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Organic matter characterization and fate in the sub-arctic Norwegian fjords during the late spring/summer period

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Abstract

The organic matter (OM) pool has been studied in two sub-arctic north Norwegian fjords, Balsfjord and Ullsfjord, in July 2001 and June 2003. Besides general OM parameters such as dissolved organic carbon (DOC), particulate organic carbon and nitrogen (POC and PON), the distribution of specific compounds such as folic acid and surface active substances (SAS) was followed. The results are supported with data of salinity, temperature, and chlorophyll *a* (Chl *a*). This approach allowed assessment of the fate of the OM pool, and its distinct vertical, spatial, and seasonal variations. Fjord waters could be vertically divided into two layers: the upper mixed layer (UML), until 40 m depth, and the deep aphotic layer. Spatial variability between the two fjords is a consequence of different influences of shelf waters on the fjords. Significant enrichment of POC and PON concentrations (3–5 times), as well as those of particulate SAS and folic acid (up to 3.2 times) in the UML was recorded during the period of new production, in early June. Depletion of particulate OM in deep waters was ascribed to fast dissolution or remineralization in the UML or upper part of aphotic layer. OM in July 2001 was characterized with 15.9% higher DOC pool compared to June 2003, and had refractory properties, suggesting the fjords to be an important source of organic matter for the continental shelf ecosystem. The DOC pool in these subarctic fjords represents the major component of the OM pool. The DOC concentrations in fjords are lower than those in previously studied warmer seas (e.g. the Adriatic Sea), whereas the concentrations of folic acid and SAS are comparable to those in the Adriatic Sea.

Keywords: organic matter (OM); folic acid; surfactant activity; subarctic fjords; Norway

1. Introduction

Marine organic matter (OM) is one of the largest reservoirs of organic carbon on the Earth. Consequently, there is great interest in the ocean's organic carbon in order to provide a better understanding of the global carbon cycle (Williams and Druffel, 1987). Shelf seas make up <8% of the total oceanic surface area. Continental shelves may, however, play a disproportionately large role in oceanic carbon cycling since they represent conduits, linking terrestial sources of OM with the ocean and make up the sites where approximately one-fifth to one-third of oceanic primary production occurs (Wollast, 1991; Schlesinger, 1997). OM dynamics in coastal waters, when compared to the open ocean, is more strongly influenced by biological, chemical, and physical processes on shorter time scales. The biogenic OM produced in the sea-surface is remineralized there or is exported to deeper waters/layers, depending on the physical and biological processes in the upper water column.

Generally, dissolved organic carbon (DOC) accumulates during spring and summer in the surface waters of coastal seas like the Norwegian Sea (Børsheim and Myklestad, 1997) and the Adriatic Sea (Vojvodić and

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Ćosović, 1996). The annual accumulation of DOC and its subsequent decline in surface waters imply that DOC constitutes an important factor in a biological pump of carbon from the atmosphere to the seawater (Ducklow et al., 1995). The particulate organic carbon (POC), usually representing only 10% of DOC value (Thurman, 1985), could represent a significant part of OM in the productive months of spring and summer in the coastal seas (Gilmartin and Revelante, 1991; Reigstad et al., 2000; Gašparović and Ćosović, 2003; Gobler and Sanudo-Wilhelmy, 2003). The POC and DOC are exported from the surface to deeper waters. The vertical flux of DOC out of the surface waters is mainly mediated by turbulent mixing and convection (Rudels and Quadfasel, 1991) and by the dissolution of sinking particles (Cho and Azam, 1988).

It is estimated that 10–20% of DOM can be identified as specific compounds (Münster, 1993). The remaining DOM is a highly complex mixture that cannot be resolved into pure compounds. The determination of reactivity of organic substances in natural waters may provide a better insight into the behaviour of organic carbon and improve the understanding of carbon circulation. This can be obtained through characterization of surface active substances (SAS). SAS as a part of OM mixture in the seas represents a very reactive part. SAS accumulates in surface waters, primarily due to phytoplankton production (Žutić et al., 1981; Gašparović and Ćosović, 2001, 2003). The accumulation and decay rates of SAS are the consequence of the sum of production and consumption processes and of physical processes such as sinking and mixing. For the freshly produced SAS in the Northern Adriatic Sea the half-life time has been found to be less than a few months while for the heterodispersed SAS fraction it is of the order of weeks (Gašparović and Ćosović, 2003).

Along with this largely uncharacterized pool of OM, specific well-defined organic molecules could play a significant role as indicators of the cycling of the trace constituents in coastal seawater and are thus markers of a certain biogeochemical processes. Folic acid (FA) could be regarded as an indicator for certain phytoplankton species as a significant correlation has been found between biomarker pigments for cyanobacteria and green algae (zeaxanthine and chlorophyll *b*, respectively) and the concentration of FA (Plavšić et al., 2002). FA is widespread in marine waters and could play a role as a nutrient and at the same time could be released by micro-organisms, representing an additional pool of available organics (Le Gall and van den Berg, 1998; Plavšić et al., 1997). The spatial and seasonal distribution of FA depends on a sensitive balance between its production, consumption and UV-decomposition (Le Gall and van den Berg, 1998; Plavšić et al., 2002; Plavšić, 2004), indicating that FA should be regarded as a highly reactive compound in coastal waters.

The North Norwegian fjords are high-latitude fjords with regard to the light regime, they are, however, characterized by relatively high temperature and without significant influence by glaciers. They are strongly influenced by the Atlantic Sea water with its relatively high temperature and salinity. They experience little fresh-water run-off from autumn to the middle of May (Wassmann et al., 1996). Advection of water masses in and out of these fjords plays an important role in the ecology of this area (Wassmann et al., 1996).

The amount of solar irradiation and daylength periodicity creates particular conditions for the seasonal progression of biological processes in the fjords. The spring bloom, from late March to late April, is followed by an additional increase in primary production in the May–June period, probably due to fresh-water run-off. Primary production is usually rather low for the rest of the year (Eilertsen et al., 1981; Eilertsen and Taasen, 1984; Riebesell et al., 1995).

Very little is known about the DOC pool and the composition of this pool in North Norwegian fjords or the high-latitude sub-arctic fjords in general. Investigations from the Barents Sea have shown that 18–55% of the primary production went to the dissolved organic pool (Vernet et al., 1998). DOC thus makes up an important fraction of the carbon pool at high latitudes as well. The results of a study on organic matter reservoirs are combined here with the determination of some specific compounds such as folic acid and surface active organic substances, in two North Norwegian fjords during the late spring/summer months in 2 years. The results are supported by data on salinity, temperature and chlorophyll *a* (Chl *a*). Such an approach allowed assessment of the fate of OM pool, its horizontal, vertical and seasonal variations. This can be of interest as a part of the study of global carbon biogeochemistry.

2. Materials and methods

2.1. Study area

The two fjords selected, Balsfjord and Ullsfjord, are characteristic of the north-Norwegian coastal zone (Fig. 1). They differ from each other with respect to sill depth, width and exposure to the shelf area. Balsfjord (Station 1, 69° 23.02′ N, 19° 02.67′ E and Station 2, 69° 34.32′ N, 18° 54.62′ E) is a semi-enclosed fjord with limited exchange with coastal waters due to the shallow sill (30 m) (Eilertsen et al., 1981). It has a narrow configuration and 180 m maximum depth. It is characterized by moderate freshwater run-off, which is important for the water circulation in summer. Wind driven circulation is the most prominent (Svendsen, 1995). Carbon sedimentation is seasonally dependent with increased vertical carbon flux after the spring bloom, which is