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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 normal in 2020. The composite climate indices for sub-areas 2, 3 and 4 were all above normal, making the cumulative anomaly the 5th warmest since 1980. This is especially true for NAFO Divs. 3LNO (Grand Bank), where the index, was at its warmest value since the record-high of 2011, and at its third highest value since the time series started in 1985. In sub-areas 0-1, the initiation of the bloom was delayed for a second consecutive year in 2020. The mean abundance of non-copepod zooplankton also remained above normal across subareas 2, 3 and 4 for a 5th consecutive year and was generally higher in subareas 2-3 compared to subarea 4. Mean zooplankton biomass was near normal in 2020 for a 5th consecutive year and was higher in in subarea 2 compared to subareas 3-4.

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 Fig. 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 this year, this information will be formalized and expanded as part of a distinct Science Council Research (SCR) multidisciplinary document (this document). The information provided here is extracted from individual SCR Documents on environmental and physical oceanographic conditions on the eastern Canadian shelves (Cyr et al., 2021) and on biogeochemical oceanographic conditions in the Northwest Atlantic (Bélanger et al., 2021). 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-regions is discussed separately below.

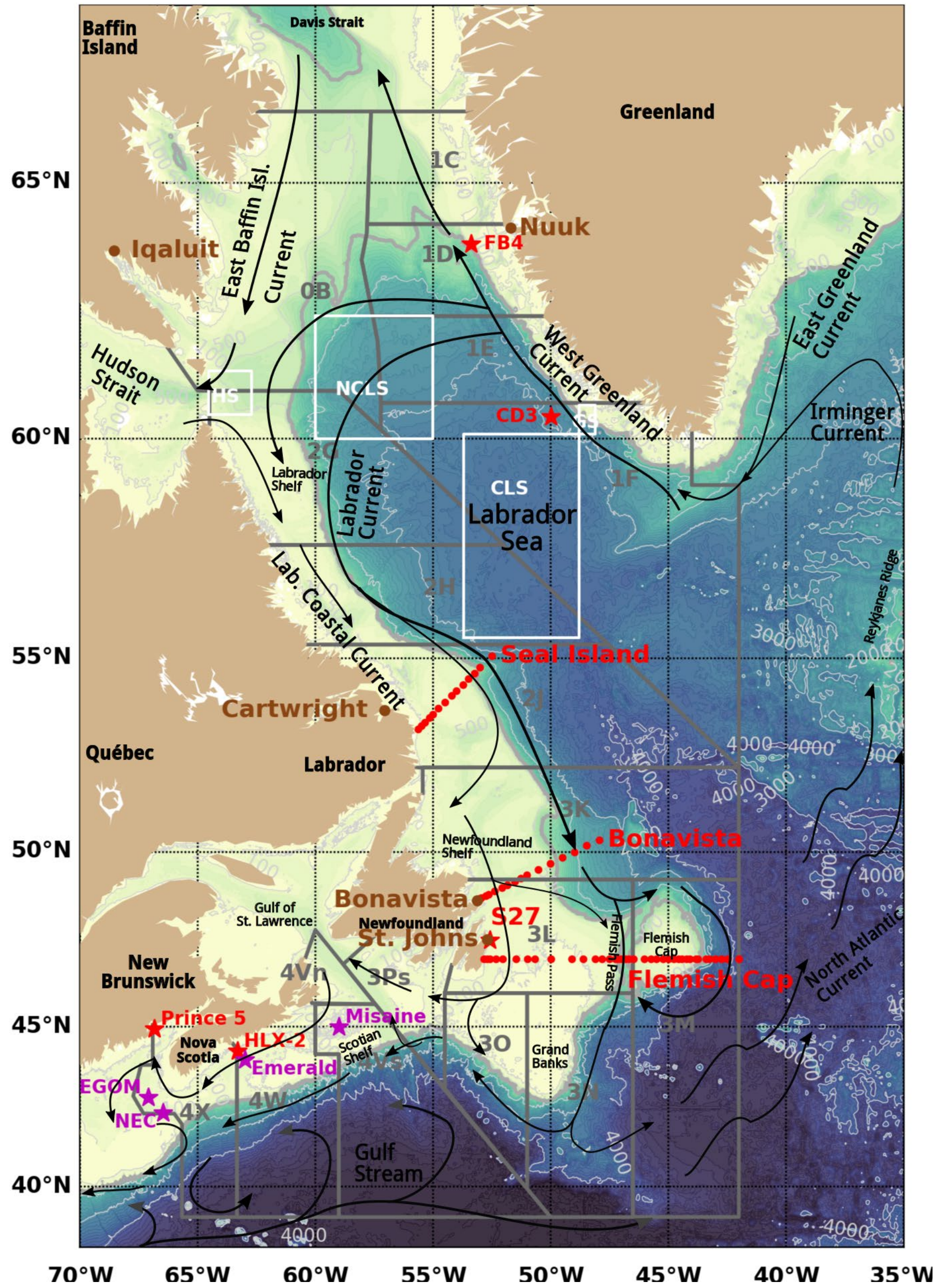
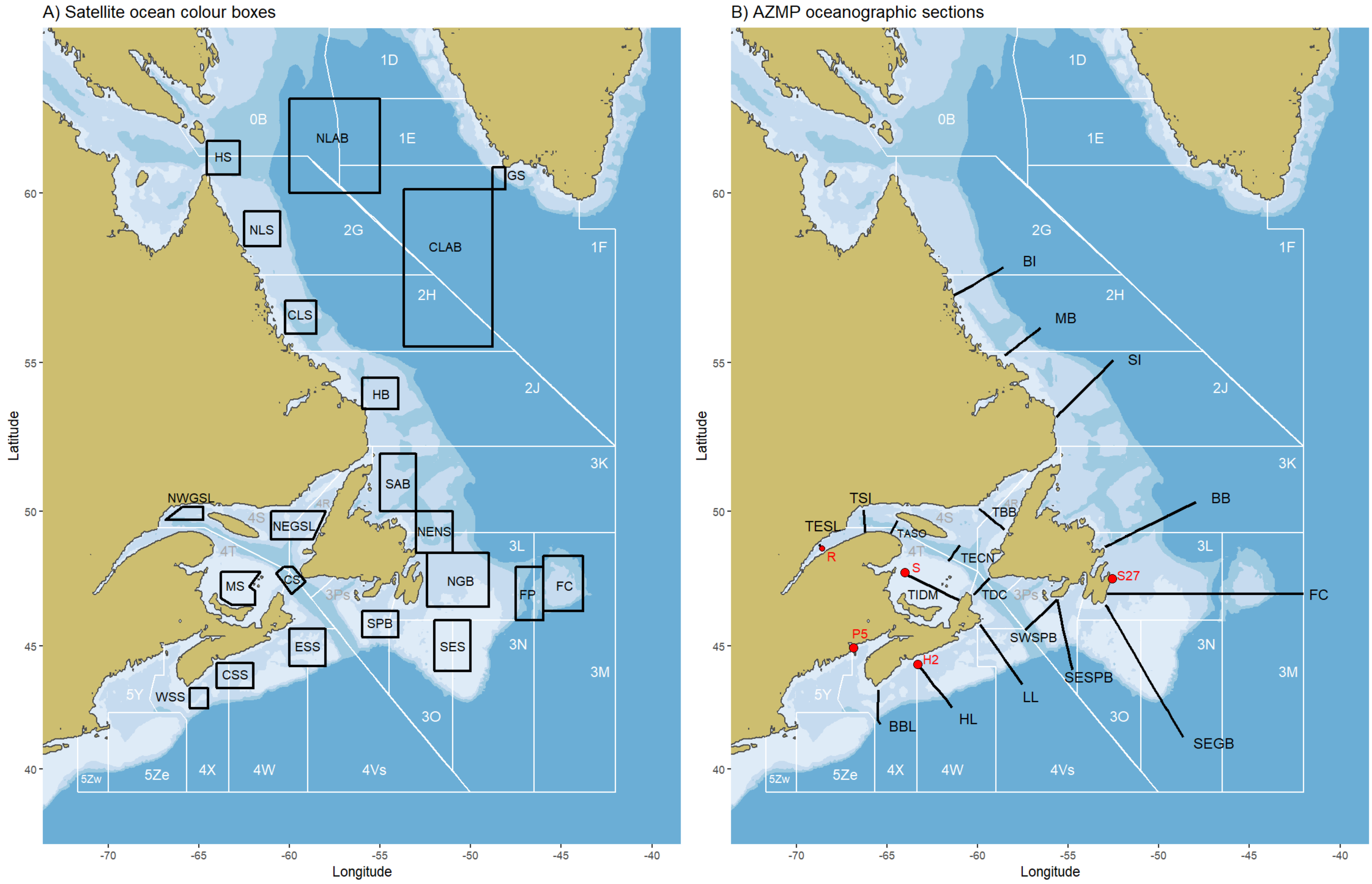


Figure 1. Map highlighting the location of the physical environmental time series used in this report. NAFO Divisions and main bathymetric features of the Northwest Atlantic are highlighted (colormap and gray contours). The thick gray contour is the isobath 1000m that is used here to delimit the continental 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 a hydrographic time series used in this report.


A) Satellite ocean colour boxes
B) AZMP oceanographic sections
NLAB
HS
GS
NLS
CLAB
CLS
HB
SAB
NWGSL
NEGSL
NENS
MS
CS
NGB
FP
FC
SPB
ESS
SES
CSS
WSS
BI
MB
SI
BB
TSI
TESL
TBB
TASO
TECN
TIDM
TDC
SWSPB
SESPB
LL
HL
BBL
SEGB
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S
S27
P5
H2
0B
1D
1E
1F
2G
2H
2J
3K
3L
3M
3N
3O
3Ps
4R
4S
4T
4Vs
4W
4X
5Y
5Ze
5Zw
Latitude
Longitude

Figure 2. Map showing the location of the biogeochemical environmental time series used in this report. NAFO Divisions and main bathymetric features of the Northwest Atlantic are also highlighted. (A) Location of the boxes used to calculate spring bloom indices (initiation, and magnitude) from satellite Ocean Color imagery: (NLAB=northern Labrador Sea, CLAB=central Labrador Sea, 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. (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=southeastern Grand Bank; TBB=Bonne Bay transect, TCEN=center Gulf transect, TDC=Cabot Strait transect, TIDM=Magdalen Islands transect, southwest Anticosti transect, Sept-Iles transect, St. Lawrence Estuary transect, LL=Louisbourg Line; HL=Halifax Line; BBL=Brown Bank Line), and coastal high-frequency monitoring stations (red circles: S27=Station 27; R=Rimouski; S=Shediac Valley; H2=Halifax 2; P5=Prince 5) where zooplankton abundance and biomass data were collected.

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.

Data availability

The different composite indices for NAFO Subarea 0 and 1 are presented in Fig. 3. Due the remoteness of this region, the number of variables entering these composite indices is limited. The climate index (Fig. 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 origins are drawn in Fig. 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/).

Phytoplankton spring bloom initiation (Fig. 3B) and magnitude (Fig. 3C) 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, [CLAB], and Greenland Shelf[GS]) (see Fig. 2 for box location). It is worth noting that the presence of sea ice at high latitudes reduces satellite data availability and increases the uncertainty around the spring bloom indices. No in-situ biogeochemical data are available 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 (Fig. 3A). After being in 2019 at its highest value since the record high of 2010, the index was normal in 2020. 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 but several notable late bloom onsets have been recorded during the late 2010s (Fig. 3B). In 2020, the initiation of the spring bloom was later than normal for a second consecutive year. Spring bloom magnitude (total production) remained mostly below to near normal between 2003 and 2020 with the exception of a few highly productive bloom in 2006, 2015 and 2018 (Fig. 3C). The late bloom onset observed in 2019 and 2020 are associated below or near normal total production for the corresponding years (Fig. 3B-C).

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

- The ocean climate index in Subarea 0-1 was normal in 2020.
- The initiation of the spring bloom was delayed for a second consecutive year in 2020
- Total spring bloom production (magnitude) was near normal in 2020

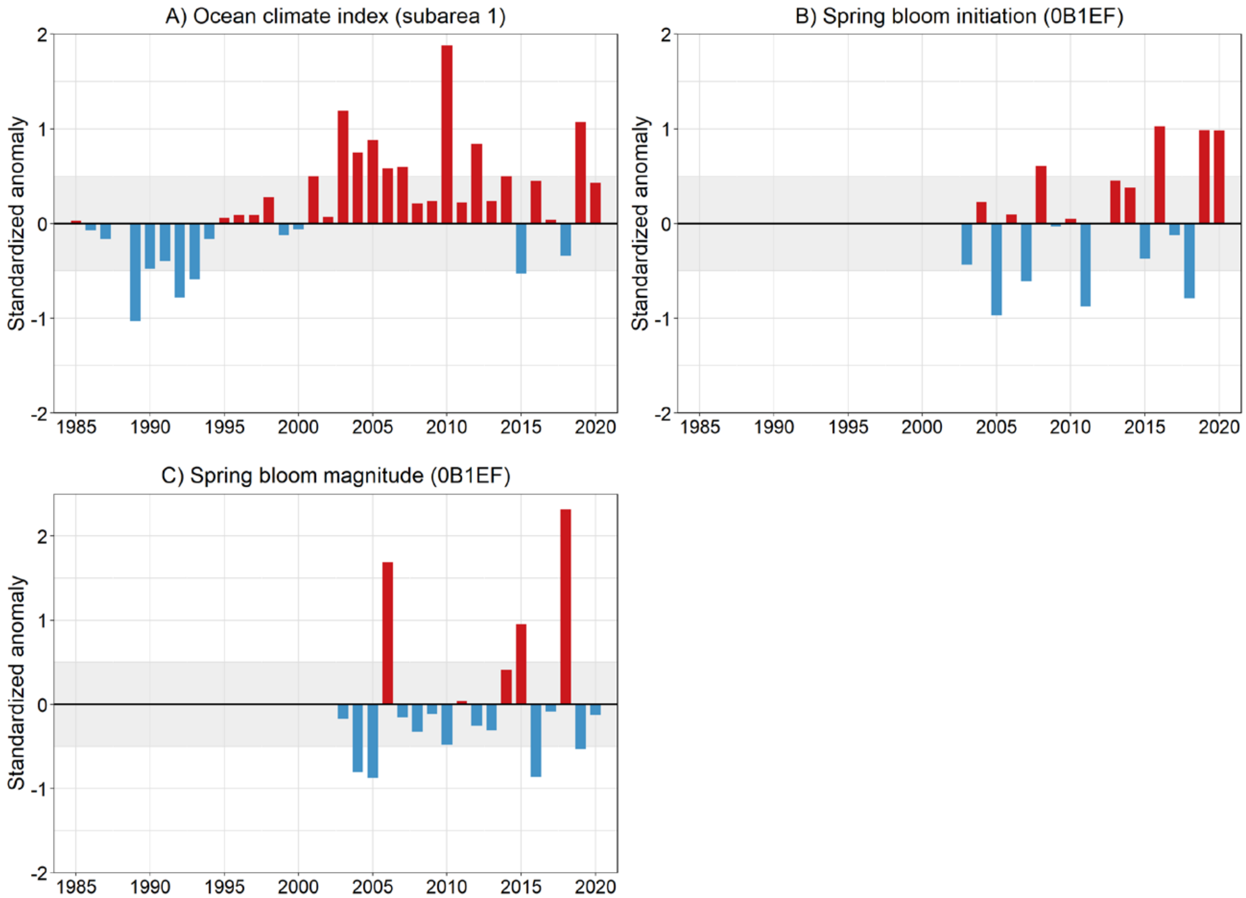

Figure 3. Environmental indices for NAFO Subarea 0 and 1. The climate index (A) for Subarea 0 and 1 is the average of 10 individual time series. These includes standardized anomalies of 4 SSTs time series, 4 temperature time series at 3 hydrographic stations and 2 air temperatures time series (see text for details). Phytoplankton spring bloom initiation (B) and magnitude (C) indices for the 2003-2020 period are derived from three satellite boxes covering NAFO Divs. 0B and 1EF (see text for details). Positive/negative anomalies indicate values above/below (or late/early timing) the long-term average for the reference period. Anomalies were calculated using the following reference periods: 1981-2010 for ocean climate index, 2003-2020 for spring bloom initiation and magnitude. Anomalies within ±0.5 SD (grey rectangle) 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.

Data availability

The different composite indices for NAFO division 3M (Flemish Cap) are presented in Fig. 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 (Fig. 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. (2021). Bottom temperatures are derived using the same procedure used in Cyr et al. (2021), but only for the top 1000m of the cap. Data used for this calculation is mostly from (although not limited to) the EU summer survey. For the bottom temperature data, the 2020 update was however not available at the time this report was prepared.

Spring bloom initiation (Fig. 4B) and magnitude (Fig. 4C) indices for the 2003-2020 period are derived from two satellite boxes (Flemish Pass [FP], and Flemish Cap [FC]; see Fig. 2A for box location). It is worth noting that the presence of sea ice and 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 (Figs. 4D & E) and biomass (Fig. 4F) indices for the 1999-20 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 section location).

Ocean Climate and Ecosystem Indicators

The ocean climate index in Division 3M (Fig. 4A) has remained mostly above normal between the late 1990's and 2013. After the record-high of 2011, the index gradually decreased reaching in 2015 its lowest value since 1993. After been below normal between 2015-2017, the index was normal between 2018 and 2020.

Spring bloom initiation has been oscillating between early and late timing between 2003 and 2020 but has remained mostly near or later than normal since 2011 (Fig. 4B). Spring bloom magnitude (total production) was below normal in 2020 after three consecutive years of above-normal production (Fig. 4C). In general, late bloom onsets are associated with limited production (Fig. 4B-C). The abundance of copepod and non-copepod zooplankton show general increasing trends throughout the 1999-2020 time series (Fig. 4D-E). However, copepod abundance decreased to below or near-normal levels over the past two years after having remained above normal from 2016 to 2018 (Fig. 4D). Similarly, the abundance of non-copepod zooplankton decreased to near-normal in 2019-2020 after four consecutive years of above-normal levels (Figure 4E). Total zooplankton biomass on the Flemish Cap has remained mostly below to near normal since 2015 with the exception of the record-high biomass observed in 2016 (Figure 4F).

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

- After being below normal between 2015 and 2017, the ocean climate index in 3M, has been normal since 2018.
- Spring bloom initiation was near normal in 2020 for a second consecutive year.
- Spring bloom magnitude was below normal in 2020 after three consecutive years of above-normal production.
- The abundance of copepod and non-copepod zooplankton was near normal in 2020 after having remained mostly above normal from 2015 to 2018.
- Zooplankton biomass was near normal in 2020 and has remained mostly near or below normal since its record-high in 2016.

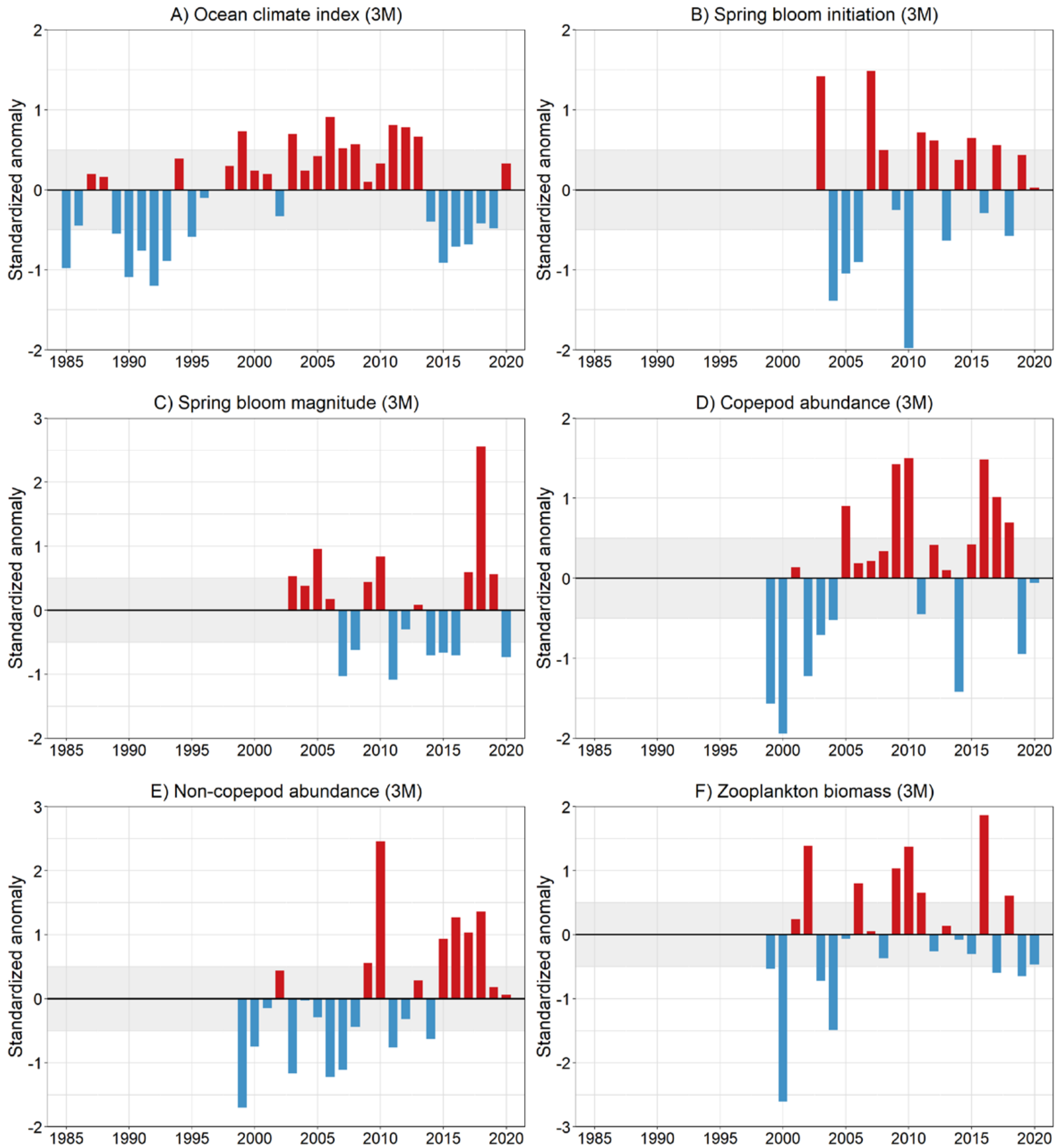

Figure 4. Environmental indices for the Flemish Cap (NAFO Div. 3M). The ocean climate index (A) for the Flemish Cap is the average of 3 time series of standardized ocean temperature anomalies of sea surface temperatures (SSTs), hydrographic section observations, and summer mean bottom temperature over the cap (see text for details). Positive/negative anomalies indicate values above/below (or late/early timing) the long-term average for the reference period. Anomalies were calculated using the following reference periods: 1981-2010 for ocean climate index, 2003-2020 for spring bloom initiation and magnitude, and 1999-2020 for zooplankton abundance and biomass indices. Anomalies within ±0.5 SD (grey rectangle) are considered near-normal conditions.

Grand Banks (NAFO Divisions 3LNO)

Environmental Overview

The water mass characteristic of the Grand Bank is 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.

Data availability

The different composite indices for NAFO division 3LNO (Grand banks) are presented in Fig. 5. Many time series are available in this well sampled region. The ocean climate index (Fig. 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. (2021). See Fig. 1 for geographical location of the different NAFO divisions, location of Station 27 (purple star) and hydrographic sections (red transects).

Phytoplankton spring bloom magnitude (Fig. 5B) and duration (Fig. 5C) indices for the 2003-2020 period are derived from two satellite boxes (Northern Grand Bank [NGB], and Southeast Shoal [SES]; see Fig. 2A for box location). Zooplankton abundance and biomass (Fig. 5D-F) indices for the 1999-2020 period are derived from two oceanographic sections (3L portion of the Flemish Cap [FC] section, and Southeastern Grand Bank section [SEGB]) and one high-frequency monitoring station (Station 27 [S27]) (see Fig. 2B for the location oceanographic sections and high-frequency monitoring station).

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 2017 that was below normal). In 2020, the ocean climate index was back to above normal value, reaching the third highest value of the entire time series started in 1985 (only 2011 and 2006 were warmest).

The initiation of the spring bloom has remained near or earlier than normal on the Grand Bank since 2017 after the two notably late blooms observed in 2015 and 2016 (Fig. 5B). Spring bloom magnitude (total production) decreased to near normal in 2020 after two consecutive years of above-normal production (Fig. 5C). Spring bloom production has remained mostly near or above normal since the record low observed in 2012 (Fig. 5C). The abundance of copepod and non-copepod zooplankton show clear increasing trend since the beginning of the time series in 1999 with anomalies transitioning form negative to positive around 2010 (Fig. 5D-E). Both copepod and non-copepod abundance remained above normal in 2020 for a 5th consecutive year with 4th highest anomaly of the time series (Fig. 5D-E). Zooplankton biomass drastically declined on the Grand Bank between 2002 and 2014 but has increased to near or above-normal levels since 2015 (Fig. 5F).

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

- In 2020, the ocean climate in NAFO Divs. 3LNO - Grand Bank, was at its warmest value since the record-high of 2011, and at its third highest value since the time series started in 1985.
- Spring bloom initiation was near normal in 2020 for a 2nd consecutive year.
- Spring bloom magnitude decreased to near normal in 2020 after two consecutive years of above-normal production.
- The abundance of copepod and non-copepod zooplankton remained above normal in 2020 for a 5th consecutive year.
- Zooplankton biomass was near normal in 2020 for a second consecutive year following the above-normal levels observed in 2017 and 2018.

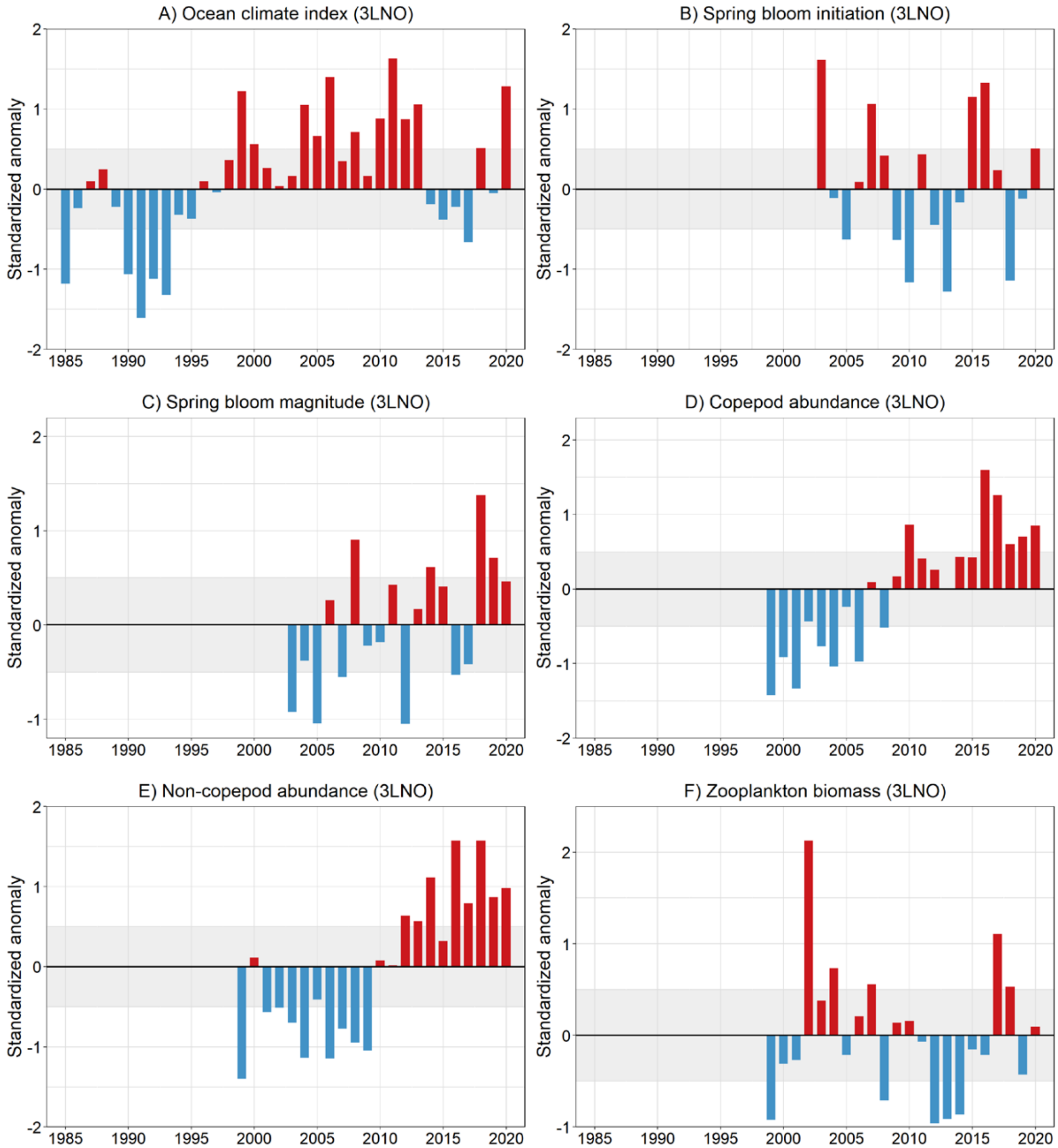

Figure 5. Environmental indices for NAFO Divisions 3LNO. The ocean climate index (A) is the average of 12 individual time series of standardized ocean temperature anomalies: SSTs for Divs. 3L, 3N and 3O, vertically average ocean temperature (0-176 m) at Station 27, mean temperature and CIL volumes over standard hydrographic sections Seal Island, Bonavista and 3L portion of Flemish Cap, and mean bottom temperature in 3LNO for spring and fall (see text for details). Positive/negative anomalies indicate values above/below (or late/early timing) the long-term average for the reference period. Anomalies were calculated using the following reference periods: 1981-2010 for ocean climate index, 2003-2020 for spring bloom initiation and magnitude, and 1999-2020 for zooplankton abundance and biomass indices. Anomalies within ±0.5 SD (grey rectangle) are considered near-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.

Data availability

The different composite indices for NAFO subareas 2, 3 and 4 during 1985-2020 are presented in Fig. 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 (Fig. 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 Fig. 1. Most of these data are also presented in Cyr et al. (2021), 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 initiation (Fig. 6B) and magnitude (Fig. 6C) for the 2003-2020 period are derived from 17 satellite boxes distributed across NAFO subarea 2 (Northern [NLS] and Central [CLS] Labrador Shelf, and Hamilton Bank [HB]), subarea 3 (St. Anthony Basin [SAB], Northeast Newfoundland Shelf [NENS], Northern Grand Bank [NGB], Flemish Pass [FP], Flemish Cap [FC], Southeast Shoal [SES], and St. Pierre Bank [SPB]), and subarea 4 (Northwest [NGSL] and Northeast Gulf of St. Lawrence [NEGSL], Magdalen Shallows [MS], Cabot Strait [CS], Eastern [ESS], Central [CSS] and Western Scotian Shelf [WSS]) (see Fig. 2A for box location). Zooplankton abundance and biomass indices (Fig. 6D-F) for the 1999-2020 period are derived from 18 oceanographic sections and five high-frequency coastal sampling stations distributed across NAFO subarea 2 (Beachy Island [BI], Makkovik Bank [MB], and Seal Island [SI]), subarea 3 (Bonavista Bay [BB], Flemish Cap [FC], Southeast Grand Bank [SEGB], and Station 27 [S27]), and subarea 4 (Eastern St. Lawrence [TESL], Sept-Îles [TSI], Southwest Anticosti [TASO], Bonne Bay [TBB], Central GSL [TECN], Magdalen Islands [TIDM], Cabot Strait [CS], Rimouski [R], Shediac Valley [S], Louisbourg [LL], Halifax [HL], Browns Bank [BBL], Halifax-2 [H2], and Prince-5 [P5]) (see Fig. 2B for the location oceanographic sections and high-frequency monitoring stations).

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 2006, 2010 and 2012 being respectively the second, third and first 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 (5th warmest year since 1980).
Mean timing of the spring bloom initiation across subareas 2-3-4 remained mostly near normal between 2003 and 2020 with few overall early onsets in 2006 and 2010, and one year where blooms were delayed across the region in 2015 (Fig 6B). Overall spring bloom mean production also remained near mostly near normal throughout the time series except for the above-normal spring productions observed in 2003 and 2006 and for the below-normal production of 2008 (Fig. 6C). Spring bloom production was lower in subarea 2 compared to subareas 3 and 4 in 2018 and 2019 and was near-normal in all subareas in 2020 (Fig 6C). Mean copepod abundance across subareas 2-3-4 rapidly increased between 1999 and 2006 before leveling off to near normal levels until 2015 (Fig. 6D). Anomalies have been mostly positive in all three subareas since 2010 with above normal levels observed in 2016 and 2020 (Fig. 6D). Copepod abundance was especially high in subarea 2 in 2020 (Fig. 6D). Mean abundance of non-copepod zooplankton increased in all subareas in the early 2010s and has remained above normal since 2016 (Fig. 6E). In general, the abundance of non-copepods was comparatively higher in subareas 2 and 3 than in subarea 4 between 2016 and 2020 (Fig. 6E). Mean zooplankton biomass in the region decreased from above normal in 2002 to below normal in 2015 (Fig 6F). Biomass has since remained at near-normal level, especially due to an increase in subarea 2 and 3 (Fig. 6F).

Recent Highlights in Ocean Climate and Lower Trophic Levels

- In 2020, subareas 2, 3 and 4 were all above normal, making the cumulative anomaly the 5th warmest since 1980.

- Spring bloom initiation and magnitude were, on average, near normal in subareas 2-3-4 in 2020.

- Mean copepod abundance was above normal in 2020 and especially higher in subareas 2-3 compared to subarea 4.

- Mean abundance of non-copepod zooplankton remained above normal across subareas 2-3-4 for a 5th consecutive year and was generally higher in subareas 2-3 compared to subarea 4.

- Mean zooplankton biomass was near normal in 2020 for a 5th consecutive year and was higher in in subarea 2 compared to subareas 3-4.

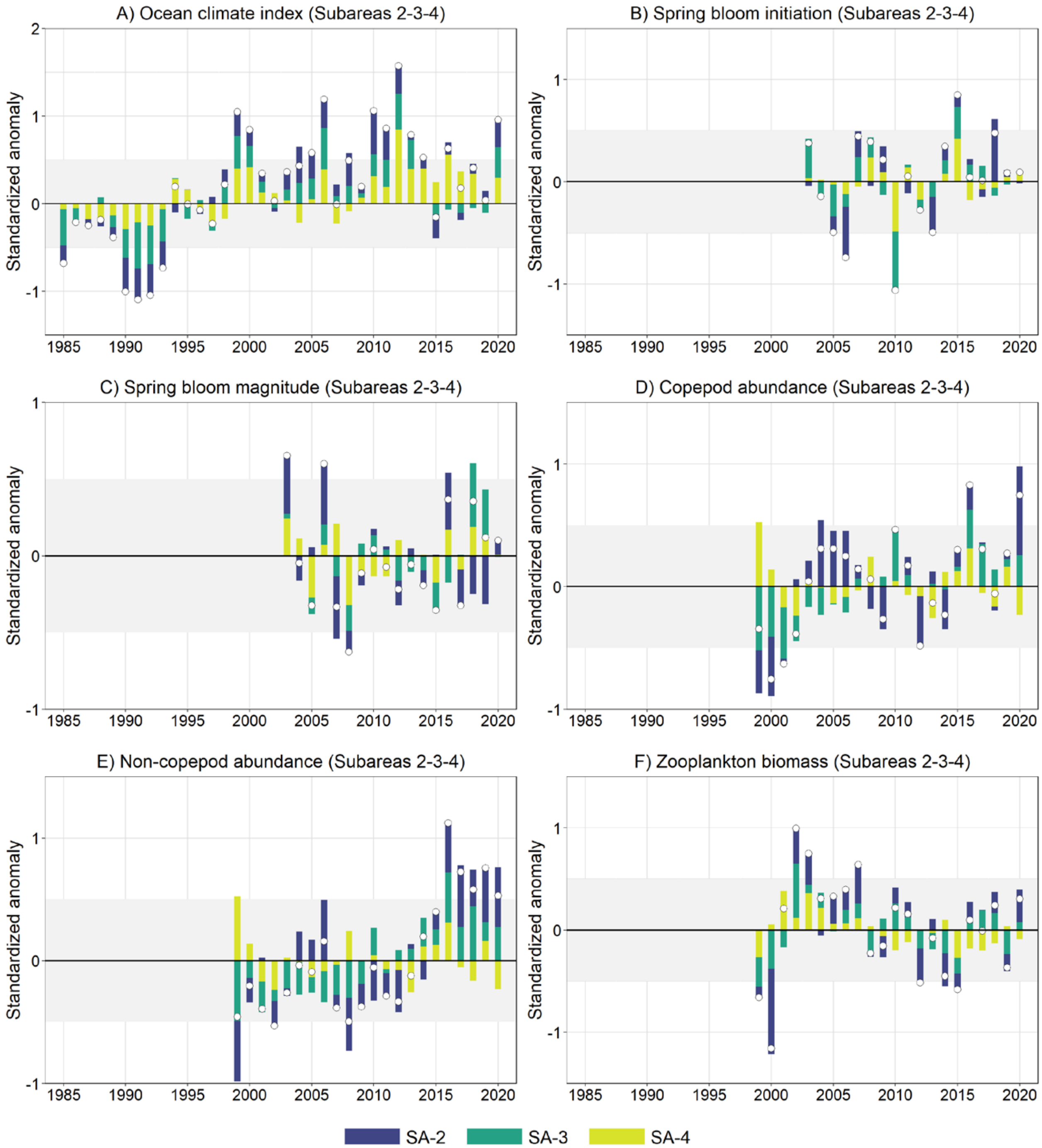

Figure 6. Environmental indices for NAFO Subareas 2-3-4. Anomalies for ocean climate index (A) are the result of the average of 8, 16 and 12 individual time series respectively for SA 2, 3 and 4 (see text for details). Mean positive/negative anomalies (open white circles) indicate conditions above/below (or late/early timing) the long-term average for the reference period. Colour bar height indicate the relative contribution of each subarea to the mean anomaly. Anomalies were calculated using the following reference periods: 1981-2010 for ocean climate index, 2003-2020 for spring bloom initiation and magnitude, and 1999-2020 for zooplankton abundance and biomass indices. Anomalies within ±0.5 SD (grey rectangle) are considered near-normal conditions.

Summary

Highlights of this report can be summarized as follows:

- A large majority of ocean indicators were normal in 2020.
- In 2020, composite climate indices in subareas 2, 3 and 4 were all above normal, making the cumulative anomaly the 5th warmest since 1980. For NAFO Divs. 3LNO (Grand Bank), the index, was at its warmest value since the record-high of 2011, and at its third highest value since the time series started in 1985.
- The initiation of the spring bloom in sub-areas 0-1was delayed for a second consecutive year in 2020.
- Mean abundance of non-copepod zooplankton remained above normal across subareas 2, 3 and 4 for a 5th consecutive year and was generally higher in subareas 2-3 compared to subarea 4.
- Mean zooplankton biomass was near normal in 2020 for a 5th consecutive year and was higher in in subarea 2 compared to subareas 3-4.

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