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Stratification and mixing in the Limfjorden in relation to mussel culture

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Abstract

The physical regime of Limfjorden in northern Denmark has been investigated with the aim of defining its role in controlling the food supply to a community of benthic filter feeders, which is dominated by commercially valuable mussels. A two-week campaign of hydrodynamic observations at different spatial scales was undertaken in May/June 2003 as part of an interdisciplinary study. The results reveal that the water column in Limfjorden switches periodically between stratified and mixed conditions in response to meteorological forcing. During calm periods, stratification develops in response to solar heating. This stratifying tendency is opposed principally by wind stirring indirectly through wave motions. Due to the low velocities, there is very little generation of turbulence due to shear stresses at the bed. The mussels appear to have a subtle effect on turbulence levels very close to the bed, but in this system the effect of mussels on the hydrodynamics of the whole water column is limited.

A reduced physics model of the competition between these processes has been developed, which incorporates the effects of waves and of shallow water on the absorption of solar radiation. When forced by observed data for wave activity and surface heating, the model simulates the principal features of the observed evolution of water column stability.

Stratification is usually detrimental to mussel growth, as it limits access of mussels to food in the upper water layers. However, if mussels are capable of depleting the whole water column under fully mixed conditions, brief periods of stratification could theoretically act as a temporary refuge for phytoplankton, allowing the population to recover. The ultimate effect of this hydrodynamic switching of the system needs further assessment.

Keywords: Density stratification; Mixing processes; Mussel fisheries; Phytoplankton; Denmark; Limfjorden

1. Introduction

Stratification and mixing can have a large impact on the supply of phytoplankton to benthic filter feeders (Frechette and Bourget, 1985). Phytoplankton is produced in the upper water layers, and is transported towards the bed by turbulent mixing. In systems with high densities of benthic filter feeders, such as shellfish beds, the consumption rate can out-compete the transport rate. This results in a depletion boundary layer near the bed (Ackerman et al., 2001; Muschenheim and Newell, 1992).

Depletion can occur in a well-mixed water column, but its effect is usually not very pronounced (Wildish and Kristmanson, 1984). In less well mixed systems, however, where periods of strong stratification may occur,

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the lower region of the water column is decoupled from the upper region of the water column by stability induced either by surface heating and/or density-driven circulation. The pycnocline prevents diffusion of phytoplankton, oxygen and nutrients, so that the boundary depletion layer cannot be replenished from above. Prolonged periods of stratification can have serious detrimental effects on shellfish populations (Dolmer, 2000). Reduced food supply can result in reduced growth, and in extreme cases oxygen depletion can wipe out entire mussels beds.

The EU project MaBenE[1] aims to develop fully coupled ecological models for ecosystems dominated by benthic filter feeders, in order to optimise shellfish production in terms of yield as well as nature conservation. This requires thorough knowledge of the interplay between the physical regime and the biota in these systems. In this study we aim to produce a sound physical description of the hydrodynamic regime in Limfjorden, a large wind-driven system that sustains a large commercial mussel fishing industry. It is intended as a first step towards the development of fully coupled biological–physical models.

The time scale and intensity of stratifying events have an important influence on the health of benthic mussel cultures. By identifying the major causes of stratification it may become possible to predict both of these factors. Short term stratifying events which are long enough to allow phytoplankton populations to grow in the upper layer but short enough so as not to starve the mussels may be beneficial to the mussel population in the long term. If the stratification persists over a long enough time period so as to stop the supply of food and oxygen to the mussels, then the implications for the mussel population can be drastic.

2. The Limfjorden regime

Limfjorden in Denmark, is a large, shallow body of water lying across the Jutland peninsular connected to the North Sea on the west coast, and the Kattegat on the east coast. Both connections, Sallingsund in the West, and Aggersund in the East are shallow channels. The two other channels draining into the central basin (Risgårde and Feggesund, are of limited importance for the main through flow. The centre of Limfjorden opens into a large shallow basin, Løgstør Bredning, where the field sites of the present study were located (Fig. 1). The total volume of water in Limfjorden amounts to 7.1 km^3, the average water depth is about 4.5 m. The depth of Løgstør Bredning is on average 5.8 m.

Throughout most of the year, the wind blows from a westerly direction, with the exception of the summer period, which is dominated by easterly winds that are usually low in energy. Water temperatures in Limfjorden average around 2–3 °C in the winter period, and 15–17 °C in the summer period. There is a constant intrusion of high saline water from the North Sea (32–34 psu) and an input from the Kattegat of low saline water (19–25 psu). Furthermore, there is a freshwater input of 2.7 km^3 per year from the surrounding area. Limfjorden is a microtidal system with a tidal amplitude of 0.1–0.2 m. During summer, water exchange and circulation through Limfjorden are mainly driven by a predominantly easterly wind (Dolmer, 2000). A combination of wind and tide is responsible for a net flow from the North Sea (Thyborøn kanal) through Limfjorden to the Kattegat of 8.7 km^3 $year^{-1}$ on average. The corresponding residence time of the water is around 225 days on average for the entire water body (Dame and Prins, 1998).

Limfjorden is a eutrophic water body affected by nutrient input from the surrounding watershed. This results in high primary production rates of up to 1000 mg C m^{-2} d^{-1} in summer (Dolmer and Frandsen, 2002) which supports a high level of biomass of benthic suspension-feeders. Limfjorden contains a large mussel fishery based primarily on a wild population with annual landings of 80,000–100,000 t of mussels. A large proportion of these fisheries is located in Løgstør Bredning. The majority of mussels are harvested from the bed, although mussels grown from rafts are becoming more common.

3. Methods and observational campaign

Field observations were undertaken in Limfjorden from the 26th of May until the 6th of June 2003 with a focus on the study site in Løgstør Bredning (Fig. 1). Current meters with temperature and salinity loggers were deployed at a long term monitoring station (3708), at the study site (M and S) and at the 4 boundaries to Løgstør Bredning (Sallingsund, Feggesund, Aggersund and Risgårde). A permanent meteorological station was located on the island of Livø, which measured wind speed and direction, temperature, humidity and solar radiation. During the two weeks of the campaign, the weather was, on average, exceptionally warm and calm for the area. During several consecutive days there was virtually no wind.

[1] MaBenE: Managing Benthic Ecosystems in relation to Physical Forcing and Environmental constraints. This project is sponsored by the EU under the 5th framework, contract no EVK3-CT-2002-00071.