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

by

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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 2021. This is especially true for NAFO Divs. 3LNO (Grand Bank), where the index, was at its second warmest value since the time series started in 1985. The composite climate indices for sub-areas 2, 3 and 4 altogether was at a record-warm value. Spring bloom initiation in 2021 for subareas 0-1 was the earliest of record during a year marked by unusually low sea ice coverage in the North Atlantic. The abundance of copepod and non-copepod was at a record high on the Grand Bank (3LNO) in 2021, continuing a trend of above-normal levels that started back in 2016.

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). New from year 2021, this information has been formalized and presented as part of a distinct Science Council Research (SCR) multidisciplinary document (see Cyr and Bélanger, 2021).

The information provided here is extracted from individual SCR Documents on environmental and physical oceanographic conditions on the eastern Canadian shelves (Cyr et al., 2022) and on biogeochemical oceanographic conditions in the Northwest Atlantic (Bélanger et al., 2022). 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.

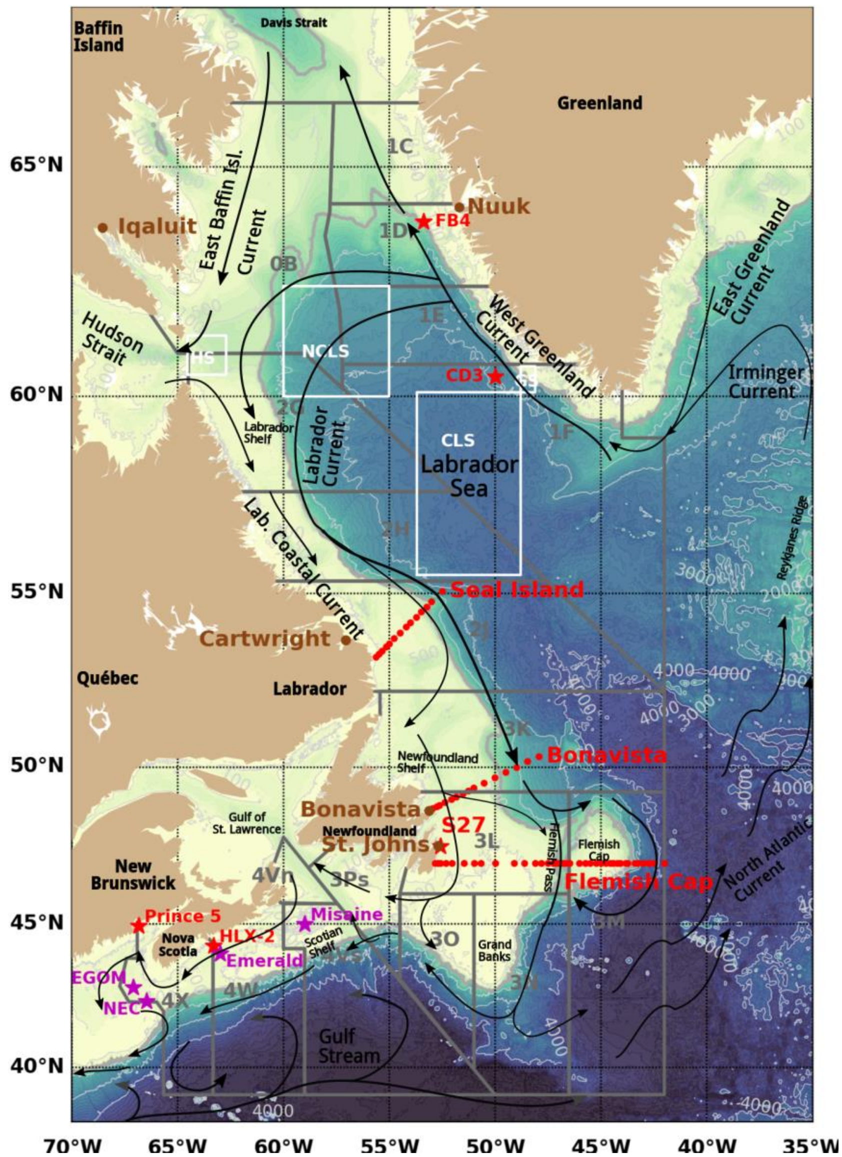

Figure 1. Map highlighting the location of the physical environmental time series used in this report. NAFO Divisions and main bathymetric features of the Northwest Atlantic are highlighted (colormap and gray contours). The thick gray contour is the isobath 1000m that is used here to delimit the continental 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 geographical boxes used for SST calculation on the Greenland Shelf (GS), Central Labrador Sea (CLS), North Central Labrador Sea (NCLS) and Hudson Strait (HS) are drawn in white. The CLS box also correspond to an hydrographic time series used in this report.

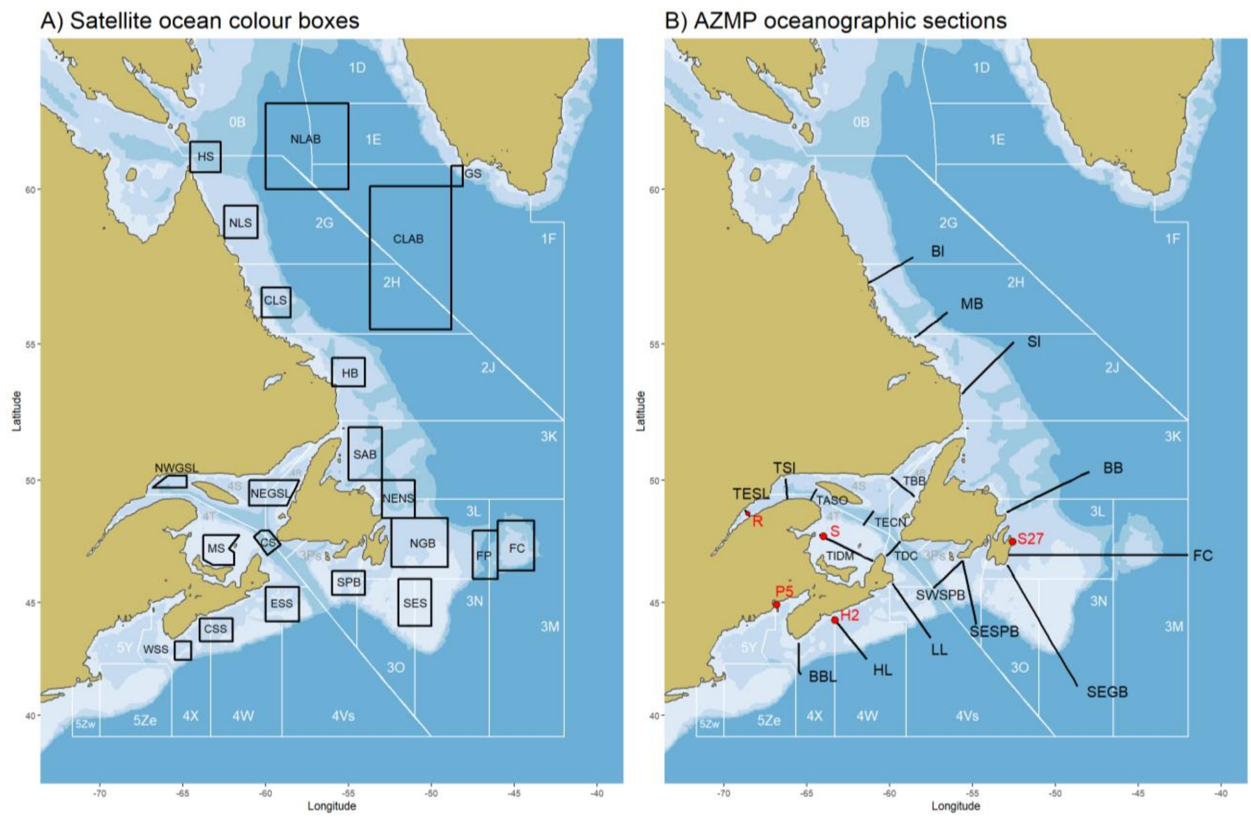

Figure 2. (A) Location of the boxes used to calculate spring bloom indices (initiation, duration, and magnitude) from satellite Ocean Color imagery: HS=Hudson Strait, NLS=northern Labrador Shelf, CLS=central Labrador Shelf, HB=Hamilton Bank, SAB=St. Anthony Basin, NENS=northeast Newfoundland Shelf, FP=Flemish 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 (Figure 3A) is the average of 10 individual time series of standardized ocean temperature anomalies: sea surface temperatures (SSTs) West Greenland Shelf, North and Central Labrador Sea and Hudson Strait, vertically average ocean temperature in the Central Labrador Sea (20-1800m), 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 at this location), 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/). However, the 2021 update for FB-4 and CD-3 were not available.

Phytoplankton spring bloom initiation and magnitude indices for the 2003-2020 period are derived from four satellite boxes located in NAFO Divs. 0B1EF (Hudson Strait [HS], Northern [NLAB] and Central [CLAB] Labrador Sea, Greenland Shelf [GS]; see Figure 2 for boxes location). It is worth noting that the presence of sea ice and the limited daylight hours at appropriate angle of incidence in the fall at theses high latitudes reduces satellite data availability and increases the uncertainty around the spring bloom indices. No in-situ biogeochemical data were available for subareas 0 and 1 in 2021.

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 (Figure 3A). After being in 2019 at its highest value since the record high of 2010, the index was normal in 2020 and again above normal in 2021. Before the warm period of the last decade, cold conditions persisted in the early to mid-1990s.

Spring bloom initiation has been oscillating between early (negative anomalies) and late (positive anomalies) timing between 2003 and 2020. In 2021, the average timing of the spring bloom in Subarea 0B1EFT was the earliest of the time series and followed the two latest bloom onset on record for the region (Figure 3B). Spring bloom magnitude (total production) remained mostly below or near-normal between 2003 and 2020 with the exception of a few highly productive bloom in 2006, 2015 and 2018 (Fig. 3C). In 2021, mean bloom magnitude in the region was slightly higher than normal (Fig. 3C).

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

- The ocean climate index in Subarea 0-1 above normal in 2021.
- Mean initiation timing of the spring phytoplankton bloom in 2021 was the earliest of the time series.
- Spring bloom magnitude (total production) was slightly below normal in 2021

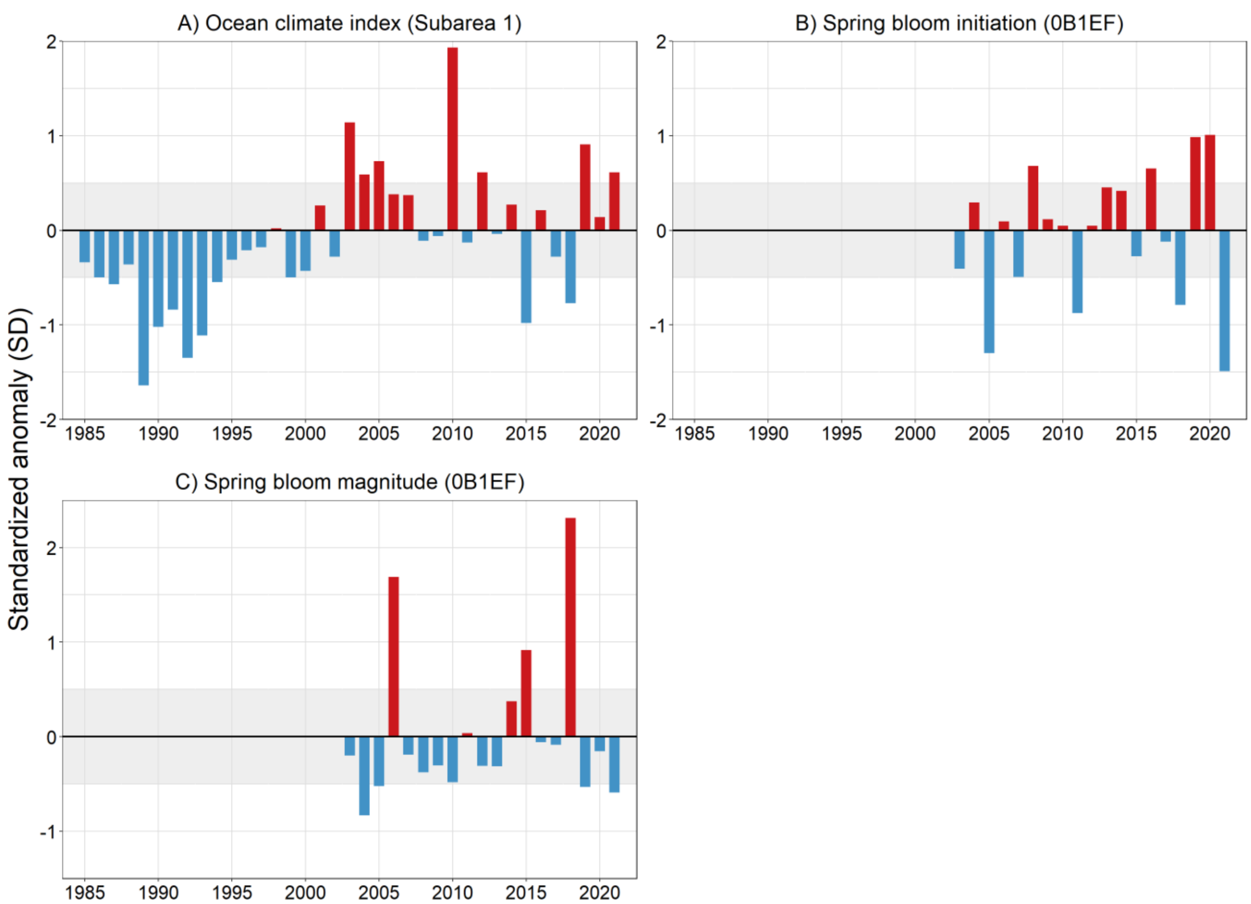

Figure 3. Annual anomalies of environmental indices for NAFO Subareas 0 and 1. The ocean climate index (A) for the period 1990-2020 is the average of 10 individual time series. These includes standardized anomalies of 4 SSTs time series, 4 temperature time series at 3 hydrographic stations and 2 air temperatures time series (see text for details). Spring bloom anomalies (B, C) for the 2003-2021 period are derived from four satellite boxes (HS, NLAB, CLAB, GS – see Fig. 2A for satellite box locations). Positive (negative) anomalies indicate late (early) bloom timing or magnitude 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 4A) 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. (2022). Bottom temperatures are derived using the same procedure used in Cyr et al. (2022), but only for the top 1000 m of the cap. Data used for this calculation is mostly from (although not limited to) the EU summer survey.

Spring bloom initiation and magnitude indices for the 2003-2021 period are derived from two satellite boxes (Flemish Pass [FP] and Flemish Cap [FC]; see Fig. 2A for boxes 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 Flemish Cap [FC] section that extend 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 2021, limited ship time availability restricted seasonal sampling to summer only.

Ocean Climate and Ecosystem Indicators

The ocean climate index in Div. 3M (Figure 4A) has remained mostly above normal between the late 1990s and 2013. After the record high of 2011, the index gradually decreased reaching in 2016 its lowest value since 1993. After being below normal between 2015-2019 (with the exception of 2018 that was normal), the index was normal in 2020 and 2021.

Mean spring bloom initiation timing has been oscillating between earlier and later than normal between 2003 and 2020 with no clear variation pattern except for three consecutive early blooms from 2004 to 2006 (Figure 4B). Spring bloom magnitude (total production) has also been oscillating between above and below and above normal throughout the time series with a change in the sign of the anomalies (positive to negative) every 2-3 years (Figure 4C). Bloom magnitude returned to near normal in 2021 after the below-normal levels of the previous year and the three consecutive years of above-normal production from 2017-2019 (Figure 4C). In general, early bloom onsets (i.e., negative initiation anomalies) are associated with higher primary production (i.e. positive magnitude anomalies) and vice versa, but there are exceptions (Fig. 4B-C). Total copepod abundance rapidly increased between 1999 and 2010 and varied more during the 2010s although it mostly remained near or above normal except for the low abundances recorded in 2014 and 2019 (Figure 4D). The abundance of non-copepods showed a general increase from 1999 to 2018 but followed by a decline in the late 2010s similar to that of copepod (Figure 4D, E). In 2021 the abundance of both copepods and non-copepods was back to above normal (Figure 4D, E). Total zooplankton biomass generally increased during the 2010s despite interannual variability, and remained mostly near normal afterwards besides the high value of 2016 (Figure 4F). In 2021, mean zooplankton biomass in the region was slightly above normal (Figure 4F).

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

- After being mostly below normal between 2015 and 2019 (except for 2018), the ocean climate index in 3M, has been normal in 2020 and 2021.
- The initiation of the spring phytoplankton bloom was earlier than normal in 2021 after 2 consecutive years of near-normal timing.
- Spring bloom magnitude returned to near normal in 2021 after the low production spring of 2020.
- The abundance of copepods and non-copepods as well as total zooplankton biomass increased to above normal in 2021 after two consecutive years of near or below-normal levels.

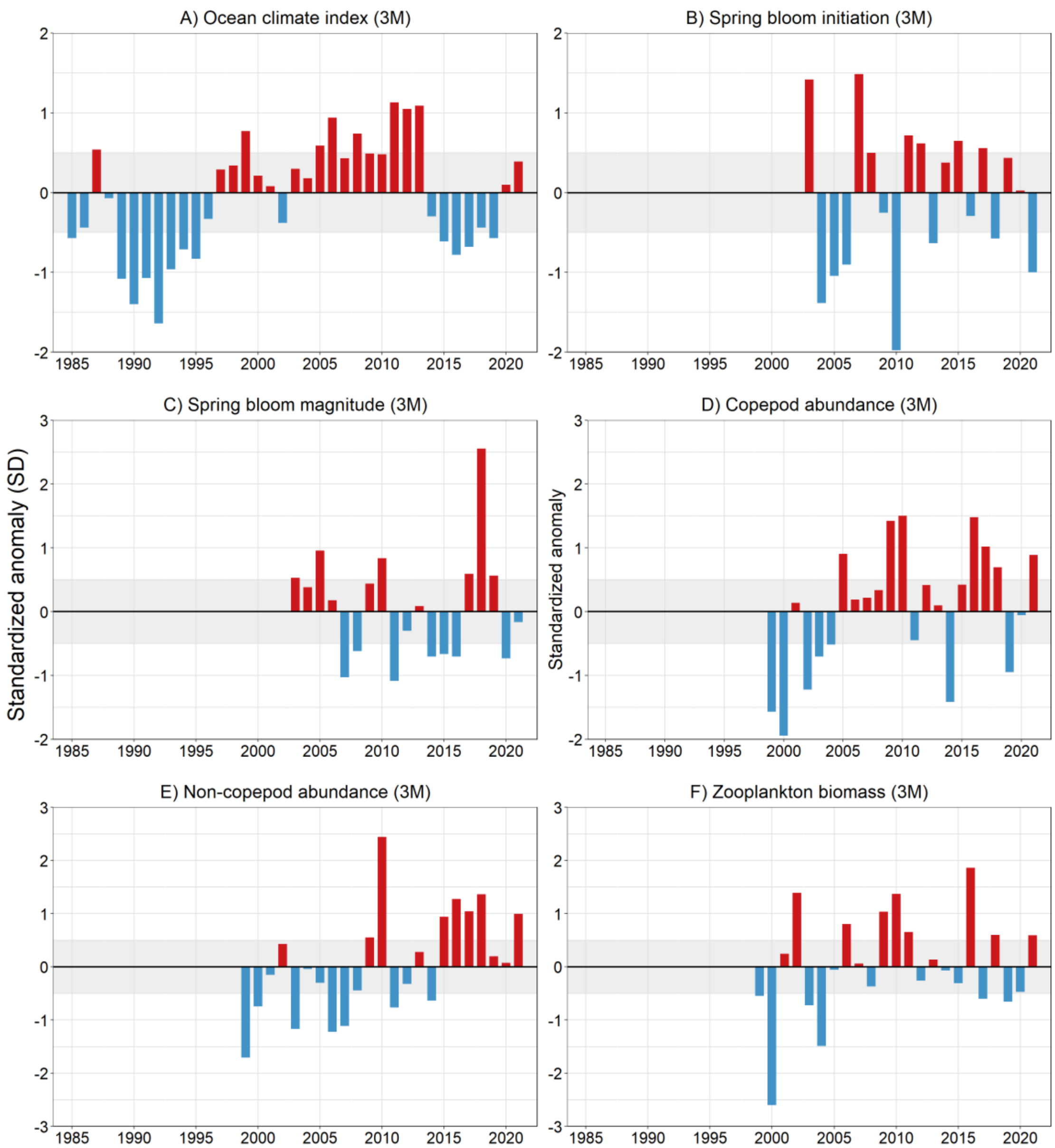

Figure 4. Annual anomalies of environmental indices for Flemish Cap (in NAFO Div. 3M). The ocean climate index (A) for the period 1990-2020 is the average of three time series of standardized ocean temperature anomalies of sea surface temperatures (SSTs), hydrographic section observations and summer mean bottom temperature over the cap (see text for details). Spring bloom anomalies (B, C) for the 2003-2021 period were averaged over two satellite boxes (FP, FC – see Fig. 2A for satellite boxes locations). Zooplankton anomalies (D-F) for the period 1999-2021 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: 1981-2010, 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 is thus a reliable index 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 5A) is the average of 12 individual time series of standardized ocean temperature anomalies: sea surface temperatures (SSTs) for Divs. 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. (2022). See Figure 1 for geographical location of the different NAFO divisions, location of Station 27 (purple star) and hydrographic sections (red transects).

Spring phytoplankton bloom initiation and magnitude indices for the 2003-2020 period are derived from two satellite boxes (Northern Grand Bank [NGB], and Southeast Shoal [SES]; see Fig. 2A for boxes location). Zooplankton abundance and biomass indices for the 1999-2020 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. Limited research vessel availability in 2021 resulted in the cancellation of the spring and fall AZMP surveys. Furthermore, zooplankton collection at S27 was limited to one sample per month from April through December. Consequently, the calculation of the 2021 zooplankton indices was based on a limited number of data (FC summer only and nine S27 samples) and should be interpreted with caution.

Ocean Climate and Ecosystem Indicators
The ocean climate index in Divs. 3LNO (Fig. 3A) has remained mostly above normal between the late 1990s and 2013, reaching a peak in 2011. The index has returned to normal conditions between 2014 and 2019 (except for 2015 and 2017 that was below normal). In 2020 and 2021, the ocean climate index was back to above normal value, reaching in 2021 the second highest value of the entire time series started in 1985 (only 2011 was warmest).

There was a general shift toward earlier spring bloom timing on the Grand Bank from 2003 to 2013 despite interannual variability (Figure 5B). Spring bloom timing remained either near or later than normal afterward except for the early blooms of 2018. Spring bloom magnitude (total production) was quite variable in 3LNO throughout the time series with no clear temporal pattern (Figure 5C). Total spring production in 2021 was third lowest of the time series after three years of a steady decline that followed the 2018 record high (Figure 5C). The abundance of copepods and non-copepods generally increased throughout the time series with a clear transition from negative to positive anomalies around 2010 (Figure 5D, E). Abundance has remained above normal since 2016 for both groups with a record high for copepods and one of the three highest values on record for non-copepods in 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 2021, biomass was above normal for the third time over the past five years (Figure 5F).

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

- In 2021, the ocean climate in NAFO Divs. 3LNO - Grand Bank, was at its second warmest value of the entire time series started in 1975 (after the record high of 2011).

- Spring bloom initiation was near normal in 2021 for a 3rd consecutive year.

- Spring bloom magnitude decreased to below normal in 2021 and was among the lowest of the time series.

- The abundance of copepods and non-copepods remained above normal in 2021 for a 6th consecutive year with a time series record high for copepods.

- Zooplankton biomass was above normal in 2021 for the third time over the past five years.

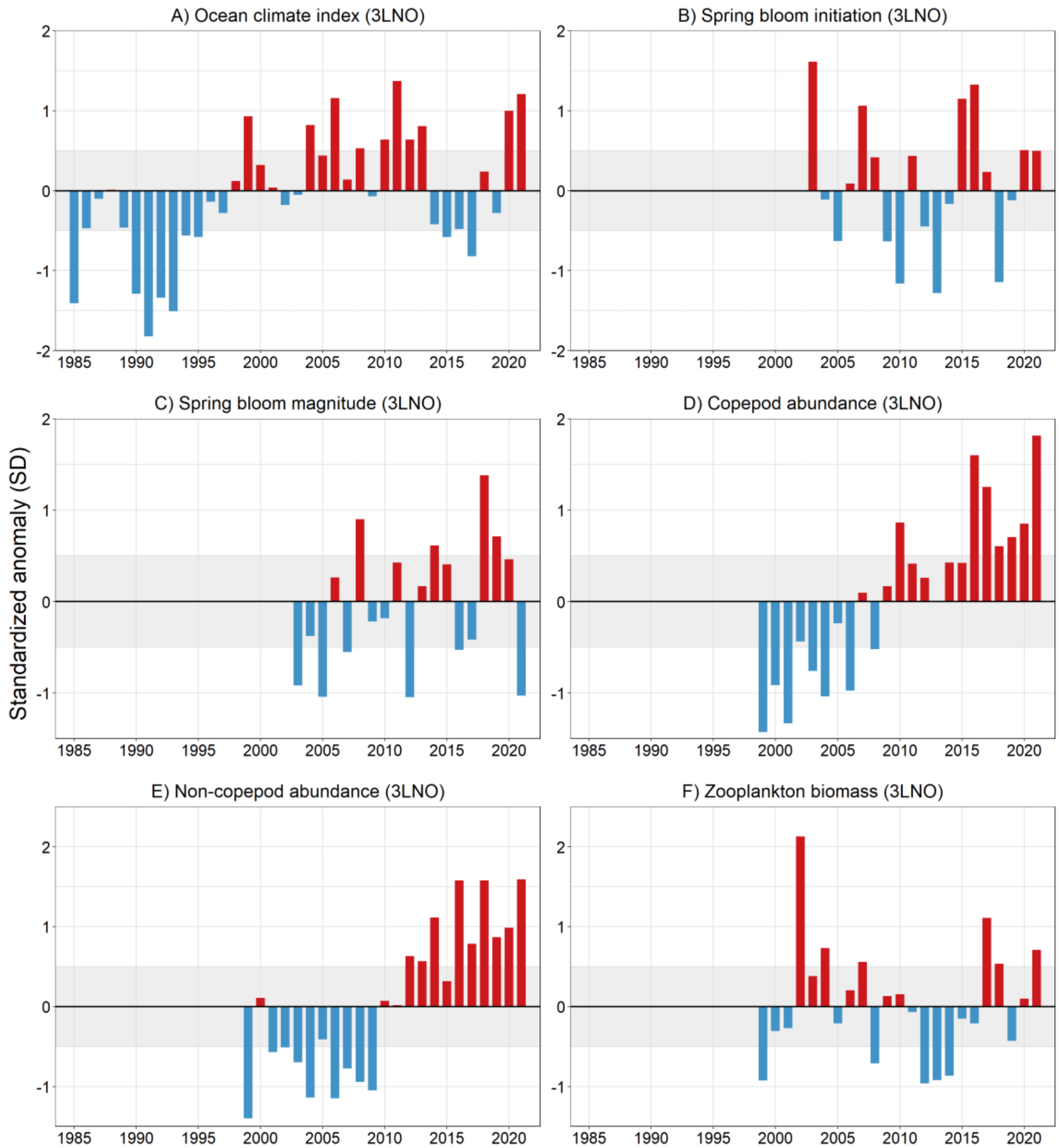

Figure 5. Annual anomalies of environmental indices for NAFO Divisions 3LNO. The ocean climate index (A) during 1985-2012 is the average of twelve individual time series of standardized ocean temperature anomalies: SSTs for Divs. 3L, 3N and 3O, vertically average ocean temperature (0-176 m) at Station 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 2003-2020 period were averaged over two satellite boxes (NGB, SE – see Fig. 2A for boxes location). Zooplankton anomalies (D-F) for the 1999-2021 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: 1981-2010, 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 -1-2°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 1985-2021 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 6A), the standardized anomalies for SA2 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 SA3, 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 SA4, 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. (2022), 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/). In 2021, all these time series were available, except the bottom temperature in 4VWX.

Phytoplankton spring bloom indices (initiation and magnitude) are averaged over three satellite boxes 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 boxes 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 SA2; during spring, summer and fall in SA3 and SA4. In addition to the reduced spatial and seasonal coverage of SA3 (see 3LNO section above), limited vessel availability also resulted in the cancellation of the 2021 spring and summer surveys. Zooplankton indices for SA3 and part of SA4 were therefore calculated using only summer and fall data, respectively, and result should be interpreted with caution.

Ocean Climate and Ecosystem Indicators

A cumulative climate index for NAFO sub-areas 2, 3 and 4 (from the Labrador Shelf to the Scotian Shelf) is presented in Fig. 4A. After a somewhat cold period from the late 1980s to the early 1990s, the index has remained relatively high since about the mid-2000's, with 2012 and 2006 being respectively the second, third warmest anomalies since 1985. After a recent return to near-normal values between 2014 and 2019 (mostly driven by cooler temperatures in SA 2 and 3) the index was back to a positive anomaly in 2020 and 2021, the latter year being the warmest on record for the region (since 1950, although only shown since 1985).

Mean timing of the spring phytoplankton bloom was variable across subareas 2-3-4 but remained mostly near normal from 2003-2020 with only two years of early (2006, 2010) and one year of late (2015) bloom onset (Fig 6B). In 2021, Mean timing of the bloom was earlier than normal, partly because of the low sea ice coverage in SA2 that allowed for early bloom onsets on the Labrador Shelf (Figure 6B). Mean spring bloom production was also variable and mostly near normal throughout the time series including in 2021 (Figure 6C). Mean copepod abundance generally increased from 1999 to 2005, then slightly decreased until the mid-2010s before increasing again to above-normal levels in recent years (Figure 6D). The abundance of non-copepods was near normal during most of the 2000s and increased in the early 2010s to reach above-normal levels from 2016 onwards except for the near-normal value of 2021 (Figure 6E). The increase in both copepod and non-copepod abundance over the past six years, including in 2021, was mainly driven by the conditions in SA2-3 (Figure 6D, E). Mean zooplankton biomass increased in the early 2000s to a maximum in 2002, and then gradually decreased to a minimum in the mid-2010s (Figure 6F). Biomass has remained near normal since with generally higher values in SA2-3 compared to SA4 (Figure 6F). Although mean biomass was near-normal in 2021, anomaly values for SA2-4 and SA4 were respectively higher and lower than those observed during the five previous years (Figure 6F).

Recent Highlights in Ocean Climate and Lower Trophic Levels

- In 2021, subareas 2, 3 and 4 were all above normal, making the cumulative anomaly the warmest on record.

- Spring bloom initiation was, on average, earlier than normal in subareas 2-3-4 in 2021, mostly because of the early bloom onsets observed on the Labrador Shelf (SA-2).

- Total spring production (bloom magnitude) was near normal in in 2021 in subareas 2, 3 and 4.

- Mean copepod abundance was above normal for a second consecutive year in 2021 and particularly high in subarea 3.

- Mean abundance of non-copepod zooplankton was near-normal in 2021 after five consecutive years of above-normal observations. Abundances in subareas 3 and 4 were comparable to those observed in recent years but decreased in Subarea 2.

- Mean zooplankton biomass was near normal in 2021 but varied among regions with some of the highest values on record for subareas 2 and 3, and a time-series lowest for subarea 4.

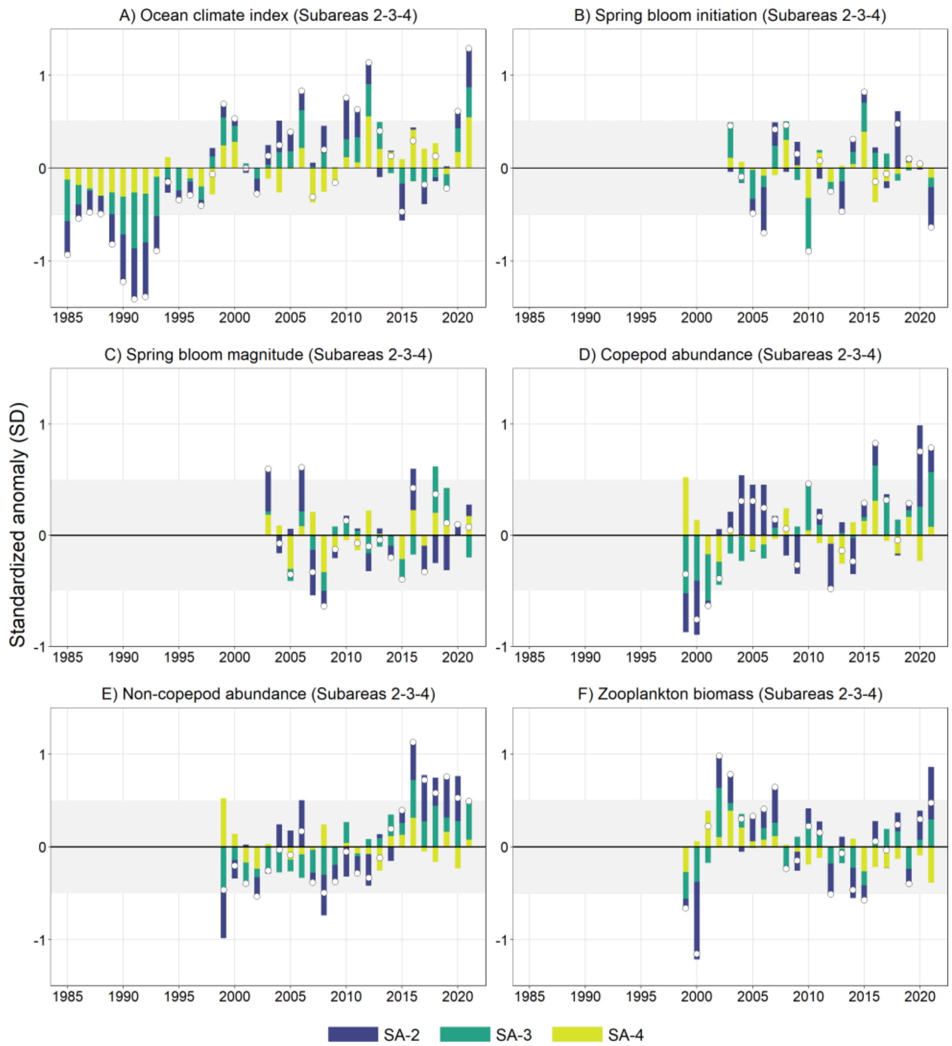

Figure 6. Annual anomalies of environmental indices for NAFO Subareas 2 to 4. The ocean climate index (A) during 1990-2020 is the average of 8, 16 and 12 individual time series respectively for SA 2, 3 and 4 (see text for details). Spring bloom anomalies (B, C) for the 2003-2020 period were averaged over two satellite boxes (NGB, SE – see Fig. 2A for boxes location). Zooplankton anomalies (D-F) for the 1999-2021 wee averaged over three (NLS, CLS, HB), seven (SAB, NENS, NGB, FP, FC, SES, SPB) and seven (NEGSL, NWGSL, MS, CS, ESS, CSS, WSS) ocean colour satellite boxes for Subarea 2, 3 and 4, respectively (see Fig. 2A for boxes location). Zooplankton anomalies were averaged over three sections (BI, MB, SI) for SA-2, three sections (BB, FC, SESG) and one hight-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: 1981-2010, 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 2021.
- In 2021, composite climate indices in subareas 2, 3 and 4 were at a time series record warm. Divs. 3LNO (Grand Bank), the index, was at its second warmest value since the record-high of 2011.
- Spring bloom initiation in 2021 for subareas 0-1 was the earliest of record during a year marked by unusually low sea ice coverage in the North Atlantic.
- The abundance of copepod and non-copepod was at a record high on the Grand Bank (3LNO) in 2021, continuing a trend of above-normal levels that started back in 2016.

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