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Deposition and benthic mineralization of organic carbon: A seasonal study from Faroe Islands

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ABSTRACT

Seasonal variations in sedimentation and benthic mineralization of organic carbon (OC) were investigated in a Faroese fjord. Deposited particulate organic carbon (POC) was mainly of marine origin, with terrestrial material only accounting for <1%. On an annual basis the POC export from the euphotic zone amounted to 10.2 mol C m^{-2} yr^{-1} equating to 37% of the net primary production, and maximum sedimentation rates were associated to the spring bloom. The dynamics in the benthic solute exchange were governed by stratification that isolated the bottom water during summer and intensified sediment resuspension during winter. The POC export from the euphotic zone could not sustain the benthic mineralization rate (10.8 mol C m^{-2} yr^{-1}) and the calculated burial rate (9.8 mol C m^{-2} yr^{-1}) of organic material in the central basin. This indicated considerable focusing of material in the central part of the fjord. This was supported by the fact that the measured benthic mineralization rate – in contrast to most investigations – actually increased with increasing water depth. In August, when mineralization was at its maximum, the dissolved inorganic carbon (DIC) release from the sediment increased by 2.2 mmol m^{-2} d^{-1} for every m increase in water depth at 30–60 m depth. Due to sediment focusing, the OC burial in the deepest part of the fjord was 9.8 mol C m^{-2} yr^{-1}. This was 2.4 times higher than the average OC burial in the fjord, estimated from the total sedimentation, and benthic mineralization accounting for the water depth related changes in activity. The study in Kaldbaksfjørður underscore that fjords are important sites for long time OC burial, but emphasize the need for accounting for spatial variations when extrapolating results from a single or few stations to the scale of the entire fjord.
Regional terms: Faroe Islands, Kaldbaksfjørður

1. Introduction

Fjords are hotspots for deposition, mineralization and preservation of organic carbon (OC), and are estimated to account for 11% of the global long-term marine OC burial although they cover <0.1% of the global ocean surface area (Smith et al., 2015). However, carbon burial rates vary more than ten fold among fjords, reflecting the diversity in productivity and key drivers governing the preservation efficiency, such as the OC amount of terrestrial origin, or entrained from the marine environment outside the fjord (Sørensen et al., 2015; Wiedmann et al., 2015). The boundaries for OC production and consumption in the fjords also play a crucial role in preservation efficiency (Burdige, 2007). These boundaries represent the hydrographic settings governed by freshwater runoff from land as well as wind and tidal mixing, the nutrient and light availability, and the timing and abundance of biota consuming the OC produced (Skei et al., 2003).

The influence from anthropogenic activity remains one important factor that also is variable. In distinct unpopulated areas climate change is the main cause for long-term changes (Rysgaard et al., 1998; Sørensen et al., 2015; Wiedmann et al., 2015), while eutrophication can alter the carbon cycle significantly in fjords near densely populated and industrial areas (Lomstein et al., 1998; Therkildsen et al., 1993). Faroese fjords may be subjected to both influences. Eutrophication mainly from the expanding aquaculture and climate change, where the expected changes are warming and increased precipitation that may result in landslides (Hansen, 2011).

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In Faroese fjords, the persistent influence of the North Atlantic Current (Hansen and Østerhus, 2000) implies little seasonal variation in seawater temperatures (6–11 °C) and salinity (32–35.5) (Gaard et al., 2011). They do, however, exhibit seasonal variations in productivity due to variations in light availability, with day lengths from 5 h during winter to 20 h in the summer. Short-term variations in weather conditions can have major implications for the hydrography and productivity in Faroese fjords. Low pressures passing across the islands mainly from west induce strong wind events (>15 m s^{-1}) and heavy rain during all times of the year although more frequent during winter. These short-term fluctuations influence horizontal flow and vertical mixing of seawater in the fjords, which imply high nutrient availability in the euphotic zone. Thus, solar radiation rather than nutrient availability set the limit for primary production, which is 2–3 times higher production than in neighbouring regions, such as Icelandic, Norwegian and Scottish fjords (Gaard et al., 2011).

In this study, the seasonal variations in benthic supply and mineralization of organic material were investigated in a fjord that is located centrally in the Faroe Islands, representing settings sheltered from ocean swells and strong currents. Data are used to evaluate implication of spatial and temporal variations and to establish an annual carbon budget for the fjord.

2. Materials and methods

2.1. Study site and sampling scheme

The Faroe Islands is an archipelago, located at 62° N, 7° W. Kaldbaksfjørður is a classic long (6.6 km) and narrow (0.5–1.7 km) sheltered fjord. At the entrance is a sill at 40 m depth, while the maximum water depth is 60 m (Fig. 1). The general hydrography reflects a year round two-layered system. The 8–20 m deep surface layer (salinity: 32.1–34.9 and temperature: 5.8–11.4 °C) receives freshwater run-off from the 42 km^2 watershed through plentiful rivers distributed around the fjord, while the inflowing deep water mass (salinity: 34.9–35.3 and temperature: 6.2–10.8 °C) consists of Faroe Shelf water (Gaard et al., 2011). Wind induced mixing of the water masses occurs at all times of the year, creating a highly dynamic system, and a wide transition zone between the upper and lower water masses, rather than a sharp pycnocline. The density difference between the surface water and the deeper water is mainly due to salinity difference. During the study, the maximum density difference (1.55 kg m^{-3}) was observed in autumn, when precipitation was highest. Throughout the rest of the study, the stratification was weak, with density differences <0.5 kg m^{-3} (Gaard et al., 2011). From mid-June to September 2006, the water column was divided into 3 layers, due to an additional thermocline at ~40 m depth. The stratification led to isolated bottom water during this period and the O_2 concentration declined to a minimum of 136 μM in August (á Norði et al., 2011). The hydrodynamics cause a high flushing rate of the euphotic zone, with high inflow of nutrients throughout the summer. The season with sufficient light for primary production in the euphotic zone extends from April to October. These natural settings resulted in an annual primary production of ~335 g C m^{-2} yr^{-1} (Gaard et al., 2011).

The watershed of the fjord is mostly uncultivated and unpopulated. The main anthropogenic nutrient input to the euphotic zone was from fish farming activity. However, the high natural inflow of nutrients implies that the anthropogenic input has little effect on, the primary production (Gaard et al., 2011). Deposition of food and faecal waste from the fish farm had no effect on the overall conditions in the central basin targeted in this study (á Norði et al., 2011).

From May 2006 to May 2007, three sediment cores were on 11 occasions recovered at the 52 m deep station T (Fig. 1). The sediment cores were used to determine the inventory of OC and the benthic solute exchange of O_2, Dissolved inorganic Carbon (DIC), NH_4^+ and NO_3^-. At one occasion (October 2006) 12 sediment cores were sampled at 50–55 m bottom depth within an area of 1 km^2 near station T to evaluate potential spatial variation in the study area.

In August 2006 and 2007 sediment was sampled at 8 other locations covering a depth range of 35 to 55 m to evaluate any potential depth relation in diagenetic activity. In October 2009 sediment cores were taken for determination of excess ^{210}Pb to assess the carbon burial rate at station T.

Vertical particle and OC fluxes were continuously measured with sedimentation traps deployed at 20, 40 and 50 m depth near station T. In addition, the C:N ratio of the suspended material was measured at 5, 10 and 20 m depth in the water column on 11 occasions throughout the study period. The carbon content and C:N ratio of riverine material was measured in three of the rivers entering the inner part of the fjord in January and February 2009 (Fig. 1).

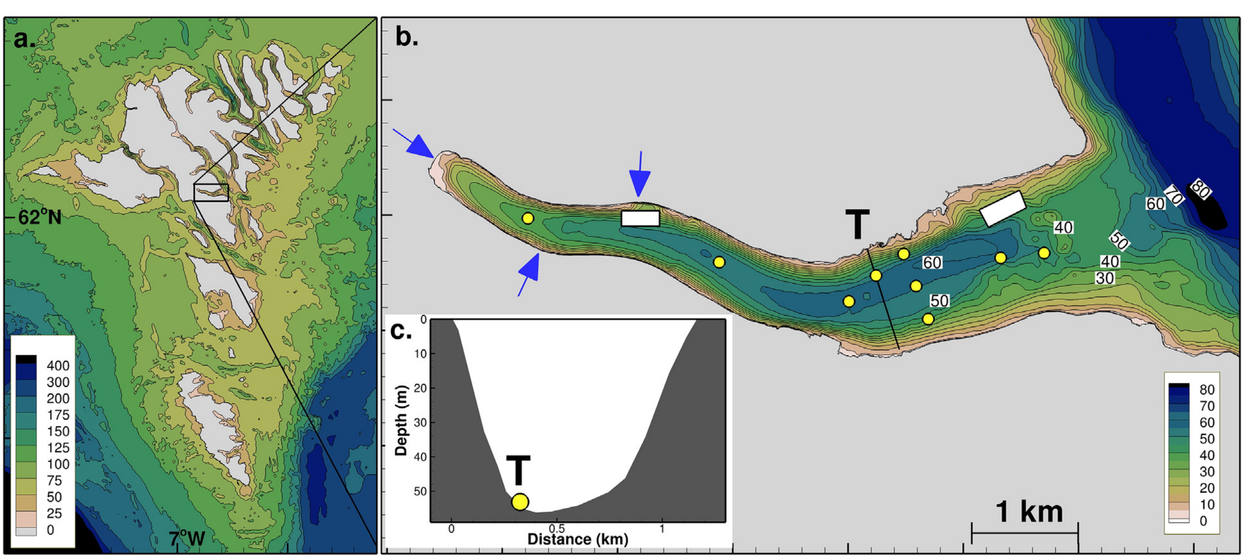

Fig. 1. (a) location of Kaldbaksfjørður in the central Faroe Islands (b) Sediment sampling stations (yellow dots). The time series sampling station is marked T. Blue arrows mark the rivers, where OC and C:N ratio in riverine water was measured. The two fish farming areas in Kaldbaksfjørður are shown as white blocks, but they did not affect conditions at the measuring sites. (c) Bottom depth at a north-south cross section (indicated by a black line in (b)) through station T which is located at the base of the ~14° steep slope. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

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