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# Temporal and spatial variability of zooplankton on the Faroe shelf in spring 1997–2016

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ABSTRACT

Zooplankton availability during spring and summer determines the growth and survival of first-feeding fish larvae, and thus impacts the recruitment to both fish prey species and commercial fish stocks. On the Faroe shelf, however, the relative importance of oceanic versus neritic zooplankton species has hitherto not been well understood. In this study, spatio-temporal variability in zooplankton community structure and size spectra on the Faroe shelf is investigated using observations from late April during the period 1997–2016. The main objective was to explore which environmental variables influence the zooplankton community structure in early spring. The zooplankton community in the permanently well mixed central shelf inside the tidal front consists of a mixture of neritic, cosmopolitan and oceanic species. In this region, redundancy analyses showed that chlorophyll concentration had a positive effect on abundance of neritic copepods and meroplankton as well as all zooplankton $< 1.2$ mm. The abundance variability of these species shows increased production around 2000 and 2008–2009. The highest zooplankton abundance, mainly consisting of *Calanus finmarchicus*, is however observed off-shore from the tidal front, especially on the western side of the Faroe Plateau. A shift in *C. finmarchicus* phenology occurred around 2007, resulting in earlier reproduction of this species, and this variability could not be explained by the employed regional environmental parameters. Our results indicate that the Faroe shelf biological production is more dependent on the local primary production and neritic zooplankton species than on the large oceanic *C. finmarchicus* stock.

## 1. Introduction

The Faroe shelf sustains several economically important fish stocks including cod, haddock and saithe (ICES, 2016), which spawn during spring (Steingrund et al., 2005). Earlier studies have revealed a close relationship between primary production and fish recruitment and fish growth (e.g. Eliasen et al., 2011; Gaard et al., 2002; Steingrund and Gaard, 2005). Zooplankton is a critical trophic link between phytoplankton and fish prey species, commercial fish stocks and seabirds, although details in such links are still poorly understood (Eliasen et al., 2011). In this context it is important to better understand the variations in zooplankton abundance and their associations with physical changes in the marine environment. The Faroe Marine Research Institute's monitoring programme on biological oceanography around the Faroe Islands started in the 1990s with sampling stations covering the central part of the shelf and to a lesser extent also the outer shelf waters. The present study is based on material sampled during the last week of April. This recurrent cruise has been placed at a critical time in spring (late pre-bloom and early bloom phase) enabling investigations on the match-mismatch between the spring bloom development, subsequent zooplankton reproduction and community development and occurrence of first-feeding fish larvae.

In previous studies, the Faroe Plateau has been divided into exclusive domains based on oceanography (e.g. Larsen et al., 2009, 2008) and recently also on phytoplankton variability (Eliasen et al., 2017). One main division is formed by the tidal front at the approximately 100–150 m bottom depth contour, which separates the permanently well mixed central shelf (hereafter CS) from the surrounding seasonally stratified outer shelf (Fig. 1) (Hansen et al., 2005; Larsen et al., 2009, 2008). Off the Faroe Plateau, the water in the upper layers (0–500 m) is dominated by warm and saline pole ward flowing Atlantic water. In the near-bottom layer, cold and less saline overflow water flows equator wards from the depths of the Norwegian Sea through the Faroe-Shetland Channel and the Faroe Bank Channel into the North Atlantic Ocean (Hansen and Østerhus, 2000). The temperature and salinity on the Faroe Plateau is generally higher on the western side, and lower on the

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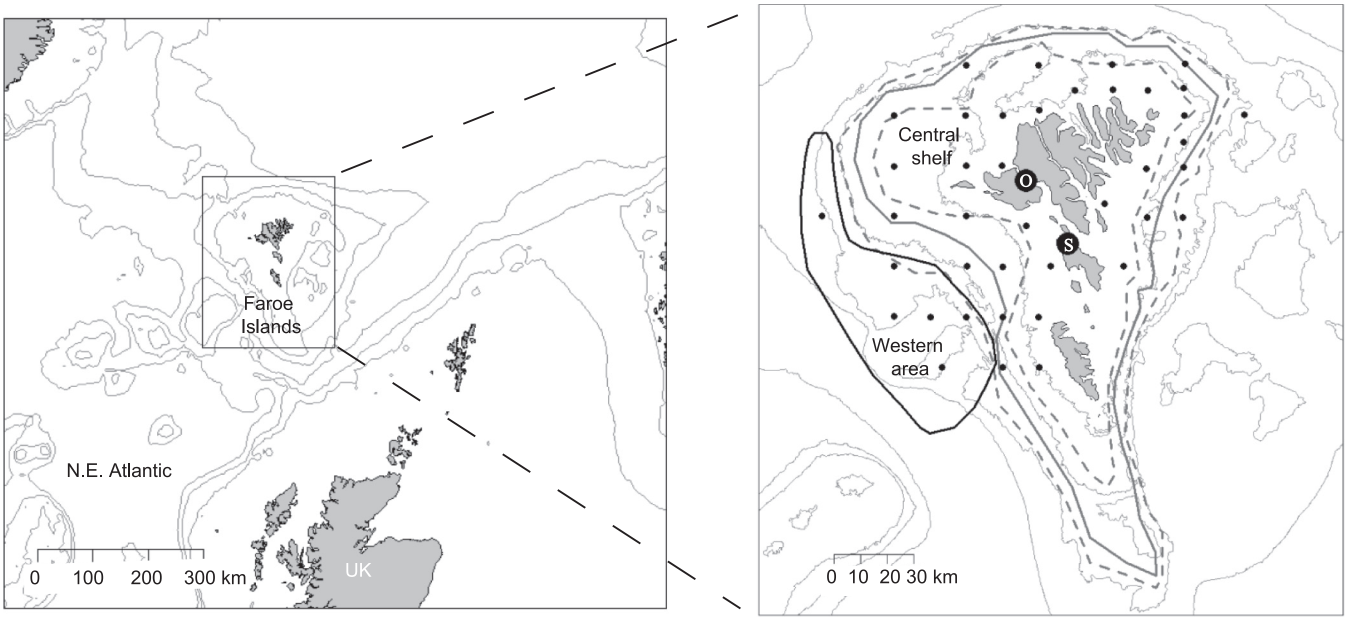


**Fig. 1.** Map of the North East Atlantic (left) and the Faroe shelf (right). The thick grey lines on the map of the Faroe Shelf shows the average position of the front and the area between the grey dashed lines cover a depth interval equal to two standard deviations from the average front position (from Larsen et al., 2009). The well mixed area inside the shelf front is denoted central shelf (CS). The black dots represent stations typically sampled on the standard cruise in late April. 'O' and 'S' denote fixed coastal stations on the shelf, while the area inside the thick black line shows position of the outer western area (W) (see Section 2.3 for definition of areas). The grey lines represent 200, 500 and 1000 m bottom depth contours and 100, 150, 200 and 500 m bottom depth contours in the left and right panel, respectively.

eastern side. This is due to the influence of the relatively warm and saline North Atlantic Current coming from the south-west. As this water crosses the Iceland-Faroe Ridge in a clock-wise path around the Faroe Plateau, it is cooled and freshened due to a combination of atmospheric influence and admixture of colder and less saline water north of the ridge (Larsen et al., 2012). Due to effective winter cooling in the shallow waters and excess precipitation over land, the temperature and salinity during spring in the CS are respectively ~1 °C and ~0.1 psu lower than in the outer shelf waters (Larsen et al., 2009). The average residence time of the CS water is estimated to be 1–2 months, but is likely highly variable (Eliasen et al., 2016; Larsen et al., 2008; Rasmussen et al., 2014). The separation of the CS from the outer shelf supports separate planktonic species and interannual variation in phytoplankton abundances on the shelf have led to an exchange-hypothesis, which suggests that variable cross-shelf exchange dilutes the phytoplankton biomass inside the tidal front, and thus induces variations in the phytoplankton accumulation (Hansen et al., 2005; Eliasen et al., 2005; Eliasen et al., 2016). This mechanism seems to explain some of the variability in phytoplankton biomass prior to June (Eliasen et al., 2016). The zooplankton community within the CS basically consists of neritic species, although it is also influenced by variable amounts of oceanic species (Gaard, 2003, 1999). Oceanographically, as well as biologically, the waters in the CS and the outer shelf are therefore quite different. The CS ecosystem is relatively spatially confined making it well suited for ecological studies.

On the Faroe shelf the phytoplankton spring bloom usually occurs in April–May, but it is highly variable, both in timing and in magnitude (Debes et al., 2008b; Hansen et al., 2005). Inside the ~120 m bottom depth contour, the zooplankton species composition in spring is a mixture of neritic copepod species (mainly *Temora longicornis* and *Acartia* sp.), meroplankton (e.g. cirripedia larvae, decapod larvae and polychaete larvae), cosmopolitan zooplankton species (e.g. *Pseudocalanus* sp., appendicularians and chaetognaths) and oceanic zooplankton species, which are advected from the offshelf environment (Gaard, 1999). The biomass in the zooplankton community during spring and early summer is usually dominated by the large, oceanic copepod *Calanus finmarchicus* (Debes et al., 2005; Gaard, 1999). The deep overflow transports large quantities of overwintering *C. finmarchicus* from the deep Norwegian Sea (Gaard, 1999) through the Faroe Bank Channel west of the Faroes (Heath and Jónasdóttir, 1999). The northern Irminger Sea and Iceland Basin are also centres of overwintering *C. finmarchicus* (Heath et al., 2000) from where individuals can be carried toward the Faroes with the north eastward directed Atlantic inflow branch (Hansen and Østerhus, 2000). Between late March and late April the overwintered individuals migrate toward the surface (Gaard and Hansen, 2000). Import of *C. finmarchicus* onto the Faroe shelf during spring after the individuals have ascended to the upper layer requires horizontal advection and thus, this transport will vary according to the exchange rate. Investigations on the zooplankton abundance in the CS have shown interannual variations, where the ecosystem shifts between dominance of neritic zooplankton species some years (e.g. 1993–1995 and 2000) and horizontally advected oceanic species other years (e.g. 1996–1997) (Gaard, 2003, 1999).

In recent years recruitment to the Faroe cod and haddock stocks has failed (ICES, 2016). This failure is partly a result of high fishing mortality, but natural environmental variability also appears to be important (Steingrund and Gaard, 2005). The role of zooplankton in these changes is stimulating this particular study as survival of first feeding fish larvae during the early life phase is a well known bottleneck in fish recruitment (Hjort, 1914). The larvae feed on zooplankton and phenological synchronization between the larvae and zooplankton is a prerequisite for larval survival (Cushing, 1990). The available studies of the zooplankton community on the Faroe shelf in spring are one-two decades old (Debes and Eliasen, 2006; Gaard, 2003, 1999). They document large variations in the abundance and community structure of the zooplankton, but the data on zooplankton only includes taxonomic abundances, not sizes. With regards to feeding conditions of fish larvae, taxonomic abundances are important, but equally or perhaps more important is the size spectra of the zooplankton (Frank and Leggett, 1986). Because the zooplankton assemblage in the CS is composed of zooplankton from different geographical origins and with different life strategies (Debes and Eliasen, 2006; Gaard, 1999), the species may respond differently to changes in regional temperature and food concentration, and their abundance may also change as a result of