Implications of Accelerated Sea-Level Rise (ASLR) for Denmark:

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Denmark has three times officially evaluated the expected national impacts of anthropogenically induced climate changes. The most recent report (Fenger, Jørgensen, Halsnæs 1996) was based on the 2nd IPPC Assessment. It contains fairly popular contributions from a series of individual scientists and institutions and was edited in collaboration with *The Ministry of Environment and Energy, The Danish Meteorological Institute* and *Research Centre Risø*. The chapters on impacts constitute the basis of reports to the climate convention. The publication of Danish reports based on the 3rd IPCC Assessment is currently being discussed. These reports will probably be designed in a somewhat different form, and are planned to appear soon after the release of the IPCC Assessment in 2001.

Generally it has been found that the impacts of projected climate changes for the next 100 years (2-3°C increase in temperature and related changes in precipitation) are modest and in some cases (*e.g.,* agriculture) even beneficial. The impacts of projected sea-level rise (50 cm) are likewise considered to be modest. Denmark is very ambitious in its attempts to limit emission of greenhouse gases - notably CO_2, and costs of *mitigation* are widely discussed. Adaptive preparations to *impacts of climate changes* however, are very limited and only few preliminary evaluations of *economic consequences* have been carried out.

Monitoring of sea levels

Sea level in Danish waters is monitored intensively and has been so for decades. In Denmark, systematic sea-level measurements were initiated by the Danish Meteorological Institute (DMI) in the 1880s. The DMI has obtained in this way sea-level time series over 100 years long from 10 separate stations throughout the country. Today, DMI operates 15 on-line stations, and their output is used for i.a. warnings of increased sea level and floods, based on a calculation of wind and air pressure (Aakjær, 2000). In recent decades, a series of water level monitors have been established for various other purposes, and DMI is now responsible for the collection of data from about 40 stations. The results are available on the internet. Internationally, DMI collaborates with institutions, which are responsible for measurements along the coast of the Baltic Sea. This collaboration takes place within the European organisation EuroGOOS (European component of Global Ocean Observing System), and will be expanded in the coming years. Along the west coast of Jutland, the Danish Coastal Authorities have operated 10 stations on line since the 1970s.

Recent trends

Due to vertical land movements, differential sea-level trends occur throughout Denmark. The 110 years time-series show a nearly continuous rise in mean sea level in The Wadden Sea of about 1 mm/year, whereas measurements on the northern and eastern part of the country indicate nearly constant sea levels. These trends have been reviewed with reference to climate changes by Duun-Christensen (1992). If past trends are projected, sea level is estimated to rise by 10 cm in the southern part of the country, and to fall slightly in the northwestern part. When the expected impacts of an increased greenhouse effect are taken into account, a total global sea-level rise of 50 cm is estimated to produce rises of 18 to 46 cm in Denmark within the next century, mostly in the southern part of the country.

Coastal erosion

Since the end of the last ice age about 10,000 years ago, the Danish coastline has changed markedly as a consequence of relative land settlements and elevations as well as constant erosion. Projected sea-level rise will exacerbate existing problems along the Danish coasts. It further appears (Binnerup, 2000) that impacts due to possible changes in the direction and strength of winds may be as important as those attributed to sea-level rise. By and large, expected impacts could probably be counteracted by running maintenance. Coast nourishment is an increasingly used technique. In 1992 it was estimated (Jacobsen *et al*., 1992) that it would cost about 60 million Dkr. per cm sea-level rise on 120 km of the west coast of Jutland from Lodbjerg to Nymindegab (present prices 75 million Dkr.).

Risk of floods

Despite the protection afforded by dykes, sea-level rise will increase the risk of floods. Thus, Andersen (1996) calculated that at Torsminde Havn an extreme water level with a current one hundred year return period will occur every 20 years (*i. e.*, five times more often) if sea level rises by 0.5 m. Recent floods have led to the establishment of local emergency forces in some coastal cities.

Infrastructure

During the 1970s, a possible sea-level rise of about 30 cm within the next 200 years (corresponding to the projected value without climate changes) was taken into account in the planning of the dike system of southern Jutland. In future planning of flood risks, a expected 50 cm sea-level rise is now included (Møller, 2000).

In the planning of the Copenhagen Metro and the new town district "Ørestad" on Amager, a most likely total sea-level rise of 52 cm in 2100 is assumed (Frisk, 2000). Danish sewerage systems and waste water treatment plants have so far generally been planned without taking a climate induced sea-level rise into account. Now the possibility is recognised, but it is assumed that potential problems can be solved with pumping systems (Andersen, 2000).

Fresh water supply

In Denmark, high drinking quality is obtained primarily from groundwater sources (99%). Salt (NaCl) in the water is normally due to underground salt deposits (Jacobsen, 1994). Only in a few areas, such as smaller islands (*e.g.,* Samsø) and along low-lying coasts (*e.g.,* Køge Bugt on Zeeland), is seawater intrusion into freshwater aquifers a problem. Locally, this problem may become more important with sea-level rise. However, it is the increasing pressure associated with groundwater withdrawal, which is expected to generate most pressure on freshwater supplies and result in significant salinisation. The on-going National Water Resources Model (GEUS, 2000) aims at giving an overview of the consequences for water resources and water quality of soil pollution, changes in area use and climatic changes.

Near shore ecosystems

Salt meadows, littoral meadows and salt marches are important habitats for near shore ecosystems, especially as breeding grounds for many birds. They have therefore been extensively studied, but so far with little or no regard to impacts of an increased greenhouse effect. The aim of the planned SMART (Salt Marsh - Advance or Retreat) project (Edelvang, 2000) is to develop a model for a forecasting tool that could be used to predict future salt marsh development, advance or retreat, over time scales of decades. Also, the economic costs associated with maintaining salt marshes in a healthy and natural state as desired by the community will be assessed. Possible impacts of sea-level rise on near shore habitats on the Baltic coast of Denmark have been discussed by Vestergaard (1997), but no definite solutions and no economical evaluations have been produced. There is an ongoing debate on the controversy between nature conservation and protection of land. The near-shore and shallow marine areas constitute "responsibility landscapes", and it is argued that future use of these areas, including built-up, should allow a retreat of relevant ecosystems in the case of increased sea level and coastal erosion. Already some marginal areas have been given up. In other cases sedimentation has so far been able to keep pace with the sea-level rise.

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