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Seasonal C-cycling variability in the open and ice-covered waters of the Barents Sea: an introduction

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1. Introduction

Models of the ocean–atmosphere system demonstrate the potentially great importance of polar oceans to the regulation of atmospheric CO_2. This is due, in great part, to the action of the surface biota (Barnard et al., 1984; Sarmiento and Toggweiler, 1984; Sundquist and Broecker, 1985; Erickson et al., 1990). Phytoplankton are the major producers of organic matter in open waters and account for approximately 30% of the world's primary production (Falkowski, 1980). These primary producers dominate the recycling of dissolved and potentially volatile carbon at the ocean–air interface. In particular they act as sink for carbon dioxide (CO_2).

Compared to other areas of the world's ocean, polar seas have a large influence on the atmosphere's CO_2 content (Anderson et al., 1998, 1999), mainly due to deepwater formation and plume entrainment. Segregation of atmospheric CO_2 in polar seas takes place, in great part, through the action of the surface biota (Slagstad et al., 1999; Bostrøm, 2000). One way the taken-up carbon becomes inaccessible to the atmosphere is through gravitational sinking to intermediate depths in particulate form or intermediate and deepwater formation. Quantification of sources and sinks of carbon is instrumental to the basic understanding of marine ecosystems. A major loss of organic matter produced in the euphotic zone takes place through settling of phytoplankton cells, faecal pellets and phytoplankton-derived detritus (Wassmann, 1998). The sinking of POM links the surface primary production to food webs beneath the euphotic zone and finally supplies the organic matter and energy to the benthic communities (Smetacek, 1984; Grebmeier et al., 1988).

Arctic shelves such as the Bering Straight, the Chuchi Sea and the Barents Sea belong to the most productive environments on earth, particularly during springtime. A distinct spring bloom at the MIZ edge and the long duration of the MIZ bloom as the ice edge recedes northwards during summer adds to the high productivity of Arctic shelves. North–south spatial ecological gradients of nutrients, phytoplankton and higher trophic levels similar to temporal succession observed at any one location are typical for the Barents Sea (Sakshaug and Skjoldal, 1989; Vernet et al., 1998; Wassmann et al., 1999). The bloom development, the secondary production and the fate of the organic matter along the west Spitsbergen and east Greenland shelf is not known in detail. However, the physical forcing and the ice dynamics in

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the latter area are different from the relatively well-known Barents Sea shelf as the main currents are longitudinal, not perpendicular to the ice edge.

The downward flux potential of POM is strongly modified by the prevailing planktonic food web structure (Heiskanen, 1998), which largely determines the physical properties of the sinking and the retention capacity of the pelagic community (Wassmann, 1998). For a better understanding of carbon cycling in the European Arctic we need first an elementary understanding on (a) how vertical export of biogenic matter into the oceans interior is regulated and (b) how net carbon is exported by North Atlantic Deep Water formation. Finally, we need to know how the biogenic matter is transported by along or cross-shelf currents. This demands adequate investigations of primary production, plankton dynamics and vertical flux on the background of adequate investigations of the physical oceanography.

2. The Barents Sea and C-cycling investigations

The Barents Sea is a high-latitude ecosystem and one of the most productive regions over the World Ocean (Zenkievitch, 1963; Bogorov et al., 1968; Skjoldal and Rey, 1989; Sakshaug 1997). This marginal sea type ecosystem is characterised by a shallow shelf (Fig. 1) and a complex hydrography that has a zonal structure (Loeng, 1991). It demonstrates a striking combination of large distances and shallowness, high-latitude light conditions and substantial advection of heat, salt, nutrients and biomass by the Norwegian Atlantic Current (e.g. Ådlandsvik and Loeng, 1991; Sakshaug et al., 1995). The ice can cover up to 90% of the sea surface in winter, but there is no multiyear ice (Vinje and Kvambek 1991). The ice-edge zone crosses most of the shelf during the spring bloom progress to the north (Sakshaug and Skjoldal, 1989).

The plankton community in the Barents Sea has been intensively investigated since the beginning of the last century, in particular by Russian scientists (e.g. Linko, 1907; Jashnov, 1939; Zelikman and Kamshilov, 1960). Over the last 30 years system ecological work that primarily focussed upon hydrodynamics, productivity, plankton and biological base of one of the words largest fisheries has been carried out in the Barents Sea. From the Russian side good summaries were presented by Degtereva (1973), Druzhkov and Makarevich (1992), Makarevich and Larionov (1992), Larionov (1997) and Timofeev (1997). Between 1984 and 1990 the Norwegian Research Council supported system ecological programme PRO MARE focussed intensively upon the central and western region of the Barents Sea, in particular along the transect that is the focus of the present investigation (Fig. 1). For an overview of the basic results derived from this programme, see Sakshaug et al. (1991). However, the main transect of PRO MARE had also been previously investigated since 1979 (e.g. Skjoldal et al., 1987). Based upon the entire information regarding the physical, chemical and biological oceanography in the region Wassmann and Slagstad (1993) modelled the seasonal and interannual dynamics of carbon flux along the transect. Still based upon the PRO MARE data this 2D model was succeeded by a 3D investigation of carbon flux over the entire Barents Sea (Slagstad and Wassmann, 1997).

Sensitivity testing of these two models and general progress in arctic plankton ecology provided the strategy on how to improve the comprehension of seasonal carbon cycling in the Barents Sea. Among several aspects, better insight into CO_2 uptake (e.g. the role of the ocean in climate change), the entire size spectrum of plankton organisms (e.g. small-bodied phyto- and zooplankton organisms are widespread and important also in cold-water systems), grazing (e.g. top-down control) and vertical flux regulation (e.g. retention versus export food webs) was found mandatory. A preparatory investigation along the transept (Fig. 1) and including several new elements characteristic for the present investigation was carried out in May 1993 (e.g. Hansen et al., 1995; Matrai and Vernet, 1997; Andreassen and Wassmann, 1998; Vernet et al., 1998; Wassmann et al., 1999). The experience of this prestudy provided the basic concept for the current project.

3. The Arctic Light and Heat programme

The Norwegian National Committee for Polar Research (Polar Committee) formulated a strategic plan for Norwegian research in the Arctic in 1995. At the same time, the Norwegian Research Council approved a plan for the Polar Committee to develop a

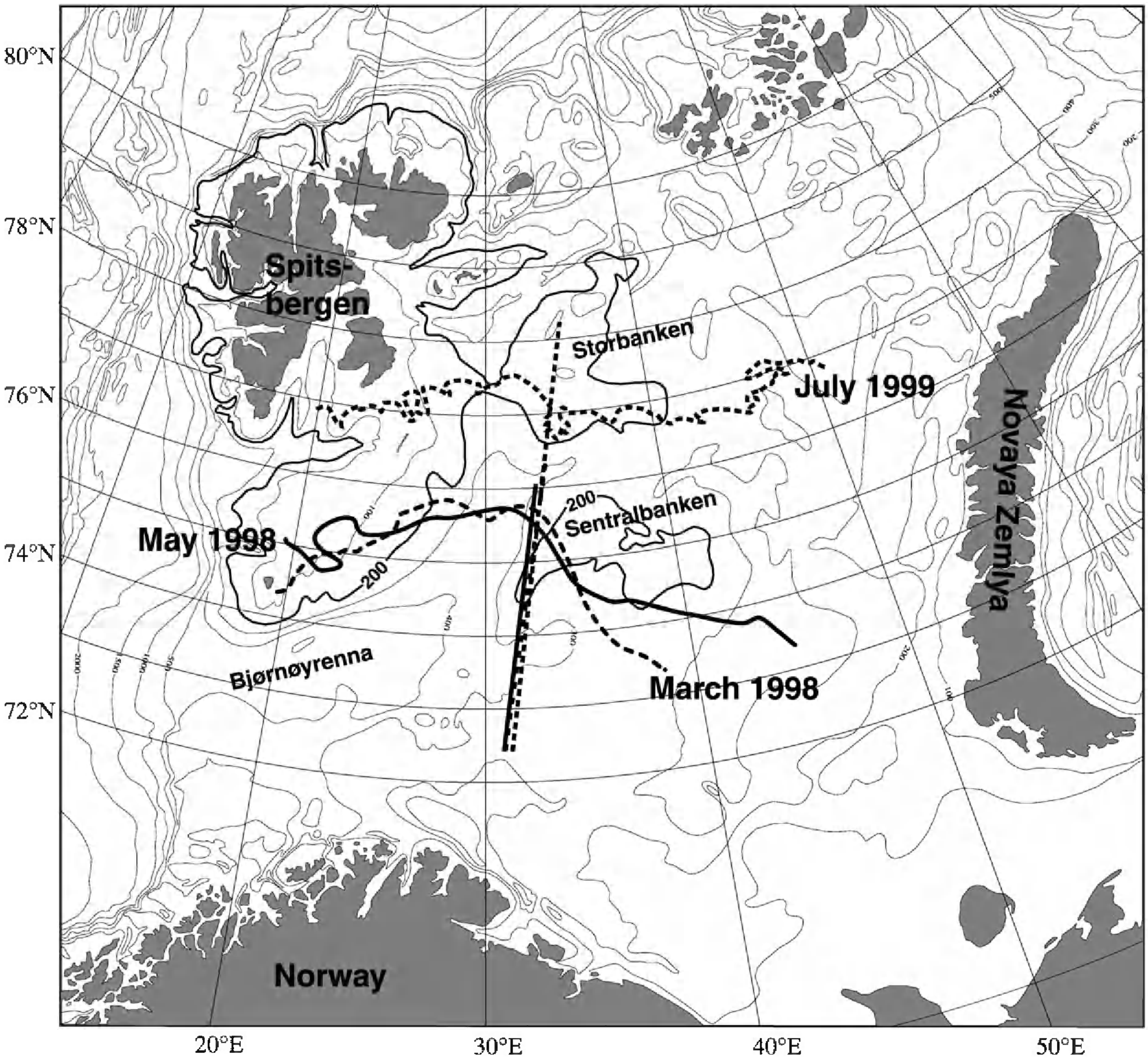

Fig. 1. The investigation area in the central Barents Sea and the investigated transects and ice edge locations during three cruises in March 1998, May 1998, and July 1999.

new Arctic research programme. As a result of the strategic plan, the "Arctic Light and Heat" (ALV) research programme was established in 1996 with a duration of 5 years. The programme's goals have been to improve knowledge of:

- natural and anthropogenic variation in climate and radiation
- the impacts of climate and radiation on organisms, populations and interactions between populations
- feedback mechanisms and interactions between arctic biota and climate.

The programme was designed to advance research that coupled physical environmental parameters with biological components of the Arctic, while contributing to increasing the understanding of the relationship between the climate system and the ecosystem in the Arctic. The programme portfolio was therefore a combination of both cross-disciplinary and multidisciplinary projects, together with projects that contributed to cross-disciplinary aspects or that served to link different disciplines or that complimented or supplement other projects. It was inside the frame of ALV that financial support for the present investigation was provided to the Norwegian College of Fishery Science to carry out the cross-disciplinary project "Seasonal C-cycling variability in the open and ice-covered waters of the Barents Sea."

4. The scientific approach in the field

Three cruises to the central Barents Sea and the MIZ in March 1998 (late winter), May 1998 (spring)

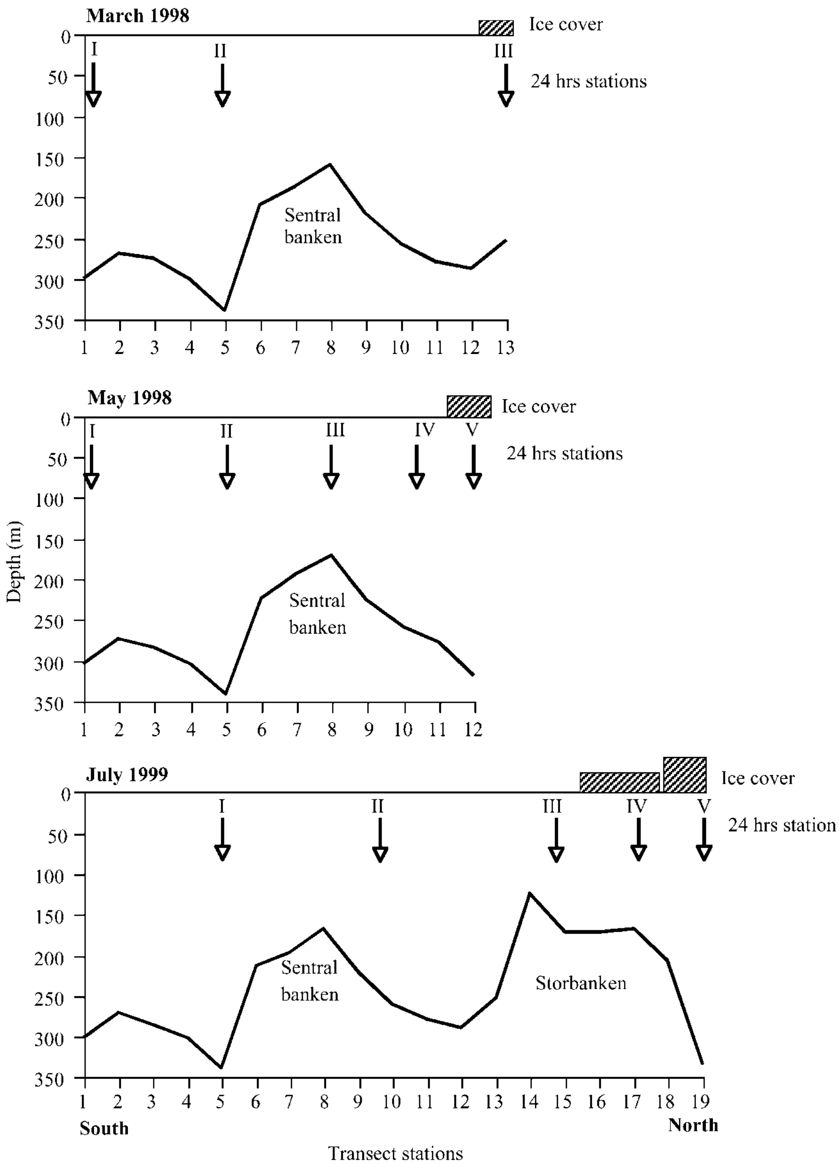

Fig. 2. Topography and ice index along the investigated transects in the central Barents Sea in March and May 1998 and July 1999. Transect stations (x-axis) as well as the 24-h stations (Roman numerals) are shown.

and July 1999 (summer) were carried with the ice-enforced R/V *Jan Mayen* of the University of Tromsø. A transect, stretching from 72°N, 30′ E towards the northeast was covered in all three cruises (Fig. 1). The research vessel investigated the transect from south to north by CTD and water samples (CO_2, nutrients, phyto- and protozooplankton) every 20 nautical miles. In addition, mesozooplankton data were obtained every 40 nautical mile (Arabic numerals, Fig. 2). The vessel entered the marginal ice zone and penetrated into the ice depending on ice condition and ship time availability (see ice index, Figs. 1, 2). The length of the cruises depended thus on the position of the ice edge. After an evaluation of the available data at the northern end of the transect, 3–5 24-h stations (Roman numerals, Fig. 2) were selected for process studies such as primary production (data not shown), vertical export and mesozooplankton grazing and egg production. These stations were visited on the return to Norway.

5. Objectives and tasks

The seasonal C-flux variability and some significant processes and components along a south–north gradient in the western Barents Sea are the main objective of the present investigation. In particular we focus upon the marginal ice zone and the ice-covered northernmost regions that so far have not been adequately investigated due to lack of a research vessel that could operate in these waters. The present investigation focussed upon a number of basic elements or cluster of components. In parenthesis are the relevant contributions presented in the present volume.

- Nutrients, suspended biomass and pico- to mesoplankton (Reigstad et al., 2002; Ratkova and Wassmann, 2002; Arashkevich et al., 2002)
- Vertical flux in the upper 200 m (Olli et al., 2002; Wexels Riser et al., 2002)
- CO_2 uptake dynamics (Kaltin et al., 2002)
- Grazing, egg production and faecal pellet production (Pasternak et al., 2002; Wexels Riser et al., 2002).

Some additional studies were carried out in June/July 1999 when bacterial activity (Howard-Jones et al., 2002), bacterial assimilation of ammonium and nitrate (Allen et al., 2002), grazing by microzooplankton (Verity et al., 2002), the stable isotope compositions of dominant copepods (Sato et al., 2002) and ^{234}Thorium fluxes (Coppola et al., 2002) were investigated.

6. Future development of C-cycling studies

This volume summarises the most prominent information from the central Barents Sea and its MIZ, places it into a comprehensive perspective, interprets the processes in terms of variable meteorological forcing and attempts to address interannual variability. Thus, it represents the quintessence of the present understanding of C-cycling in the Barents Sea. In the near future, a new generation of physically–biologically coupled 3D model has to be developed, which, based upon the validation data from the present investigations, approximates the consequences of climate change for the C flux. Future sensitivity tests of this new model and general improvements of the knowledge regarding the physical, chemical and biological oceanography in the Barents Sea or the Arctic will give rise to new sets of issues that deserve consideration. These insights will ultimately result in a new, future C-cycling project that is based upon this set of issues. The future project supposedly combines field investigations with modelling work into a concerted action. In this manner, modelling not only summarises the obtained knowledge, it also represents the base for future investigations which directs research. In ecosystem research, modelling should ideally take place *before* rather than *after* the investigation. This alternating research strategy results in new generations of models, which improves our comprehension rather in a cyclic than in a linear manner.

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