Statens forurensningstilsyn
Norwegian Pollution Control Authority

INFORMATION

2358
2007





Figure 2. The sugar kelp forest common in 1990's has been replaced by a silty turf algae community. Pictures are from 5 m depth at station Buøy, Arendal, Southern Norway. Source: The Norwegian Coastal Monitoring Program. Photo: NIVA

Long-range transported nutrients and the status of the sugar kelp on the south coast of Norway

A large shift in the coastal marine vegetation, from sugar kelp forest to silty turf algae communities, took place at the Norwegian Skagerrak Coast between 1996 and 2002, after decades of eutrophication and recent climatic events causing elevated sea temperature. The eutrophication of these coastal waters is largely influenced by long-range transported nutrients from the Southern North Sea. The nitrate concentration in the coastal current running along the coast was doubled in 1980-1995 and 75% of the winter-spring nitrate originated from the German Bight. Reductions in discharges from the continental rivers are lately reflected in reduced input from long-range transported nutrients and reduced nutrient concentrations in the Norwegian Coastal Current. Modelled results indicate that the 2005 riverine input from Continental rivers, the Kattegat (including the Baltic) and local Norwegian rivers to the affected coastline may have the proportions 45, 25 and 30 %. The Norwegian discharges of nutrients to the south coast of Norway are now of more relative increasing importance than the long-range transported nutrients.

Sugar kelp forest

Surveys on the sugar kelp forest (*Saccharina latissima*, synonym with *Laminaria saccharina*) in 1996-2006 by the Norwegian Institute for Water Research (NIVA) on behalf of the Norwegian government have uncovered a dramatic decline in the abundance of the sugar kelp forest along the southern coasts of Norway. The losses of sugar kelp at the Norwegian West and Skagerrak coasts are estimated to 50 and 90 % respectively (figure 1). Due to this, the sugar kelp has been assigned as a 'near threatened species' by the Norwegian Red List of species (2006). The decline in sugar kelp abundance is most pronounced in sheltered waters, where the kelp forest in large areas has been replaced by a silty turf community dominated by filamentous algae (figure 2). The shift in vegetation is most probably a result of long time eutrophication combined with recent climatic events causing increased sea temperature, inter alia.

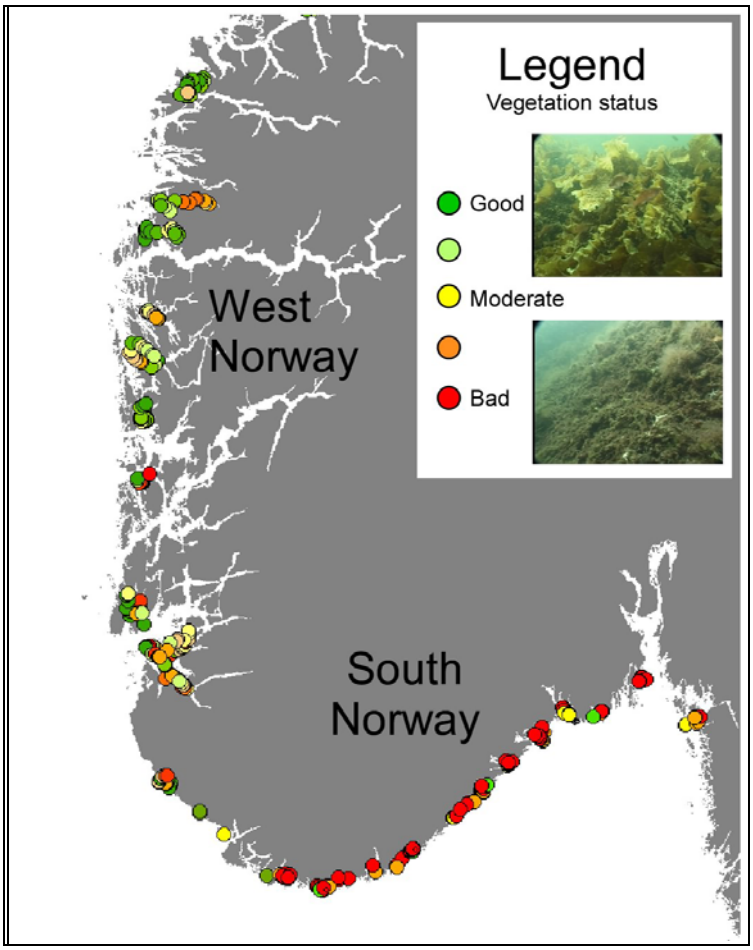


Figure 1. Vegetation status based on the abundance of sugar kelp and filamentous algae on tentative sugar kelp locations along the sheltered South Coast of Norway. Source: Moy et al 2007b. Sugar Kelp Report 2. (in Norwegian) sft.no.

The kelp forests are highly productive and diverse communities, providing habitat for many associated organisms and are important feeding and nursery areas for many species of fish. On contrary, the turf communities of short-lived and mainly summer seasonal species provide less food and shelter for juveniles. The ecological consequences of these changes in the coastal zone vegetation are still unknown.

Nutrient concentrations

In the 1980's the nitrate concentration in the surface water at the Norwegian Skagerrak coast increased dramatically from 4.4 µM to 9 µM (average winter-spring concentration, 0-30m depth) and the nitrate concentration was high throughout the 1990's (figure 3). These coastal waters are situated "down stream" of both local and remote sources. The Norwegian Coastal Current, running from east to south-west along the Norwegian Skagerrak coastline, is a mixture of waters from the Jutland Current, the Kattegat (with water from the Baltic) and local rivers. The Jutland Current is again a mixture of water from the Central/Southern North Sea and the German Bight.

Aure et al. (1998) calculated that the average winter-spring influence of water from the Kattegat, the North Sea and the German Bight over the years 1980-1995 was 25%, 55% and 20% respectively (figure 4). However, 75% of the winter-spring nitrate in the Norwegian Skagerrak Coastal Current originated from the German Bight. There is a good correlation (r^2=0.8) between the average nitrate concentrations in the surface water at the Norwegian Skagerrak coast and in the German Bight (figure 5). This indicates that the nutrient concentration in the Norwegian Coastal Current in Skagerrak is largely influenced by long-range transported nutrients from the southern North Sea, and especially from the German Bight.

The high nitrate concentration continued throughout the 1990's (figure 3) caused eutrophication with increased growth of filamentous algae and green algae that altered the competition between long-lived, slow-growing algae and fast-growing, opportunistic algae. Gradually the environmental quality for the sugar kelp was reduced. In addition, highly elevated summer sea surface temperatures in 1997 (and again in 2002, figure 6) may have caused a major loss of sugar kelp due to heat stress, and thus induced a shift in the sublittoral vegetation that for a long time had been stressed by eutrophication.

Continental riverine discharges that dramatically increased the nitrate

concentrations in the German Bight from 12 µM in 1970-75 to 42 µM in 1990-95 (average winter-spring concentration), have declined and the average winter-spring nitrate concentration in the German Bight is reduced to 24 µM in 2000-05. The distribution between water volumes and nutrients entering the Norwegian Coastal Current has not changed, and consequently, the contribution of long-range transported nitrate from the German Bight to the coastal waters of Norway is also reduced (figure 5).

A North Sea circulation model of wind and density driven currents (MIPOM, met.no) was inoculated with historical data of riverine nutrient discharges to the North Sea to explore their influence on the Norwegian Skagerrak coast (figure 7). The results indicate that large rivers running through Belgium, the Netherlands and Germany had a major influence on the Norwegian water quality up to year 2000. The temporal variation of influence corresponded mainly with flooding events such as in 1994-95 and 1999, but also with large-scale variations in the North Sea circulation patterns. Due to climatic events, local Norwegian rivers had a large impact on the water quality in 2000-2001. The reduced discharges from continental rivers are also reflected by the model results showing declining input from distant sources. Model-based calculations of the surface water concentrations (0-20 m) (figure 7) indicate that the 2005 input from Continental rivers (T3+T4), Kattegat (including the Baltic, Sweden and Denmark, T1+T5+T8) and local Norwegian rivers (T6) to the affected coastline may be 45, 25 and 30 %, respectively.

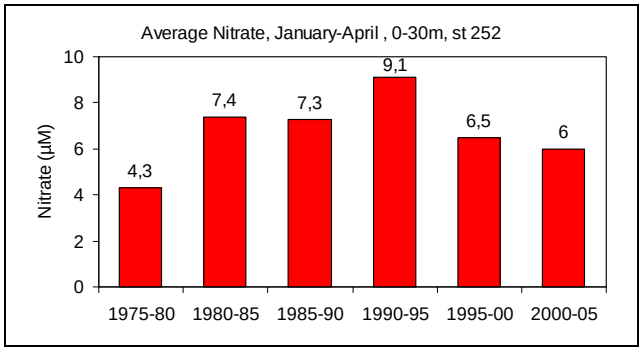


Figure 3. Average winter-spring (January-April) concentration of nitrate in the surface water (0-30m) of the Norwegian Coastal Current outside Arendal, Southern Norway. Source: Norwegian Coastal Monitoring Programme, Moy et al. 2007a

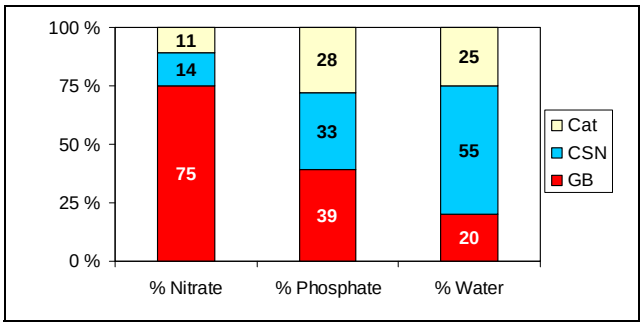


Figure 4. Contribution of nutrients and water from Kattegat (CAT), Central and Southern North Sea (CSN) and the German Bight (GB) calculated from winter-spring (January-April) observations of surface water (0-30m) in 1980-1995. Source: Aure et al. 1998.

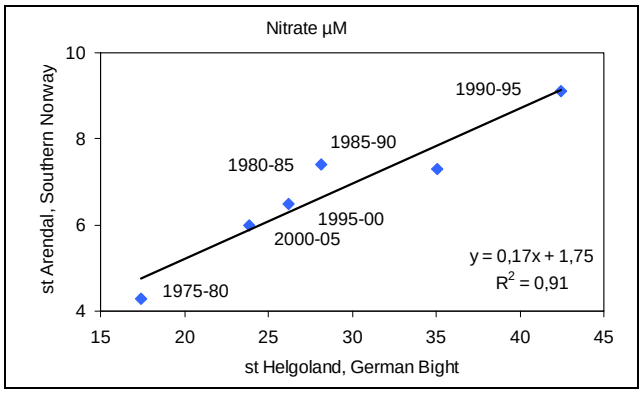


Figure 5. Nitrate concentration in 1975-2005 at Norwegian Costal Monitoring station outside Arendal, Southern Norway and at Helgoland Reede of the German Bight. Source: Franke et al 2004, Moy et al. 2007a

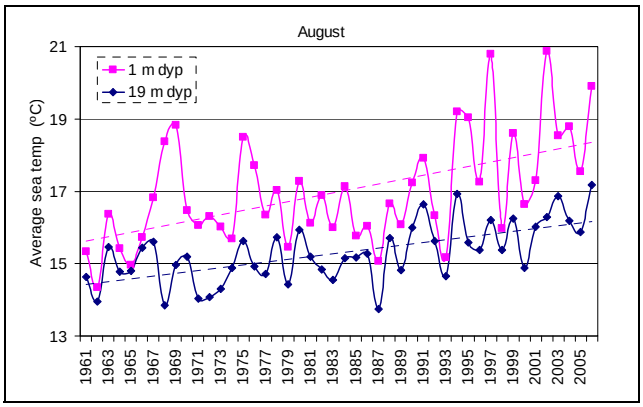


Figure 6. Monthly average sea temperature measured at 1 and 19 m depth at Flødevigen, Arendal, 1961-2006. Source: IMR

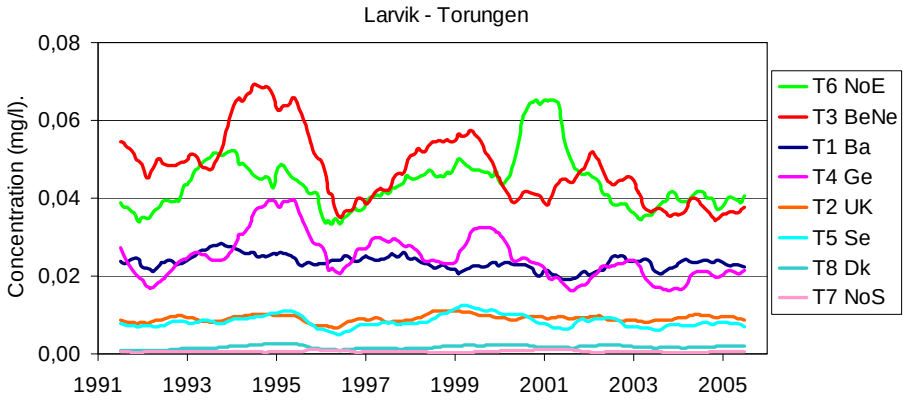


Figure 7. Modelled concentrations at a point on the south coast of Norway (coastline Larvik-Torungen) of an inert element discharged from 8 sources. The curves are 12 months gliding averages of surface water concentrations (0-20 m). The start concentrations of the inert element are equal to the actual riverine discharges of nitrogen. River districts: T1=Baltic Sea, T2=UK, T3=Belgium, Netherlands, T4=Germany (Weser and Elbe), T5=Sweden, T6=East Norway, T7=Southern Norway, T8=Denmark. Source: met.no and Moy & Stålnacke 2007

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