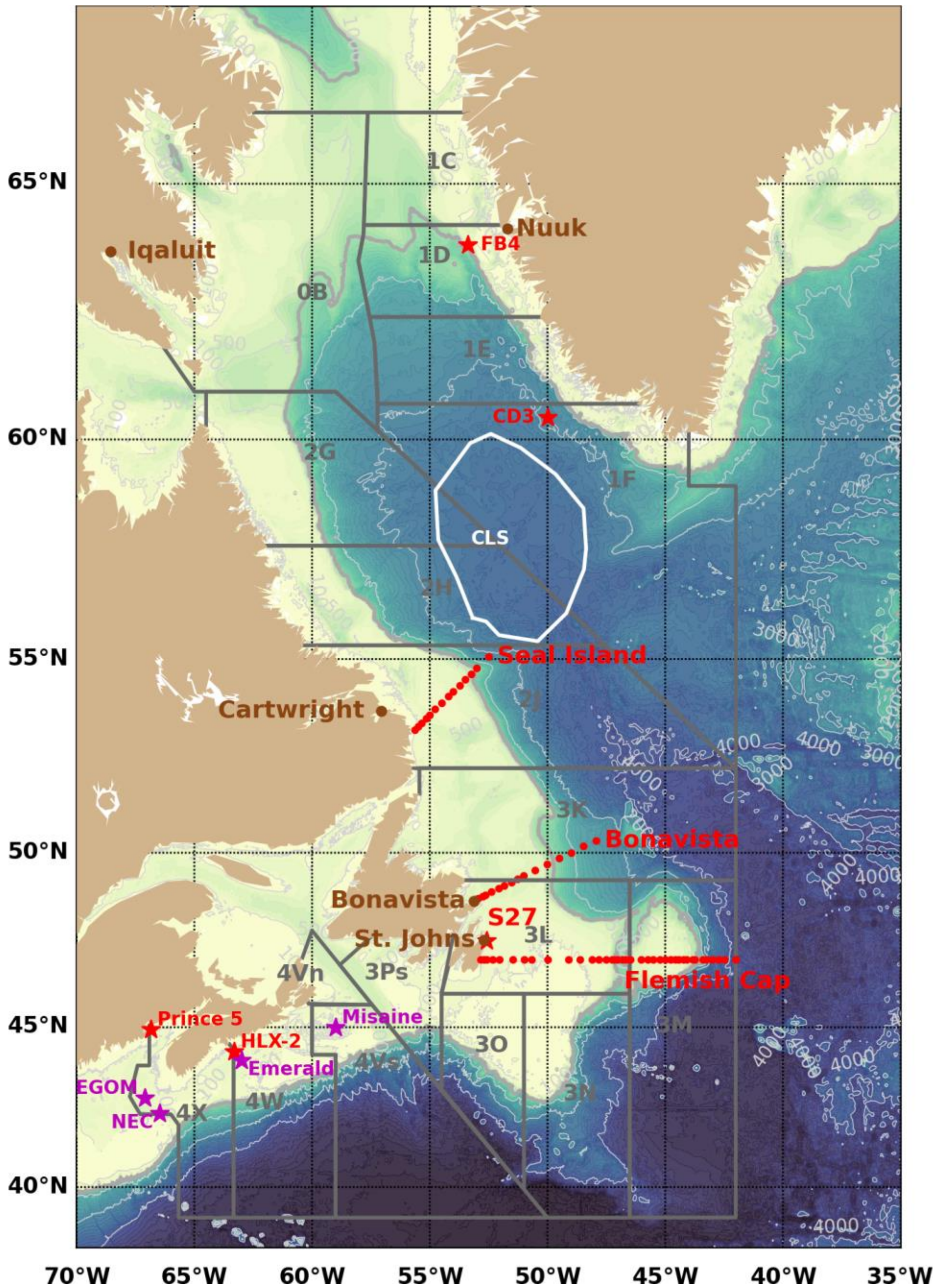


**Figure 1.** Map highlighting the location of the physical environmental time series used in this report. NAFO Divisions and main bathymetric features of the Northwest Atlantic are highlighted (colormap and gray contours). The thick gray contour is the isobath 1000m that is used here to delimit the continental shelf. A sketch of the main ocean circulation features of the northwest Atlantic is overlaid with black arrows. The hydrographic sections reported here are shown with red dots and the high-frequency fixed stations (Station 27, Halifax 2 and Prince 5) by red stars. Other stations or areas seasonally sampled for which time series are presented in this report (Misaine Bank, Emerald Basin, North East Channel – NEC, and Eastern Gulf of Maine - EGOM) are drawn with purple stars. The stations used for air temperature time series and in brown. The Central Labrador Sea (CLS) polygon used to extract an hydrographic time series used in this report is also shown.

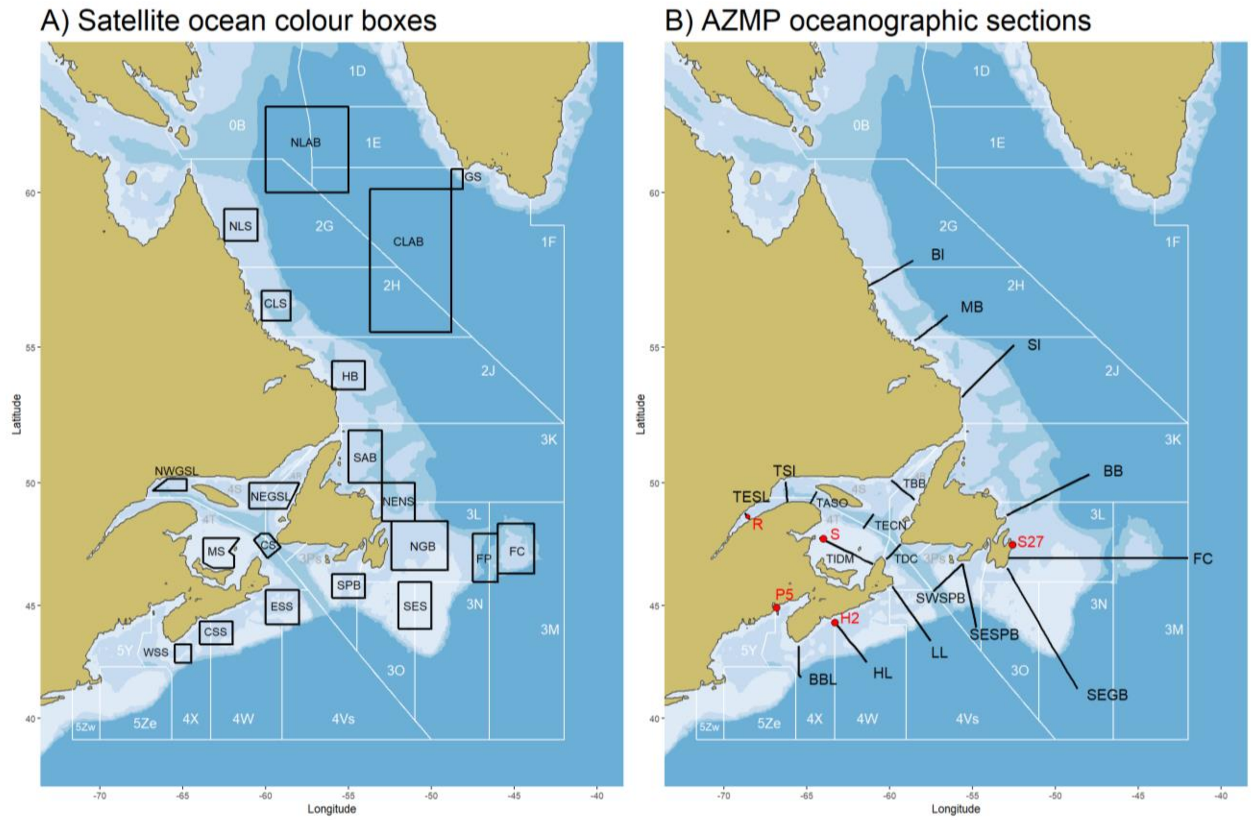


**Figure 2.** (A) Location of polygons used to calculate spring bloom indices (timing and intensity) from satellite Ocean Color imagery: HS=Hudson Strait, NLS=northern Labrador Shelf, CLS=central Labrador Shelf, HB=Hamilton Bank, SAB=St. Anthony Basin, NENS=northeast Newfoundland Shelf, FP=Flemish Pass, FC=Flemish Cap, NGB=northern Grand Bank, SES=southeast Shoal, SPB=Green-St. Pierre Bank, NEGSL=northeast Gulf of St. Lawrence, NWGSL=northwest Gulf of St. Lawrence, MS=Magdalen Shallows, ESS=eastern Scotian Shelf, CSS=central Scotian Shelf, WSS=western Scotian Shelf, GB=Georges Bank. (B) Location of Atlantic Zone Monitoring Program (AZMP) oceanographic sections (black lines: BI=Beachy Island, MB=Makkovik Bank, SI=Seal Island, BB=Bonavista Bay, FC=Flemish Cap, SEGB=Southeast Grand Bank, TBB=Bonne Bay Transect, TCEN=Central GSL Transect, TDC=Cabot Strait Transect; TESL=St. Lawrence Estuary Transect, TSI=Sept-Îles Transect, TASO=Southwest Anticosti Transect; TIDM=Magdalen Islands Transect, LL=Louisbourg Line, HL=Halifax Line, BBL=Brown Bank Line), and coastal high-frequency monitoring sites (red circles: S27=Station 27; R=Rimouski; S=Shediac Valley; H2=Halifax 2; P5=Prince 5) where biogeochemical data were collected during AZMP seasonal surveys.

## Greenland and Davis Strait (NAFO subareas 0 and 1)

### Environmental Overview

Hydrographic conditions in this region depend on a balance of ice melt, advection of polar and sub-polar waters and atmospheric forcing, including the major winter heat loss to the atmosphere that occurs in the central Labrador Sea. The cold and fresh polar waters carried south by the east Baffin Island Current are counter balanced by warmer waters are carried northward by the offshore branch of the West Greenland Current (WGC). The water masses constituting the WGC originate from the western Irminger Basin where the East Greenland Currents (EGC) meets the Irminger Current (IC). While the EGC transports ice and cold low-salinity Surface Polar Water to the south along the eastern coast of Greenland, the IC is a branch of the North Atlantic current and transports warm and salty Atlantic Waters northwards along the Reykjanes Ridge. After the currents converge, they turn around the southern tip of Greenland, forming a single jet (the WGC) that propagates northward along the western coast of Greenland. The WGC is important for Labrador Sea Water formation, which is an essential element of the Atlantic Meridional Overturning Circulation. At the northern edge of the Labrador Sea, after receiving freshwater input from Greenland and Davis Strait, part of the WGC bifurcates southward along the Canadian shelf edge as the Labrador Current.

### Index calculation and data availability

The different composite indices for NAFO Subarea 0 and 1 are presented in

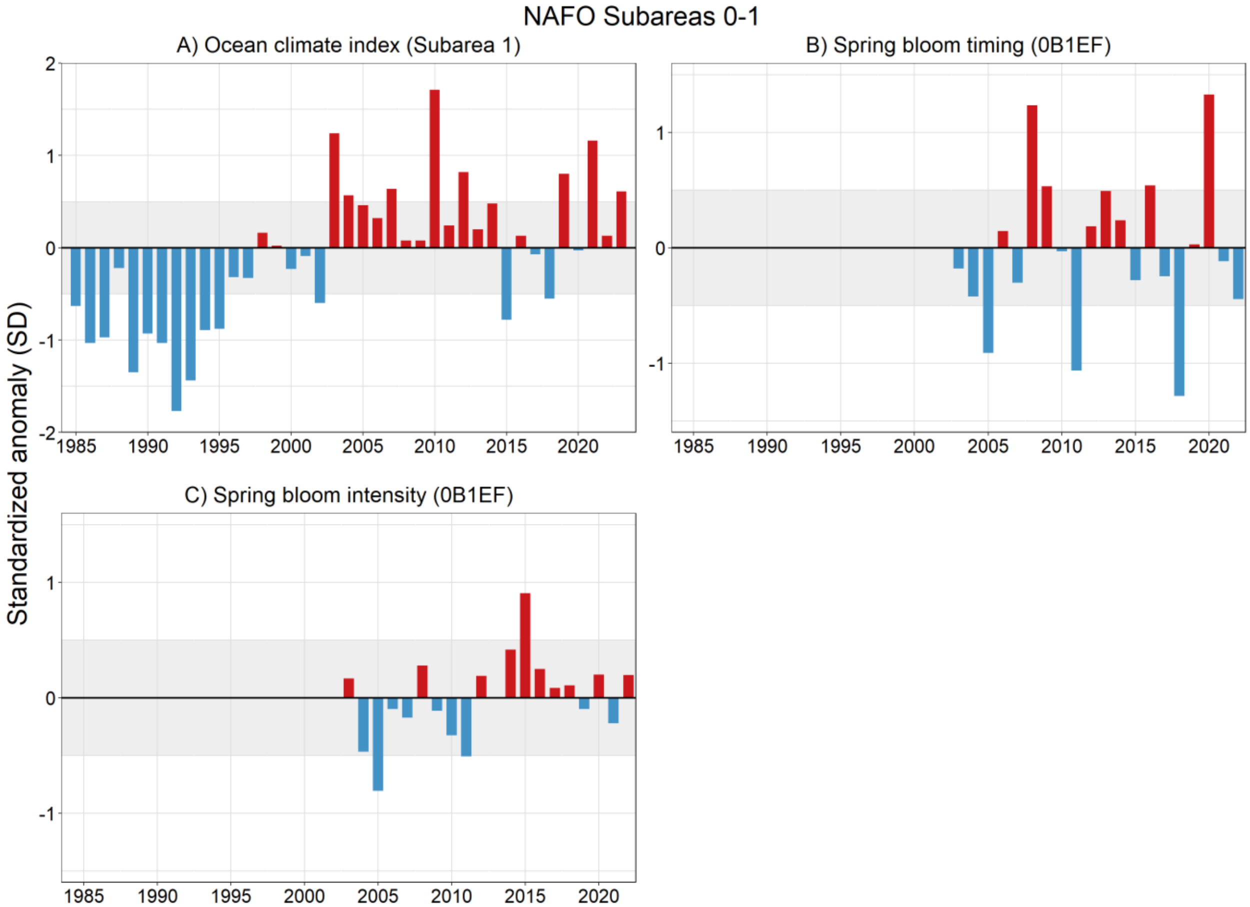


Figure **3**. Due the remoteness of this region, the number of variables entering these composite indices is limited. The climate index

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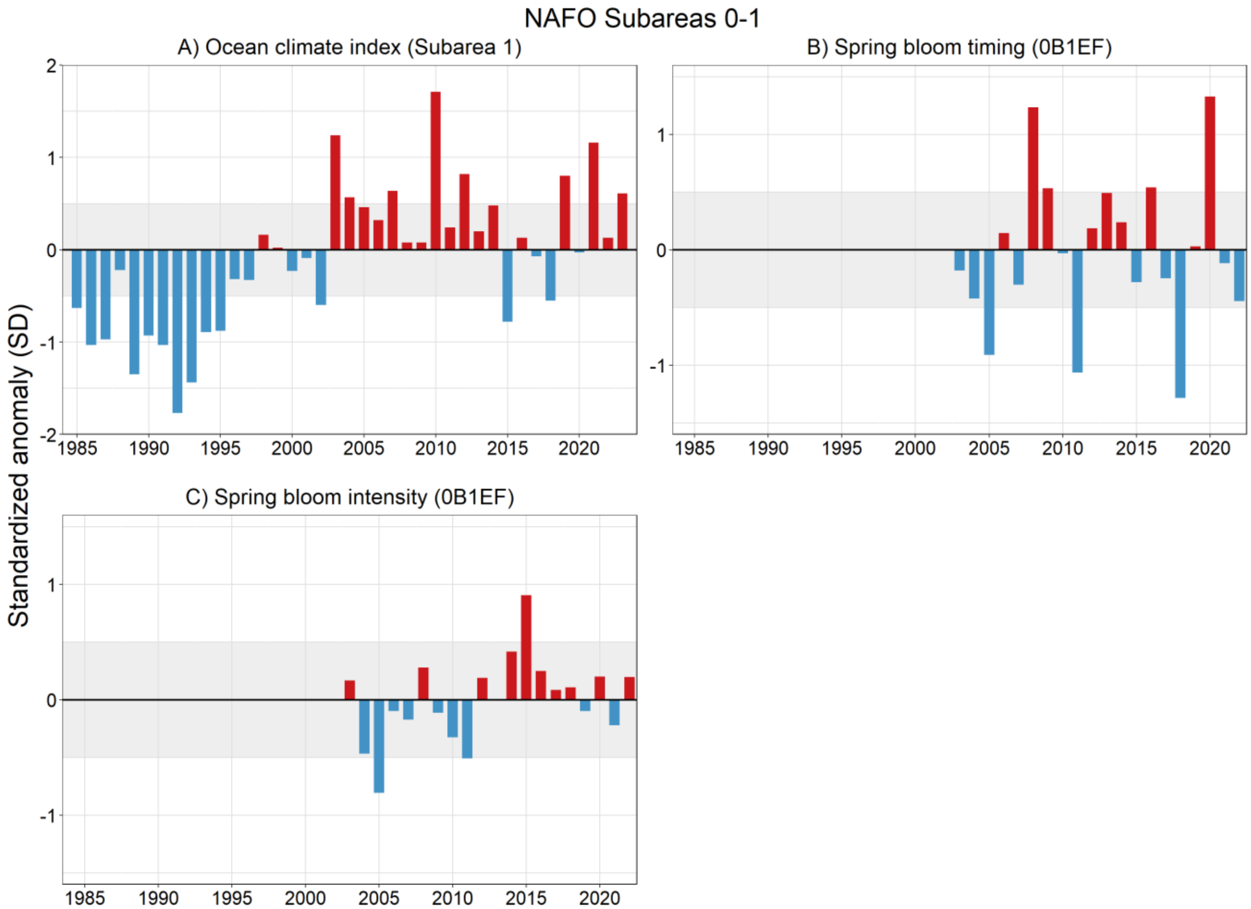


Figure **3**A) is the average of 7 individual time series of standardized ocean temperature anomalies: shallow and deep vertically average ocean temperature in the Central Labrador Sea (50-200m and 1000-1800, respectively), Fyllas Bank Station 4 (FB-4; 0-50 m) and Cape Desolation Station 3 (CD-3; 75-200 m and 2000 m), and air temperatures in Nuuk (Greenland) and Iqaluit (Baffin Island). The geographical location where these different time series origin are drawn in Figure 1 with the SST boxes in white (with the CLS box also representing the hydrographic time series in the Central Labrador Sea), the air temperature stations in brown and the hydrographic stations with purple stars. CLS, FB-4 and CD-3 hydrographic time series are obtained from the ICES report on ocean climate (IROC; https://ocean.ices.dk/iroc/). The timeseries for CD-3 and FB-4 have however not been updated since 2019 and 2020, respectively.

Spring phytoplankton bloom timing and intensity indices for the 2003-2023 period were derived from three polygons located in NAFO Divs. 0B1EF (Northern [NLAB] and Central [CLAB] Labrador Sea, Greenland Shelf [GS]; see Figure 2 for geographical location). It is worth noting that satellite data availability at theses high latitudes is impacted by the presence of sea ice and limited daylight hours at appropriate angle of incidence in later winter and early spring, increasing uncertainty around spring bloom indices. No time series of in situ biogeochemical observations are available for subareas 0 and 1.

## Ocean Climate and Ecosystem Indicators

The ocean climate index in Subarea 0-1 has been predominantly above or near normal since the early 2000s, except for 2015 and 2018 that were below normal
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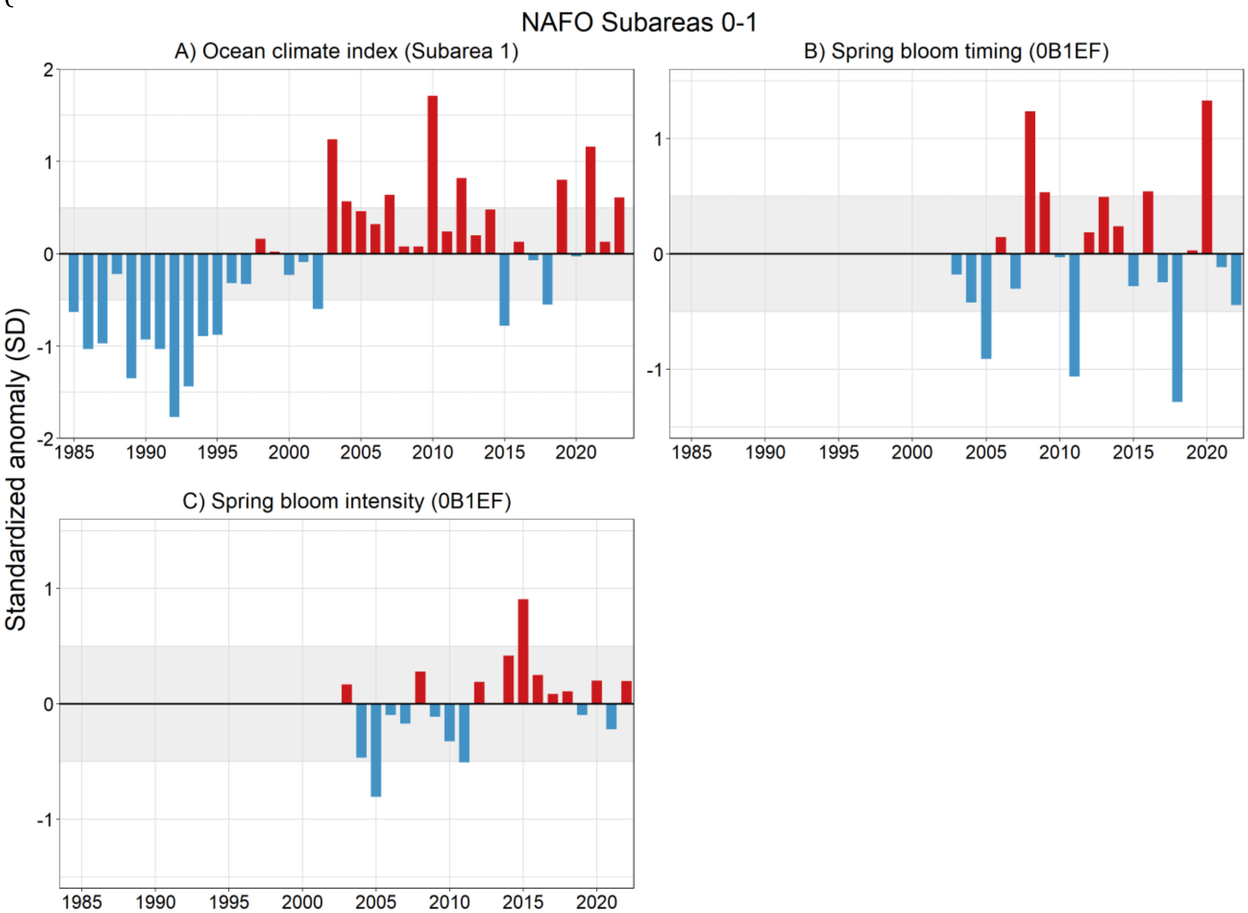


Figure **3**A). After being in 2021 at its highest value since the record high of 2010, the index was normal in 2022 and again above normal in 2023. Before the warm period of the last decade, cold conditions persisted between the mid-1980s and the mid-1990s.

Spring bloom peak production timing has been primarily near normal between 2003 and 2023, with earlier-than-normal (negative anomalies) and later-than-normal (positive anomalies) blooms alternating on a two to five-year time scale (Figure 3B ). Spring bloom intensity (average spring chlorophyll *a* concentration) displayed a general increase from below normal to above normal between 2005 and 2015, before declining to near-normal where it has since remained (Figure 3B). In 2023, mean timing of the spring bloom was near normal for a second consecutive after the record late bloom of 2020, while bloom intensity remained near normal for 7th consecutive year (Figure 3B).

## Recent Highlights in Ocean Climate and Lower Trophic Levels for Subareas 0-1

- The ocean climate index in Subarea 0-1 above normal in 2023.

- Near-normal timing and intensity of the spring bloom in 2023.

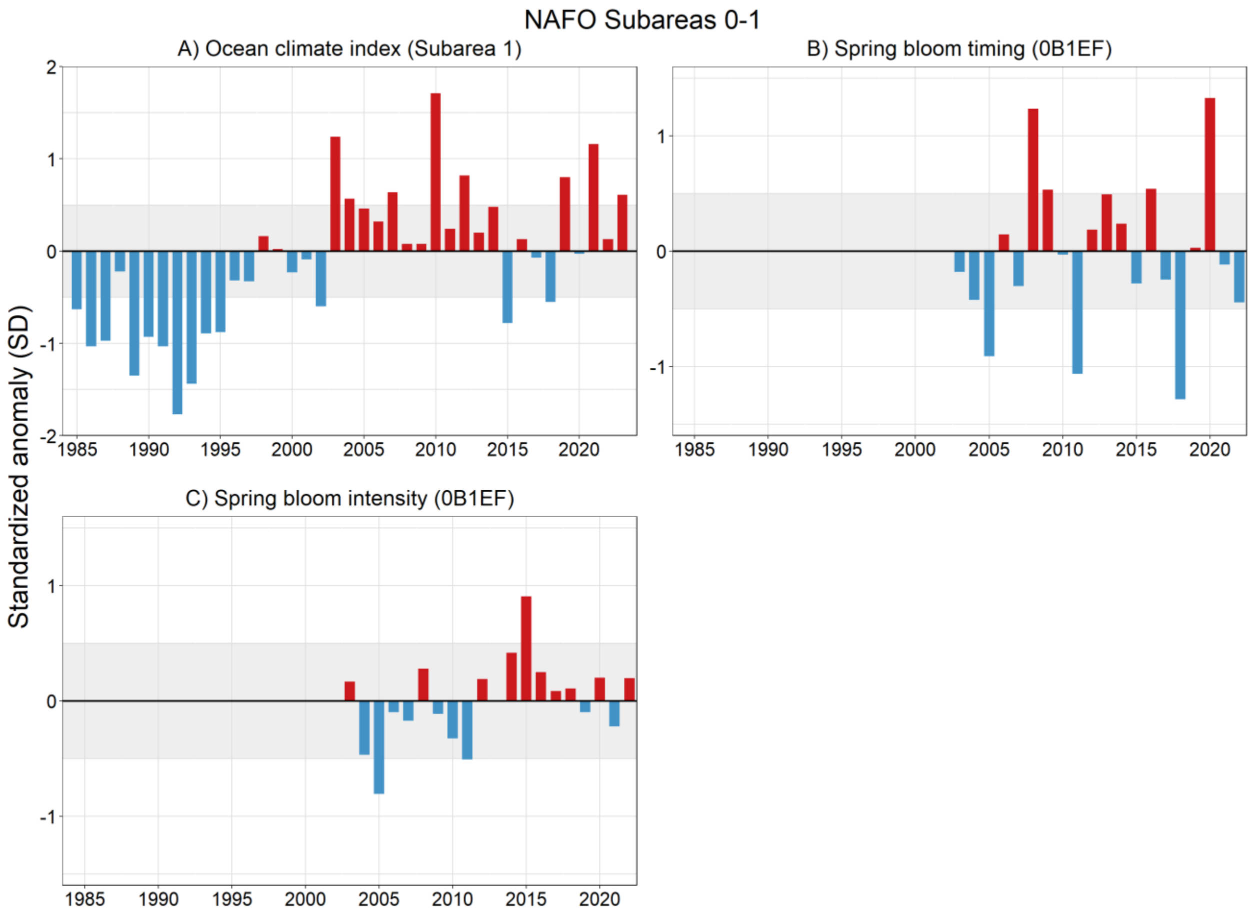


**Figure 3.** Annual anomalies of environmental indices for NAFO Subareas 0 and 1. The ocean climate index (A) for the period 1990-2020 is the average of 7 individual time series. These includes standardized anomalies of 5 temperature time series at 3 hydrographic stations and 2 air temperatures time series (see text for details). Spring bloom anomalies (B, C) for the 2003-2023 period are derived from three polygons (NLAB, CLAB, GS – see Fig. 2A for polygon locations). Positive (negative) anomalies indicate late (early) bloom timing or bloom intensity above (below) the mean for the reference period. Anomalies were calculated using the following reference periods: ocean climate index: 1981-2010, spring bloom indices: 2003-2020. Anomalies within ± 0.5 SD (shaded area) are considered near-normal conditions.

# Flemish Cap (NAFO Division 3M)

## Environmental Overview

The water masses characteristic of the Flemish Cap area are a mixture of Labrador Current Slope Water and North Atlantic Current water, generally warmer and saltier than the sub-polar Newfoundland Shelf waters with a temperature range of 3-4°C and salinities in the range of 34-34.75. The general circulation in the vicinity of the Flemish Cap consists of the offshore branch of the Labrador Current which flows through the Flemish Pass on the Grand Bank side and a jet that flows eastward north of the Cap and then southward east of the Cap. To the south, the Gulf Stream flows to the northeast to form the North Atlantic Current and influences waters around the southern areas of the Cap (**Figure 1**). In the absence of strong wind forcing the circulation over the central Flemish Cap is dominated by a topographically induced anti-cyclonic (clockwise) gyre. Variation in the abiotic environment influences the distribution and biological production of Newfoundland and Labrador Shelf and Slope waters where arctic, boreal, and temperate species coexist. The elevated temperatures on the Flemish Cap result in relatively ice-free conditions that may allow longer phytoplankton growing seasons compared to the Grand Banks where cooler conditions prevail. The entrainment of nutrient-rich North Atlantic Current water around the Flemish Cap generally supports higher primary and secondary production compared with the adjacent shelf waters. The stability of this circulation pattern may also influence the retention of ichthyoplankton on the Grand Bank which may influence year-class strength of various fish and invertebrate species.

## Index calculation and data availability

The different composite indices for NAFO division 3M (Flemish Cap) are presented in **Figure 4**. This is the smallest geographical region considered in this report, and in consequence the number of available time series is relatively low. The ocean climate index (**Figure 4**A) is the average of 3 time series of standardized ocean temperature anomalies: sea surface temperatures (SSTs) in Div. 3M, mean temperature over the offshore portion of Flemish Cap hydrographic section (stations FC-15 to FC-35) summer mean bottom temperature over the cap. SSTs and observations along Flemish Cap hydrographic section are presented in Cyr et al. (2024). Bottom temperatures are derived using the same procedure used in Cyr et al. (2024), but only for the top 1000 m of NAFO Div. 3M. Data used for this calculation is mostly from (although not limited to) the European Union summer survey.

Spring bloom indices for the 2003-2023 period are derived from two polygons (Flemish Pass [FP] and Flemish Cap [FC]; see Fig. 2A for geographical location). It is worth noting that the presence of fog in the Flemish Cap region during the spring reduces satellite data availability and increases the uncertainty around the calculation of the spring bloom indices. Zooplankton abundance and biomass indices for the 1999-2020 period are derived from a subset of 10 oceanographic stations from the portion of the Flemish Cap [FC] section extending over the Flemish Pass, the Flemish Cap, and the outer shelf break (see Fig. 2B for sections location). The FC section is generally sampled 3 times per year during AZMP spring (Apr-May), summer (Jul-Aug) and fall (Nov-Dec) surveys. In 2023, NAFO Division 3M was not occupied during the summer because of limited research vessel availability.

## Ocean Climate and Ecosystem Indicators

The ocean climate index in Div. 3M (**Figure 4**A) has remained mostly positive between the late 1990s and 2013, and negative between 2014 and 2019, including in 2015 where it reached its lowest value since 1992. Since 2020, a warming phase if emerging, with years 2023 and 2022 ranking respectively as the warmest and second warmest years since the time series started in 1985.

The timing of the spring bloom has been oscillating between earlier and later than normal with no clear variation pattern between 2003 and 2016 (Figure 4B). In 2017, the timing of the bloom was the latest of this timeseries, coinciding with very cold ocean conditions in the NW Atlantic that spring. After being mostly earlier than average between 2018 and 2021 the timing of the bloom was the second and third latest of this timeseries in 2022 and 2023, respectively. Spring bloom intensity exhibited a general decrease from 2005 to through the mid 2010s despite significant fluctuations on an annual to biannual timescale (Figure 4C). Bloom intensity has remained primarily near to below normal since 2014 with the exception of the second highest intensity of the time series in 2018 (Figure 4C). In 2023, spring bloom timing was later than normal (3rd latest of the time series) for a second consecutive year while intensity was at the third lowest level (the third latest of the time series, while bloom intensity was below normal and at its lowest level since 2014 (Figure 4C & D).

Total copepod abundance rapidly increased between 1999 and 2010 and have remained near to above normal from 2005 through 2021 except for the low abundances recorded in 2014 and 2019 (Figure 4D). In 2023, copepod abundance remained below normal for a second consecutive year following the 2nd lowest level of the time series of 2022 (Figure 4D). The abundance of non-copepods showed a general increase from 1999 through 2020 with abundance transitioning from mainly bear to below normal, to near to above normal in 2015 (Figure 4E). Non-copepod abundance was near-normal in 2023 after having declined to below normal in 2022 for the first time in 10 years (Figure 4E). Similarly to copepod abundance, zooplankton biomass exhibited an overall increase from 1999 through the mid-2010s an declined afterward (Figure 4DF). In 2023, zooplankton biomass was slightly below normal for the first time in six years (Figure 4F).

## Recent Highlights in Ocean Climate and Lower Trophic Levels for 3M

- A warming climate phase has been emerging since 2020 in 3M. Years 2023 and 2022 ranked as the warmest and second warmest on record.
- The timing the phytoplankton spring bloom was the second and third latest of this timeseries in 2022 and 2023, respectively.
- Spring bloom intensity was lower than normal for the firs time in nine years in 2023.
- Total copepod abundance was below normal in 2022 (second lowest value of the time series) and 2023.

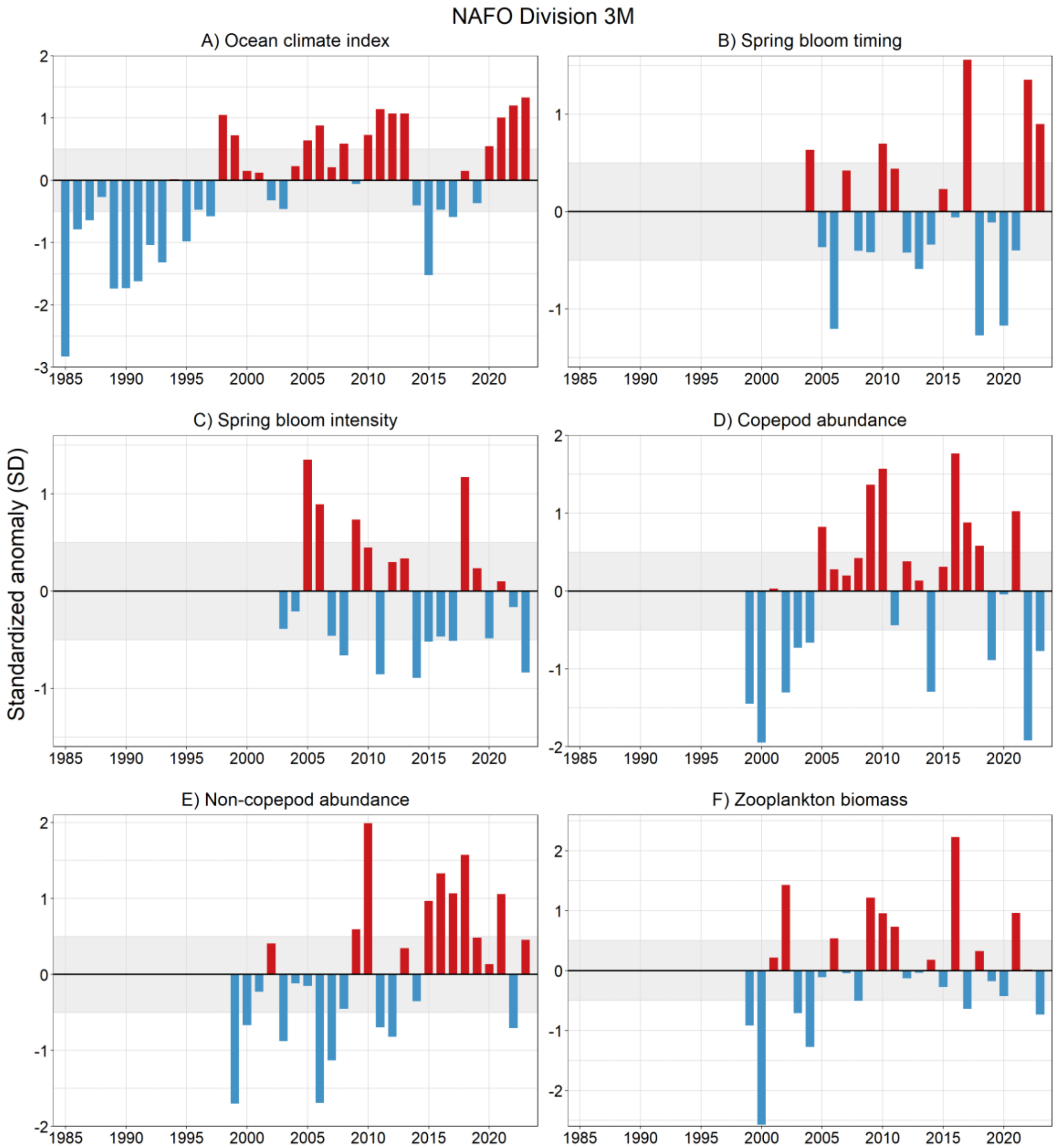


**Figure 4.** Annual anomalies of environmental indices for Flemish Cap (in NAFO Div. 3M). The ocean climate index (A) for the period 1990-2020 is the average of three time series of standardized ocean temperature anomalies of sea surface temperatures (SSTs), hydrographic section observations and summer mean bottom temperature over the cap (see text for details). Spring bloom anomalies (B, C) for the 2003-2023 period were averaged over two polygons (FP, FC – see Fig. 2A for polygon locations). Zooplankton anomalies (D-F) for the period 1999-2023 were calculated using data from the portion of the FC section located within NAFO Div. 3M (see Fig. 2B for section locations). Positive (negative) anomalies indicate late (early) bloom timing or conditions above (below) the mean for the reference period. Anomalies were calculated using the following reference periods: ocean climate index: 1991-2020, spring bloom indices: 2003-2020, Zooplankton indices: 1999-2020. Anomalies within ± 0.5 SD (shaded area) are considered near-normal conditions.

## Grand Bank (NAFO Divisions 3LNO)

### Environmental Overview

The water mass characteristic of the Grand Bank are typical of sub-polar waters, with the presence of a cold intermediate layer (CIL) formed during winter, and which last throughout the year until the late fall. The CIL (defined as water <0°C) extends to the ocean bottom in the northern areas of 3LNO, covering the bottom with sub-zero temperatures. The CIL properties are reliable indices of ocean climate conditions in this area. Bottom temperatures are higher in southern regions of 3NO reaching 1 - 4°C, mainly due to atmospheric forcing and along the slopes of the banks below 200 m depth due to the presence of Labrador Slope Water. On the southern slopes of the Grand Bank in Div. 3O bottom temperatures may reach 4 - 8°C due to the influence of warm slope water from the Gulf Stream. The general circulation in this region consists of the relatively strong offshore Labrador Current at the shelf break and a considerably weaker branch near the coast in the Avalon Channel. Currents over the banks are very weak and the variability often exceeds the mean flow.

### Index calculation and data availability

The different composite indices for NAFO division 3LNO (Grand banks) are presented in Figure 5. Many time series are available in this well sampled region. The ocean climate index (**Figure 5**A) is the average of 12 individual time series of standardized ocean temperature anomalies: sea surface temperatures (SSTs) for Divis. 3L, 3N and 3O, vertically average ocean temperature (0-176 m) at Station 27, CIL volumes on hydrographic sections Seal Island, Bonavista and inshore Flemish Cap (FC-01 to FC-20), and mean bottom temperature in 3LNO for spring and fall. All these variables are presented in Cyr et al. (2024). See **Figure 1** for geographical location of the different NAFO divisions, location of Station 27 (purple star) and hydrographic sections (red transects).

Indices for the spring phytoplankton bloom timing and intensity for the 2003-2023 period are derived from two polygons (Northern Grand Bank [NGB], and Southeast Shoal [SES]; see Fig. 2A for polygon locations). Zooplankton abundance and biomass indices for the 1999-2023 period are derived from two oceanographic sections (3L portion of the Flemish Cap [FC] section, and Southeastern Grand Bank [SEGB] section) and one high-frequency monitoring site (Station 27 [S27]; see Fig. 2B for the location oceanographic sections and high-frequency monitoring sites). The FC section is generally sampled in spring (Apr-May), Summer(Jul-Aug) and fall (Nov-Dec), while SEGB is sampled in spring and fall only. On most years, S27 is occupied on average 2-4 times monthly between from March through December. In 2023, both sections were occupied according to standard AZMP sampling protocol in addition to 33 occupations of S27 between January $8^{th}$ and November $29^{th}$.

### Ocean Climate and Ecosystem Indicators

The ocean climate index in Divs. 3LNO (Fig. 3A) was well below normal (indicative of cold conditions) between the mid-1980s and the mid-1990s. Following this cold period, the index was mostly normal to above normal between the late 1990s and 2013 (with the exception of 2009 that was below normal), reaching a peak in 2011. The index returned to normal conditions between 2014 and 2017 (except for 2016 was normal). While years 2020 to 2022 were well above normal (including 2021 and 2020, respectively the warmest and second warmest years on record for this time series started in 1985), the index returned to normal values in 2023.

Spring bloom timing has been quite variable on the Grand Bank since 2003 despite a period of consistently earlier-than-normal blooms form 2009  through 2013 (Figure 5B). Some later-than normal blooms were observed in 2015, 2017 and 2019 but bloom timing has remained near-normal since then Figure 5B). The lower-than normal spring bloom intensity observed over the past three years were among the lowest of the time series, including a record-low level for 2022 (Figure 5C).

The abundance of both copepods and non-copepods exhibited a significant increase throughout the time series, transitioning from primarily below normal to primarily above normal around 2010 (Figure 5D, E). Abundance has remained above normal since 2016 for both groups (except for copepod in 2018), with the two highest levels observed in 2016 and 2021 (Figure 5D, E). Despite remaining slightly above-normal, the 2022 and 2023 abundances represented a considerable decline compared to 2021 (Figure 5D, E). Total zooplankton biomass generally declined from the early 2000s through 2014 but has increased to near or above normal afterward (Figure 5F). In 2023, zooplankton biomass was near normal for the second consecutive year, which, similarly to copepod and non-copepod abundance, represented a decline compared to slightly above-normal level of 2021 (Figure 5F).

**Recent Highlights in Ocean Climate and Lower Trophic Levels for 3LNO**

- In 2023, the ocean climate in NAFO Divs. 3LNO - Grand Bank, was back to normal after being well above normal between 2020 and 2022.

- Spring bloom intensity was below normal for a third consecutive year in 2023 (including record low in 2022).

- The abundance of copepods and non-copepods has been mainly above normal since 2016.

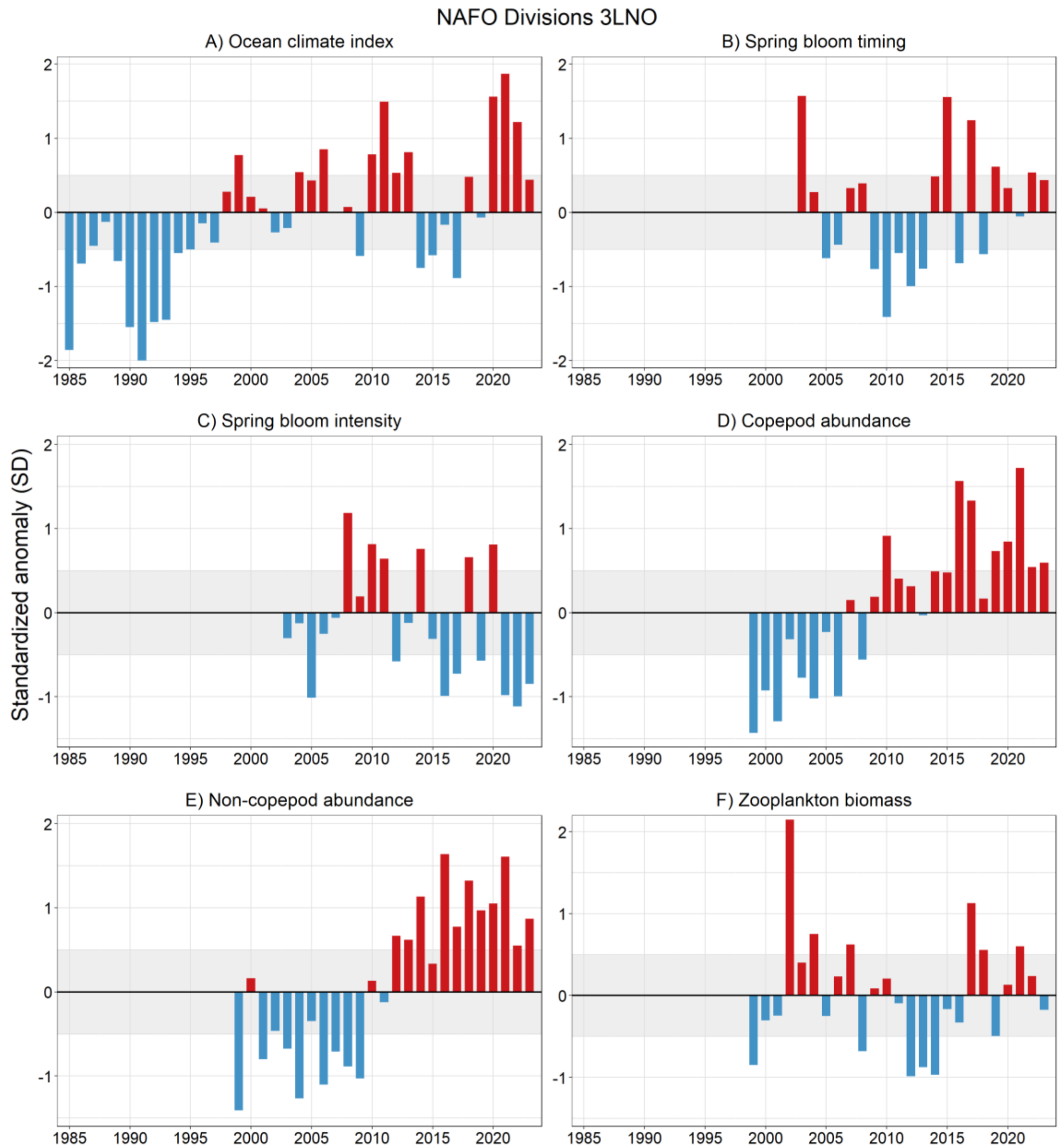


**Figure 5.** Annual anomalies of environmental indices for NAFO Divisions 3LNO. The ocean climate index (A) during 1985-2012 is the average of twelve individual time series of standardized ocean temperature anomalies: SSTs for Divs. 3L, 3N and 3O, vertically averaged ocean temperature (0-176 m) at Station 27, mean temperature and CIL volumes over standard hydrographic sections Seal Island, Bonavista and inshore Flemish Cap (FC-01 to FC-20), and mean bottom temperature in 3LNO for spring and fall (see text for details). Spring bloom anomalies (B, C) for the 2003-2023 period were averaged over two polygons (NGB, SE – see Fig. 2A for polygon locations). Zooplankton anomalies (D-F) for the 1999-2023 period are derived from two oceanographic sections (3LN portion of FC, SEGB– see Fig 2B for sections location) and one coastal high-frequency sampling site (S27). Positive (negative) anomalies indicate late (early) bloom timing or conditions above (below) the mean for the reference period. Anomalies were calculated using the following reference periods: ocean climate index: 1991-2020, phytoplankton indices: 2003-2020, zooplankton indices: 1999-2020. Anomalies within ±0.5 SD (shaded area) are considered normal conditions.

## Newfoundland and Labrador shelf, Scotian Shelf and Gulf of Maine (NAFO Subareas 2, 3 and 4)

### Environmental Overview

The water mass characteristics of Newfoundland and Labrador Shelf are typical of sub-polar waters with a sub-surface temperature range of -1 to 2°C and salinities of 32-33.5. Labrador Slope Water flows southward along the shelf edge and into the Flemish Pass region, this water mass is generally warmer and saltier than the sub-polar shelf waters with a temperature range of 3-4°C and salinities in the range of 34-34.75. On average bottom temperatures remain < 0°C over most of the northern Grand Banks but increase to 1-4°C in southern regions and along the slopes of the banks below 200 m. North of the Grand Bank, in Div. 3K, bottom temperatures are generally warmer (1-3°C) except for the shallow inshore regions where they are mainly <0°C. In the deeper waters of the Flemish Pass and across the Flemish Cap bottom temperatures generally range from 3-4°C. Throughout most of the year the cold, relatively fresh water overlying the shelf is separated from the warmer higher-density water of the continental slope region by a strong temperature and density front. This winter-formed water mass is generally referred to as the Cold Intermediate Layer (CIL) and is considered a robust index of ocean climate conditions. In general, shelf water masses undergo seasonal modification in their properties due to the seasonal cycles of air-sea heat flux, wind-forced mixing and ice formation and melt, leading to intense vertical and horizontal gradients particularly along the frontal boundaries separating the shelf and slope water masses.

Temperature and salinity conditions in the Scotian Shelf, Bay of Fundy and Gulf of Maine regions are determined by many processes: heat transfer between the ocean and atmosphere, inflow from the Gulf of St. Lawrence supplemented by flow from the Newfoundland Shelf, exchange with offshore slope waters, local mixing, freshwater runoff, direct precipitation and melting of sea-ice. The Nova Scotia Current is the dominant inflow, originating in the Gulf of St. Lawrence and entering the region through Cabot Strait. The Current, whose path is strongly affected by topography, has a general southwestward drift over the Scotian Shelf and continues into the Gulf of Maine where it contributes to the counter-clockwise mean circulation. The properties of shelf waters are modified by mixing with offshore waters from the continental slope. These offshore waters are generally of two types, Warm Slope Water, with temperatures in the range of 8-13°C and salinities from 34.7-35.6, and Labrador Slope Water, with temperatures from 3.5°C to 8°C and salinities from 34.3 to 35. Shelf water properties have large seasonal cycles, east-west and inshore-offshore gradients, and vary with depth.

### Index calculation and data availability

The different composite indices for NAFO subareas 2, 3 and 4 during 1985-2023 are presented in **Figure 6** under the form of stacked bar plots where each color correspond to a composite index for the individual subarea. Many time series are thus used to generate this figure. For the ocean climate index (**Figure 6**A), the standardized anomalies for subarea 2 is the result of the average of 8 individual time series: Sea surface temperatures (SST) in Divs. 2G, 2H and 2J, bottom temperatures in 2H and 2J in the fall, mean temperature and CIL volumes over the hydrographic section Seal Island and the air temperature in Cartwright (Labrador). For subarea 3, 16 individual time series are used: SSTs in Divs. 3K, 3L, 3M, 3N, 3O and 3P, vertically average ocean temperature at Station 27 (0-176 m), mean temperature and CIL volumes over hydrographic sections Bonavista and Flemish Cap, mean bottom temperature in 3LNO (spring and fall) and 3M (summer) and air temperature in St. John's and Bonavista (Newfoundland). For subarea 4, 12 individual time series are used: SSTs in Divs. 4Vn, 4Vs, 4W and 4X, vertically average ocean temperature at Station Prince-5 (0-90 m), surface (0-50 m) and bottom (150 m) temperature at Station Halifax-2, bottom temperature in 4VWX (summer), near bottom temperature in Emerald Basin (~250 m) and on Misaine Bank (~100 m), deep (150-200m) temperatures in the Northeast Channel (NEC) and near surface (0-30 m) temperatures in the Eastern Gulf of Maine (EGOM). Location of these data are highlighted in **Figure 1**. Most of these data are also presented in Cyr et al. (2024), except for bottom temperature in 3M and temperatures for NEC and EGOM that have been obtained from the ICES report on ocean climate, as well as data for the Emerald Basin and Misaine Bank (IROC; https://ocean.ices.dk/iroc/).

Phytoplankton spring bloom indices (timing and intensity) are averaged over three polygons for NAFO subarea 2 (NLS, CLS, HB), seven boxes for subarea 3 (SAB, NENS, NGB, FP, FC, SES, SPB), and seven boxes for subarea 4 (NGSL, NEGSL, MS, CS, ESS, CSS, WSS) (see Fig. 2A for polygon locations). Zooplankton abundance and biomass indices are averaged over 3 oceanographic sections in subarea 2 (BI, MB, SI), five sections (BB, FC, SEGB, SESPB, SWSPB) and one high-frequency monitoring site (S27) in subarea 3, and nine oceanographic sections (TESL, TSI, TASO, TBB, TECN, TIDM, TDC, LL, HL, BBL) and four high-frequency monitoring sites (R, S, P5, H2) in subarea 4 (see Fig. 2B for the location oceanographic sections and high-frequency monitoring sites). Zooplankton indices are based on data collected during summer in subareas 2; during spring, summer and fall in Subarea 3 and 4.

## Ocean Climate and Ecosystem Indicators

A cumulative climate index for NAFO subareas 2, 3 and 4 (from the Labrador Shelf to the Scotian Shelf) is presented in Fig. 4A. This index highlights the different climate phases undergone by the ecosystem since the mid-1980s. After a period from the mid-1980s to the early 1990s, the index has remained relatively high since (all years since 1995 are normal or above normal). Since 2020, a warm phase has been emerging, which includes the three warmest years on record (respectively 2021, 2022 and 2020) and 2023 that ranks as the 5$^{th}$ warmest. This time series started in1950, although only shown here since 1985.

Mean timing of the spring phytoplankton bloom was variable across subareas 2-3-4 with no clear temporal pattern (Figure 6B). After being the earliest and second earliest of the time series in 2022 and 2021, respectively, the timing of the spring bloom was at its latest in 2023. Spring bloom intensity was variable from during the 2000s, exhibited a gradual decline from near normal to a time series record low between 2011 and 2017, before increasing to above normal in 2018 (Figure 6C). Mean bloom intensity has remained near normal since 2019 (Figure 6C).

Total copepod abundance increased from 1999 to 2005, and declined afterward to slightly below normal level in 2012 (Figure 6D). The abundance of copepod was variable and primarily near normal throughout most of the 2010s, reached its two highest levels in 2020 and 2021, and declined to below normal in 2023 (Figure 6D). The abundance of non-copepods was near-to-below normal from 1999 to 2015 and above normal afterward except for the near-normal level of 2023 (Figure 6E). Trends in the abundance of copepods and non-copepods were mainly driven by subareas 2 and 3 with less variability for subarea 4 (Figure 6D, E). Zooplankton biomass exhibited a general decline across subareas 2-4 between 2002 and 2015, and has remained near normal since (except for the above-normal level of 2021) with generally higher biomass in subareas 2 and 3 compared to subarea 4 (Figure 6F).

**Recent Highlights in Ocean Climate and Lower Trophic Levels**

- In 2023, subareas 2, 3 and 4 were all above normal, making this year the 5$^{th}$ warmest on record. This continues a warming phase started in 2020 (years 2020-2022 were the three warmest on record).
- The timing of the spring phytoplankton bloom in 2023 was the latest observed in this time series, mostly because of the late bloom timings observed in subareas 2 and 3.
- Mean copepod abundance was at its lowest since 2000 (third lowest of the time series).
- The abundance of non-copepods declined to near normal in 2023 after having remained above normal for seven consecutive years.

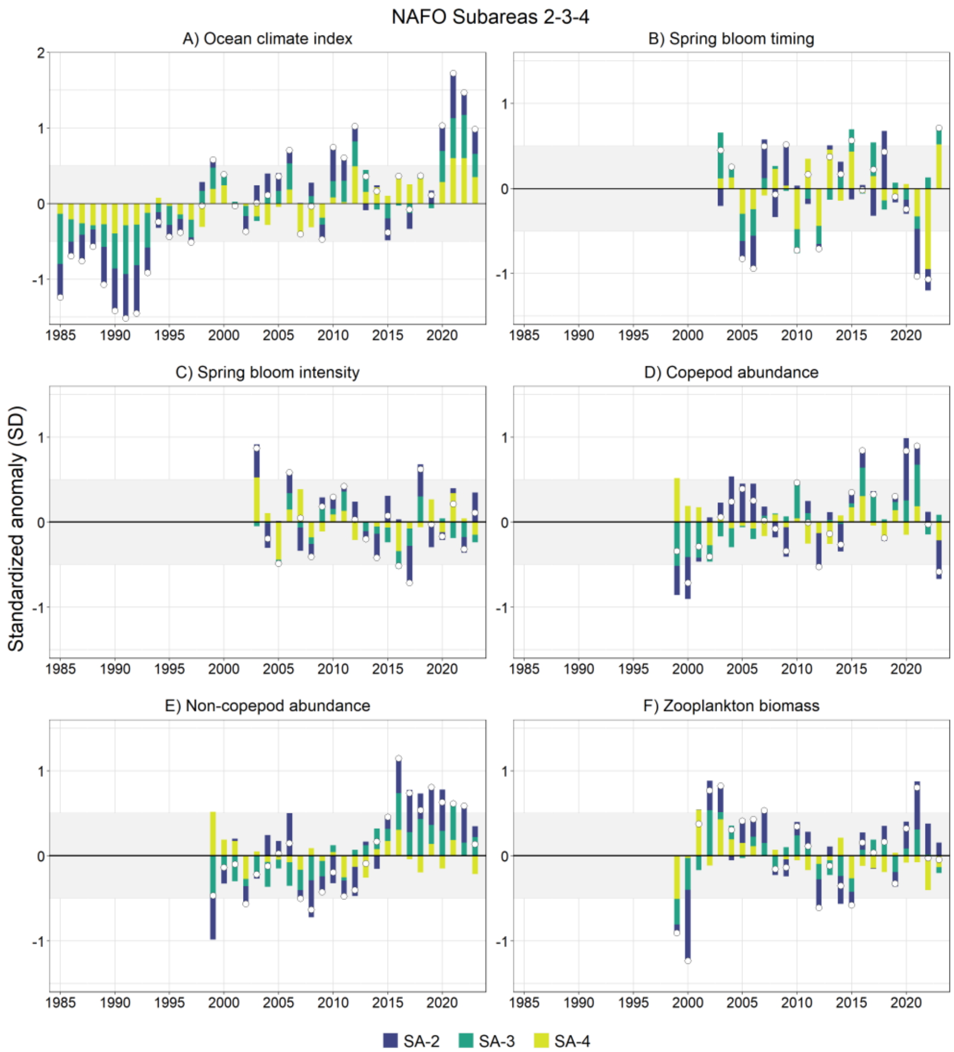


**Figure 6.** Annual anomalies of environmental indices for NAFO Subareas 2 to 4. The ocean climate index (A) during 1990-2020 is the average of 8, 16 and 12 individual time series respectively for subareas (SA-) 2, 3 and 4 (see text for details). Spring bloom anomalies (B, C) for the 2003-2023 period were averaged over three (NLS, CLS, HB), seven (SAB, NENS, NGB, FP, FC, SES, SPB) and seven (NEGSL, NWGSL, MS, CS, ESS, CSS, WSS) satellite polygons for Subarea 2, 3 and 4, respectively (see Fig. 2A for polygon locations). Zooplankton anomalies were averaged over three sections (BI, MB, SI) for SA-2, three sections (BB, FC, SESG) and one high-frequency sampling site (S27) for SA-3, and 10 sections (TESL, TSI, TBB, TECN, TDC, TIDM, LL, HL, BBL) and four high-frequency sampling sites (R, S, P5, H2) for SA-4 (see Fig. 2B for section locations). Positive (negative) anomalies indicate late (early) bloom timing or conditions above (below) the mean for the reference period. Coloured bars length indicate the relative contribution of each NAFO Subarea to the annual mean anomaly (open white circles). Anomalies were calculated using the following reference periods: ocean climate index: 1991-2020, phytoplankton indices: 2003-2020, zooplankton indices: 1999-2020. Anomalies within ±0.5 SD (shaded area) are considered normal conditions.

## Summary

Highlights of this report can be summarized as follows:

- A large majority of ocean climate indicators above normal in 2023.
- Most of the climate indices have been well above average since 2020 as part of an emerging warming phase that comprises the warmest years on record for subareas 2, 3 and 4 (especially 2021 and 2022).
- Driven by widespread colder conditions in the spring, the timing of the spring bloom was later than average in subareas 2-4 in 2023.
- The abundance of copepods and non-copepods has been mainly above normal since 2016 on the Grand Bank (3LNO) in 2021, while the abundance of copepod was below average for a second year in a row on Flemish Cap (3M).

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