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Biogeographical patterns and environmental controls of phytoplankton communities from contrasting hydrographical zones of the Labrador Sea

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ABSTRACT

The Labrador Sea is an important oceanic sink for atmospheric CO_2 because of intensive convective mixing during winter and extensive phytoplankton blooms that occur during spring and summer. Therefore, a broad-scale investigation of the responses of phytoplankton community composition to environmental forcing is essential for understanding planktonic food-web organisation and biogeochemical functioning in the Labrador Sea. Here, we investigated the phytoplankton community structure (>4 μm) from near surface blooms (<50 m) from spring and early summer (2011–2014) in detail, including species composition and environmental controls. Spring blooms (>1.2 mg chl*a* m^{-3}) occurred on and near the shelves in May and in offshore waters of the central Labrador Sea in June due to haline- and thermal-stratification, respectively. Sea ice-related (*Fragilariopsis cylindrus* and *F. oceanica*) and Arctic diatoms (*Fossula arctica*, *Bacterosira bathyomphala* and *Thalassiosira hyalina*) dominated the relatively cold (<0 °C) and fresh (salinity < 33) waters over the Labrador shelf (e.g., on the southwestern side of the Labrador Sea), where sea-ice melt and Arctic outflow predominates. On the northeastern side of the Labrador Sea, intense blooms of the colonial prymnesiophyte *Phaeocystis pouchetii* and diatoms, such as *Thalassiosira nordenskioeldii*, *Pseudo-nitzschia granii* and *Chaetoceros socialis*, occurred in the lower nutrient waters (nitrate < 3.6 μM) of the West Greenland Current. The central Labrador Sea bloom occurred later in the season (June) and was dominated by Atlantic diatoms, such as *Ephemera planamembranacea* and *Fragilariopsis atlantica.* The data presented here demonstrate that the Labrador Sea spring and early summer blooms are composed of contrasting phytoplankton communities, for which taxonomic segregation appears to be controlled by the physical and biogeochemical characteristics of the dominant water masses.

1. Introduction

Marine phytoplankton communities respond rapidly (days to weeks) to changes occurring in their physical environment due to their short generation times. Over the last few decades climate change has led to marked physical changes in the Arctic Ocean and adjacent sub-Arctic seas (Yashayaev et al., 2015) – changes which are likely to be reflected by responses in their phytoplankton communities (Anisimov et al., 2007). Climate-driven processes modify the major factors, such as light availability, nutrient input and grazing pressure that shape phytoplankton physiological traits and alter community structure (Montes-Hugo et al., 2009; Litchman et al., 2012). As the climate changes in these high latitude oceans, the parameters that define the phytoplankton phenology (seasonal and interannual variation), biomass, primary production and community structure, will all likely be modified. Alteration of the phytoplankton community propagates into marine food web dynamics and biogeochemical cycles (Finkel et al., 2010), due to traits regarding palatability, cell size, elemental stoichiometry and efficiency of carbon transport to deeper waters. A further advance in understanding the long-term responses of Arctic phytoplankton to climate change can be achieved from remote-sensing-derived observations (e.g., Arrigo et al., 2008; Pabi et al., 2008; Kahru et al., 2011; Ardyna et al., 2014) and *in situ* long-term monitoring (Head et al., 2003; Yashayaev, 2007; Yashayaev et al., 2015).

The Labrador Sea is a sub-Arctic region of the Northwest Atlantic located between Greenland and the eastern coast of Canada. In

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spite of its small size (<1% of the Atlantic Ocean), the Labrador Sea plays a critical role in the marine carbon cycle because it is one of the most productive regions of the North Atlantic, which enhances the flux of atmospheric CO_2 into surface waters (DeGrandpre et al., 2006; Martz et al., 2009). Moreover, the Labrador Sea produces the densest of all water masses that are entirely formed in the subpolar North Atlantic (Yashayaev et al., 2015), where wintertime cooling and wind forcing cause convective sinking of dense surface water, transporting carbon rapidly to the deep ocean (Tian et al., 2004). The Labrador Sea is also a region susceptible to climate change because it receives the discharge of Arctic ice-melt waters, which potentially increases the freshening of surface layers (Dickson et al., 2002; Yashayaev and Seidov, 2015). Due to its biogeochemical significance and potential vulnerability to climate change, a comprehensive understanding of the current phytoplankton communities in the Labrador Sea is crucial to detect climate change effects in the future.

The Labrador Sea is usually characterised by three distinct phytoplankton bloom regions during spring and early summer (Frajka-Williams et al., 2009; Frajka-Williams and Rhines, 2010). In contrast to the south to north progression observed in other regions of the North Atlantic (Henson et al., 2009), the northern bloom (north of 60°N, in the eastern Labrador Sea) is more intense (satellite-derived chlorophyll (1998–2006) up to 5.5 mg chl*a* m^{-3}, Harrison et al., 2013) and starts early in the season (late April). This is due to the early onset of haline-driven stratification formed by freshwater input from the West Greenland Current (Stuart et al., 2000; Frajka-Williams and Rhines, 2010; Harrison et al., 2013; Lacour et al., 2015). The western bloom located on the Labrador Shelf varies inter-annually, since it is triggered by the rapid melting of sea ice that often covers the shelf well into spring (Wu et al., 2007). The Labrador Shelf bloom development starts as the ice retreats, which is usually in May, although it may occur later (June) in some years (Head et al., 2013). The central Labrador bloom is weaker (1998–2006 satellite-derived chlorophyll < 2 mg chl*a* m^{-3}, Harrison et al., 2013) and occurs later in the season (June) as a result of thermal stratification (Frajka-Williams and Rhines, 2010). Nutrient replenishment, occurring during deep winter mixing (200–2300 m) and dependent on cumulative surface heat loss, (Yashayaev and Loder, 2009), supports the phytoplankton spring bloom once light becomes available (Harrison et al., 2013). Storm events (Wu et al., 2008b) as well as upwelling events from cyclonic eddies (Yebra et al., 2009) and glacial meltwater (Bhatia et al., 2013) have all been suggested to sustain the blooms via nutrient replenishment after these are exhausted in surface waters.

The Labrador Sea acts as a receiving and blending basin for Atlantic and Arctic waters (Yashayaev et al., 2015) and, therefore, is an ideal region to study the influence of the environmental factors that shape the phytoplankton community structure due to the Atlantic and Arctic waters that divide the region into distinct hydrographic zones (Head et al., 2000, 2003). Hydrographic zones create ecological niches, where distinct phytoplankton communities occur (Acevedo-Trejos et al., 2013; Goes et al., 2014; Brun et al., 2015). Understanding the drivers of biogeographical patterns of phytoplankton communities in the Labrador Sea will provide insights about the habitat complexity of this area, in addition to elucidating the phytoplankton responses to future changes. Plankton community structure from the Labrador Sea has previously been assessed by bio-optical, pigment or microscopic observations (Head et al., 2000; Stuart et al., 2000; Cota, 2003; Strutton et al., 2011; Harrison et al., 2013). Nonetheless, a detailed quantitative taxonomic analysis of the environmental controls on phytoplankton communities and species composition has not previously been carried out.

Based on *in situ* observations collected in the Labrador Sea during late spring and early summer (2011–2014), the specific goals of this study were:

(1) to describe the biogeographical patterns of spring phytoplankton communities across the Labrador Sea,
(2) to investigate the major hydrographic parameters that influence taxonomic segregation of phytoplankton blooms from the upper 50 m in the Labrador Sea,
(3) to discuss the major environmental drivers for specific phytoplankton groups (e.g., *Phaeocystis pouchetii* and diatoms) in this high latitude sea.

2. Methods

2.1. Study area

The Labrador Sea and the entire subpolar North Atlantic receive buoyant fresh and cold Arctic outflow (Yashayaev et al., 2015) through two major pathways. One of these pathways connecting the Labrador Sea to the Arctic Ocean originates from the Baffin Island Current that crosses Davis Strait and subsequently merges with various southward inshore flows to become the Labrador Current (LC) (Fig. 1). The other pathway starts with the East Greenland Current (EGC) in the Greenland Sea (Yashayaev and Seidov, 2015), which turns around the southern tip of Greenland and flows northwards along the Greenland coast to become the West Greenland Current (WGC) (Yashayaev, 2007) (Fig. 1). The LC is composed of two main branches: an inshore branch, which occupies the Labrador Shelf, and an offshore branch, which is centred over the 1000 m contour. The inshore branch receives waters of Arctic origin via Davis and Hudson Straits, whereas the offshore branch receives contributions from the outflow from Davis Strait and from the portion of the WGC that turns west and then south along the shelfbreak (Head et al., 2013) (Fig. 1). The inflow from Hudson Strait contains a large riverine input from Hudson Bay, increasing the contribution of estuarine waters to this water mass (15% of total volume of the LC) (Straneo and Saucier, 2008). Local ice melting also influences the properties of the LC, given that the Labrador Shelf is a seasonal ice zone, where sea ice starts forming in mid-January, reaching its maximum extent at the end of March and starts to melt in May (Wu et al., 2007).

The shallow, fresh and cold WGC presents a mixture of low salinity Arctic water from the EGC and Greenland ice melt (collectively sourced from glaciers, icebergs and Greenland ice surface melt). The WGC is also influenced by the relatively warm and saline Atlantic water, which, in turn, originates from the Irminger Current (IC) (Yashayaev, 2007; Yashayaev et al., 2015) (Fig. 1). Sea ice is prevented from forming on the Greenland Shelf, although icebergs are frequent (De Sève, 1999; Yankovsky and Yashayaev, 2014). The deep central basin (water depths from 3200 to 3700 m) of the Labrador Sea features a clockwise (anticyclonic) circulation, which in turn contributes to an anticlockwise (cyclonic) gyre nested along the outer rim of the deep basin (Yashayaev, 2007; Hall et al., 2013; Kieke and Yashayaev, 2015) (Fig. 1).

The Labrador Sea is a region with complex, yet, well-structured hydrography characterised by marked fronts maintained by the major currents such as the LC, IC and WGC. These oceanographic fronts separate characteristic zones composed of distinct water masses (Yashayaev, 2007). Boundary currents are concentrated at the Greenland and Labrador slopes, where anticyclonic/cyclonic mesoscale eddies are common, particularly Irminger Rings, located in the eastern part of the Labrador Sea (Frajka-Williams et al., 2009; Yebra et al., 2009).