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ORIGINAL RESEARCH ARTICLE

Water type quantification in the Skagerrak, the Kattegat and off the Jutland west coast

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Summary An extensive data series of salinity, nutrients and coloured dissolved organic material (CDOM) was collected in the Skagerrak, the northern part of the Kattegat and off the Jutland west coast in April each year during the period 1996—2000, by the Institute of Marine Research in Norway. In this month, after the spring bloom, German Bight Water differs from its surrounding waters by a higher nitrate content and higher nitrate/phosphate and nitrate/silicate ratios. The spreading of this water type into the Skagerrak is of special interest with regard to toxic algal blooms. The quantification of the spatial distributions of the different water types required the development of a new algorithm for the area containing the Norwegian Coastal Current, while an earlier Danish algorithm was applied for the rest of the area. From the upper 50 m a total of 2227 observations of salinity and CDOM content have been used to calculate the mean concentration of water from the German Bight, the North Sea (Atlantic water), the Baltic Sea and Norwegian rivers. The Atlantic Water was the dominant water type, with a mean concentration of 79%, German Bight Water constituted 11%, Baltic Water 8%, and Norwegian River Water 2%. At the surface the mean percentages of these water types were found to be 68%, 15%, 15%, and 3%, respectively. Within the northern part of the Skagerrak, closer to the Norwegian coast, the surface waters were estimated to consist of 74% Atlantic Water, 20% Baltic Water, and 7% Norwegian River Water. The analysis indicates that the content of German Bight Water in this part is less than 5%.

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1. Introduction

Skagerrak is heavily influenced by both the Baltic and the North Sea. About 70% of the water entering the North Sea is assumed to pass through this area (ICES, 1983), and many of the hydrographical events taking place in the North Sea will be reflected in the Skagerrak. The general circulation in the area is cyclonic (Fig. 1), and the distribution of the water masses is mainly regulated by the in- and outflow of water in the North Sea. The steep bottom topography characterised by the deep Norwegian Trench is of special importance for the steering and mixing of the water masses (Danielssen et al., 1997; Rodhe, 1996; Svansson, 1975). In addition there is a large freshwater supply to the Skagerrak from the Baltic, the Kattegat, local rivers and continental river discharge to the southern North Sea (Gustavsson and Stigebrandt, 1996). The Jutland Coastal Current appears to constitute a link between the eutrophicated waters of the southern North Sea and the waters of the Skagerrak and Kattegat, and according to Aarup et al. (1996a) its transport may be in the range of 0.01—0.02 Sv. The average total transport of the basic cyclonic circulation in the Skagerrak has been estimated to 0.5—1 Sv (Rodhe, 1987, 1992, 1996). The distribution of the relatively fresh surface waters in the Skagerrak is strongly influenced by varying weather conditions, and local wind conditions may block as well as increase the usual pattern of surface circulation (Aure and Sætre, 1981). The surface waters mainly follow the general circulation.

Eutrophication by anthropogenic nutrients has been identified as an issue of concern for the Skagerrak/Kattegat area (Anon., 1993; North Sea Task Force, 1993). In late April 1988, just after the spring bloom, a cruise was carried out by the Institute of Marine Research in the Skagerrak, the Kattegat and along the western Danish North Sea coast to investigate the environmental conditions and anomalous nutrient concentrations related to the large fresh water runoff from the German rivers and the Baltic at that time of the year (Aure et al., 1998). High nitrate concentrations were found in the surface waters of the inner Skagerrak and the Kattegat, resulting in high NO_3:PO_4 and NO_3:SiO_4 ratios as both phosphate and silicate were near the detection limits. In the beginning of May 1988, in connection with weak winds, a well defined surface layer with high temperatures and low salinities and high nitrate concentrations and nitrate/phosphate ratios (Dahl et al., 2005), a harmful bloom of the prymnesiophyte flagellate *Chysochromulina polylepis* occurred in a large part of the Skagerrak and in the entire area of Kattegat (Dahl et al., 1989; Lindahl and Dahl, 1990). This bloom killed a large number of marine species in the upper 20 m of the sublittoral zone along most of the Norwegian Skagerrak coast (Edvardsen et al., 1988; Granéli et al., 1993; Johannessen and Gjøsæter, 1990; Underdal et al., 1989), in addition to 800 tonnes of farmed fish (Skjoldal and Dundas, 1991). Possible long-term effects and recovery in the ecosystem caused by this event have been evaluated by Gjøsæter et al. (2000). Minor blooms of *Chysochromulina polylepis* were since detected in 1994 and 1995. In 1998, 2000 and 2001 harmful algal blooms caused by *Chattonella* spp. occurred in the area. The bloom of 1998 resulted in a loss of 350 tonnes of farmed salmon in addition to some wild fish

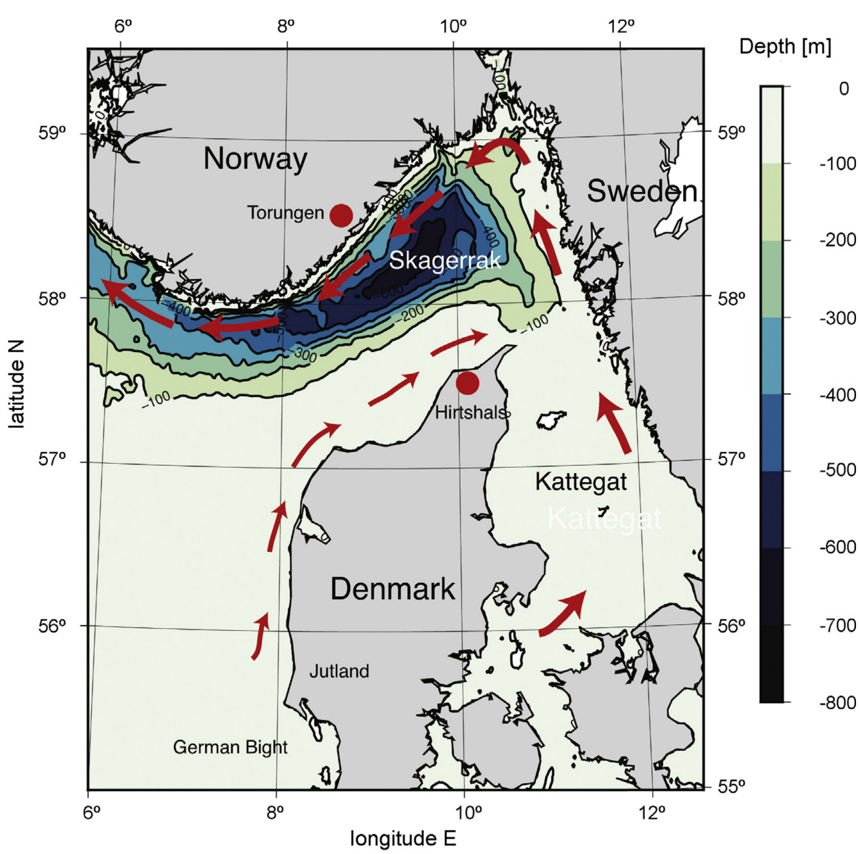

Figure 1 Currents off the Jutland west coast and in the Skagerrak and the Kattegat.