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Autor(en): **Larsen, Kurt Lykstoft**

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The Effects of the Øresund Bridge-Tunnel on the Environment

Les effets sur L'environnement du pont/tunnel traversant le Öresund

Einwirkungen der Brücke-Tunnel-Verbindung über Öresund auf die Umwelt

Kurt Lykstoft LARSEN
Graduate at Law
Min. of Transport
Copenhagen, Denmark

Kurt Lykstoft Larsen, born 1946, received his legal education at the Univ. of Copenhagen. Now responsible for questions concerning Danish fixed links in the Ministry of Transport in Denmark.

SUMMARY

In 1990 comprehensive investigations were made of the environmental consequences of a bridge/tunnel, including the effects on the marine environment in the Baltic Sea and the Øresund. The questions of raw materials, emission, noise, earthquake risk, etc. were similarly investigated. This created the basis for an inter-governmental agreement between Denmark and Sweden on the route and layout of the bridge/tunnel between Copenhagen, Denmark, and Malmö, Sweden.

RÉSUMÉ

En 1990, des investigations générales ont été effectuées des conséquences sur l'environnement d'un pont/tunnel, comprenant les effets sur le milieu marin dans la mer Baltique et de Öresund. Les questions de matières premières, émissions, bruits, risques de séisme etc furent aussi analysées. Ceci créa la base d'un accord inter-gouvernemental entre le Danemark et la Suède sur le tracé et la configuration d'un pont/tunnel entre Copenhaque, Danemark et Malmö, Suède.

ZUSAMMENFASSUNG

1990 wurden umfassende Untersuchungen der Umweltkonsequenzen einer Brücken-Tunnel-Verbindung ausgeführt, einschliesslich die Einwirkungen auf die Meeresumwelt in der Ostsee und im Öresund. Probleme betreffend Rohstoffe, Emission, Lärm, Risiko für Erdbeben u.s.w. wurden ebenfalls untersucht. Diese Untersuchungen haben die Basis für eine interbehördliche Vereinbarung zwischen Dänemark und Schweden über die Linie und den Plan für die Brücken-Tunnel-Verbindung zwischen Kopenhagen, Dänemark und Malmö, Schweden geschaffen.

1. Legislation work

For many years there have been periods when joint Danish-Swedish analyses were made for the purpose of procuring the necessary basis for making a decision on a bridge, a tunnel or a combination of both across the Øresund (the Sound).

In 1990 negotiations were resumed between Denmark and Sweden for a link consisting of a 4-lane motorway and a double-track railway line between Copenhagen and Malmö, Sweden.

In the spring of 1990 the Danish Ministry of Transport and Ministry of the Environment resolved that on the Danish side an assessment should be made of the effects of this link on the environment. The assessment is described in the report "Environment Øresund 1991" (1). Together with a similar assessment of finance, fares policy, company form, etc., of the link the assessments of the report formed the basis for the signing on 23.3.1991 the Danish-Swedish agreement on the construction of the link.
Under the agreement the two countries are bound to begin actual construction work no later than 1993, taking into consideration that

> "design of the link shall take into account what is ecologically motivated, technically feasible and financially reasonable, so that damages to the environment are avoided".

The environmental report "Environment Øresund" does not suggest measures to be taken to protect the environment from the bridge/tunnel across the Øresund but only contains an assessment of the effect on the environment of various designs. This brings the environmental assessment into conformity with the EEC's EIA (Environmental Impact Analysis) Directive.

After the passing of a Danish construction act a number of additional investigations of a technical and environmental nature will be carried out for determination of the detailed construction of the Øresund bridge/tunnel.

A prerequisite for the further work is that construction technique must be environmentally optimized. The invitation for tender and the final contracts with the construction contractors will contain the necessary requirements for ensuring the environmental conditions.

Additional conditions are that a supervising programme shall be established in connection with the construction work in order to record the environmental effects, and that it shall be possible to organize and at any time adjust the construction work so that the environmental effects are minimized.

2. Organization of the preliminary environmental analyses

As mentioned, in 1990 the Danish Ministry of Transport and Ministry of the Environment decided to prepare a preliminary assessment of the effects of the Øresund bridge/tunnel on the environment. The procedure was that a ministerial committee was appointed, consisting of the ministers of transport, environment and defence, respectively. Under this ministerial committee a so-called Øresund committee was appointed, with representatives from the ministries and others, including the Danish State Railways (DSB) and the Road Directorate.

The environmental analyses were carried out with reference to the said committees, and the actual environmental analyses were organized as follows. In an environmental management group consisting of

- construction authority: Ministry of Transport assisted by DSB and the Road Directorate
- environmental authorities: Ministry of Environment, National Agency for Physical Planning, National Agency of Environmental Protection, National Forest and Nature Agency, Ministry of Environment Geological Survey of Denmark, and at a later stage Ministry of Fisheries and the country of Copenhagen

the formulation of the assignments involved in the 10 different environmental analyses were worked out meticulously. This work went on until the middle of 1990, when the contents of the tasks were agreed upon. The formulations of the tasks were then approved by the ministerial committee.

All environmental assessments were to be based on the following technical construction of the link, which had been described in the 1987 and 89 reports. Variants of the route layout might be contemplated. Fig. 1 shows the entire layout, with an alternative route at Drogden.

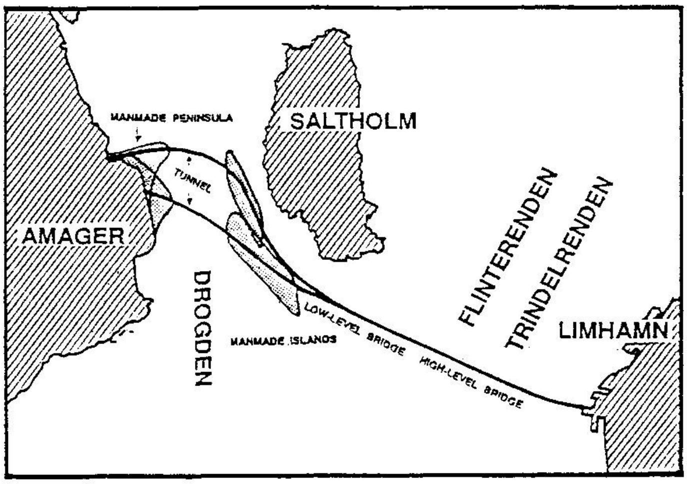

Fig. 1. Routes 1 and 2 for the Øresund bridge/tunnel

The construction in Denmark on land, covering a roughly 12 kilometre long track, follows a route between the centre of Copenhagen and Kastrup, as laid down in earlier reports. The coast-to-coast section consists of a man-made peninsula at Kastrup, from where a 2 kilometre long submerged tunnel continues under the Drogden channel. The submerged tunnel leads to a man-mace island south of the island of Saltholm. From here there will be a 2.25 kilometre long low level bridge, then towards Sweden a 7.5 kilometre long high level bridge section containing two cable stayed bridges with the necessary free span across the Flinderenden and Trindelrenden channels. The coast-to-coast section stretches over a total of 17.6 kilometres.

The 10 environmental assignments were analyses of

- geology, earthquake risk and groundwater conditions
- reclamation of raw materials; localities and their order of priority
- localities for dumping and depositing
- marine environment and biology, both long-term and short-term effects for
  - . oxygen conditions, salinity, and sedimentation layer depths and stability in the remote marine environment, i.e. the Baltic Sea, which is the largest brackish water area in the world
  - . changes in erosion and sedimentation conditions

  - flora and fauna
  - the near marine environment with sedimentation and pollution effects.
- air pollution, including carbon dioxide and nitrogen emission
- birds and seals
- marine archaeology
- noise
- plan descriptions and preservation conditions
- visual environment and architecture

With reference to the environmental management group, which was lead by the Ministry of Transport, these analyses were each carried out with a project manager from DSB/the Road Directorate and a technologically responsible person appointed by the environmental authorities. The analyses were carried out by the construction and environmental authorities' own staff, although firms of consultant engineers and architects were used extensively for especially the marine environment assignment and the visual environment. Experience from the construction of the bridge/tunnel across the Great Belt (Storebælt) was also applied, and staff from A/S Storebæltsforbindelsen, the company responsible for that project, were involved.

The environmental analyses, completed in the last half of 1990 and the first months of 1991, incurred expenditure totalling roughly 10 million DKK.

3. Actual analyses and their results

A summary of the results of the environmental analyses and a comprehensive list of literature are found in the report "Environment Øresund 1991". Danish Ministry of Transport 1991.

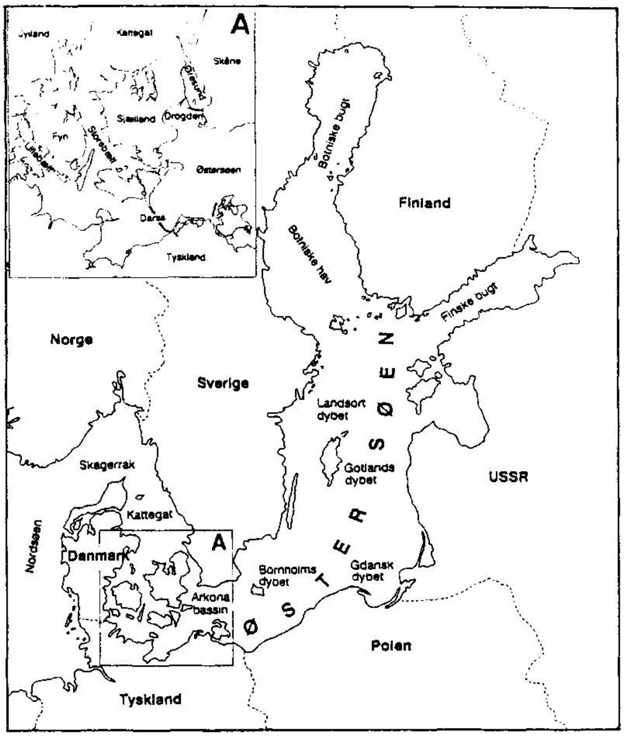

Fig. 2. Map of the Baltic Sea and surrounding territories. The construction area is shown enlarged in the top left corner

Hydrography of the Baltic Sea and the Øresund

Covering an area of 375.000 square kilometres the Baltic Sea is the world's largest brackish water area. It is a very large, deep inlet (Fig. 2), with the Kattegat and the Belts/Øresund as a threshold which impedes the exchange of water between the North Sea/Skagerak and the Baltic Sea. Consequently, changes in the current resistance in the Belts/Øresund will affect the salinity and oxygen conditions in the Baltic Sea.

The exchange of water between the Baltic Sea and the Kattegat/North Sea is primarily governed by atmospherically-conditioned differences in the water levels. In addition, the Baltic Sea is fed some 470 square kilometres of fresh water annually by the rivers. Precipitation and evaporation are practically equal, and therefore the 470 square kilometres of water must leave the Baltic Sea by way of the Øresund and the Belts.

However, differences in atmospheric pressure and forceful westerly winds will cause water movement in and out through the Belts, and the involved water volumes will grossly exceed the said quantity of river water. The exchange of water often appears as cycling flows of about a week's duration. In a normal situation it is estimated that the exchange of water goes through the Little Belt, the Great Belt and the Øresund in the proportion 1:7:3.

A longitudinal section of the Øresund is shown in Fig. 3. It will be seen that the water depth is considerable to the north and to the south but that just by the construction area there is a threshold, the "Drogden Threshold" with depths of some 7 metres. In the deep water areas the volumes of water will most often be in layers, with a lower relatively salt bottom layer and an upper layer with a low density of salt. The division between the two is often fairly sharp, and in the Øresund it normally lies at a depth of 10-13 metres. Thus, in calm periods the salt Kattegat bottom water will be prevented from reaching the Baltic Sea across the mentioned threshold.

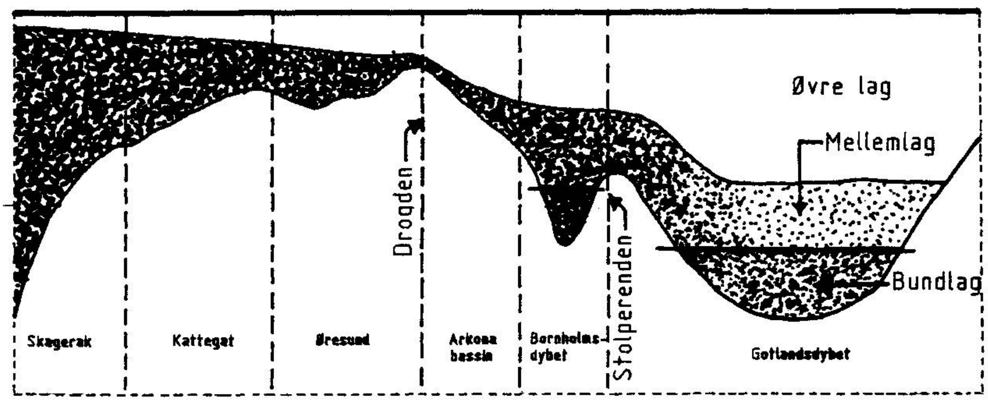

Fig. 3. Longitudinal section of the Øresund

However, during longer periods of southerly current the salt bottom water will be carried across the threshold and into the Baltic Sea. In this connection extremely long periods of violent inflow are of importance. In these cases the volumes of water in the Øresund will gradually become completely mixed, and large volumes of salt water containing oxygen will be carried to the deep basins of the Baltic Sea. It is estimated that these periods of inflow are crucial to life in the deeper parts of the Baltic Sea, but there is disagreement about the importance of the Øresund as compared to the Little Belt and the Great Belt in these extreme situations.

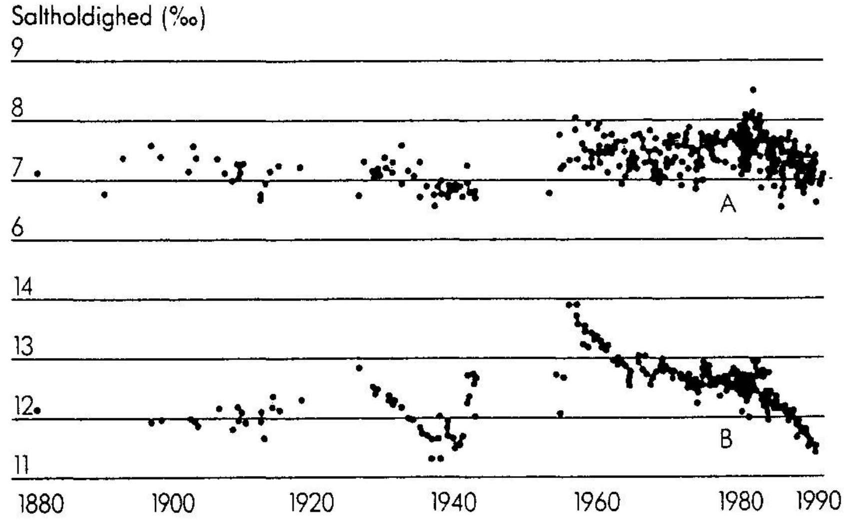

Fig. 4. Variations in salinity 1880-1990 of surface water (top) and bottom water (bottom) in the Gotland Deep.

As said, massive salt water penetration into the Baltic Sea occurs very rarely, most recently in the middle of the 1970s. This may be the reason for a fairly dramatic drop in salinity, especially in the bottom water in the Gotland Deep (Fig. 4). The salinity here has indeed been on the rise through most of the century until 1980. Others have been of the opinion that the change in this salinity should be seen in connection with the pollution of the Baltic Sea, but it should be noted that the salinity at present is not lower than it has been earlier at times when there has been a long interval between two salt penetrations.

Biological conditions in the Øresund and the Baltic Sea

In connection with the environmental investigations the fauna and the vegetation on the bottom of the Øresund in the area around the construction route were mapped.

Fig. 5 shows the distribution of the bottom fauna in the Øresund area. As could be expected the fauna forms a pattern mainly dictated by depth, bottom sediment and salinity.

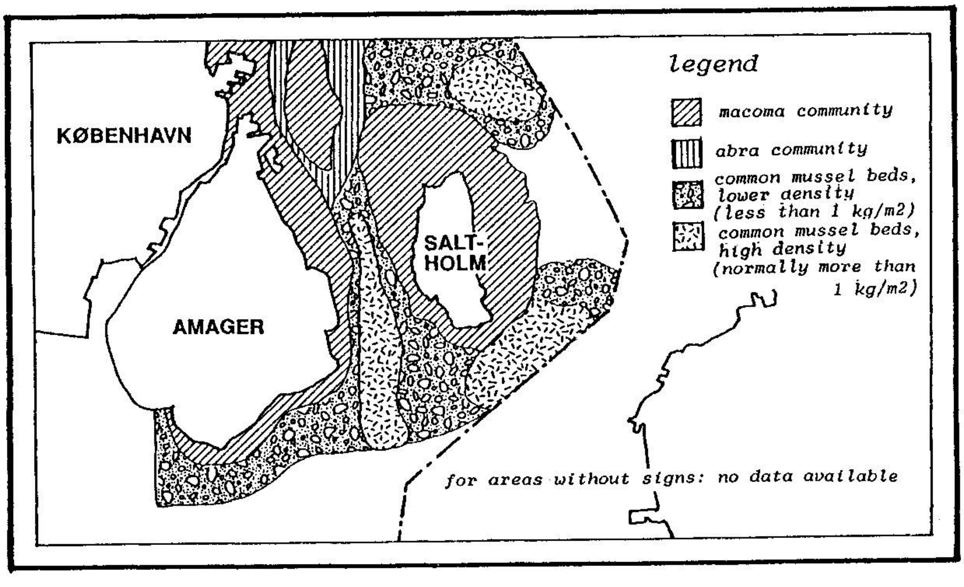

Fig. 5. Bottom fauna distribution near the route of the Øresund link.

All the shown faunas are important to the area's fish and animal life, but the focus here is specially on the areas with continuous beds of common mussels, for these are of great value to the most important bird societies in the area. The Saltholm area is a bird area of international importance. Saltholm houses Northern Europe's largest colony of breeding eiders. There are some 8,000 pairs. The island also contains large populations of breeding gulls and wading birds, and with its mussel beds is of great importance as a resting and foraging area for passing wading birds and for the tufted ducks which winter in the Copenhagen area. Finally, the area is important to the Østersø mute swans, a great number of which seek the area in the moulting period June-September when they cannot fly. The Saltholm area down to sea depths of about 4 metres has been selected as Danish EEC bird protection area No. 110. Another area by the south-east point of Saltholm is protected as a game reserve because of a small population of breeding seals.

Fig. 6 shows the distribution of the major types of vegetation in the area around Saltholm. Here, too, the distribution depends on sea depth and bottom sediment, but also the supply of nutritive salts and the penetration of light at the bottom are of importance to the distribution of the types of vegetation.

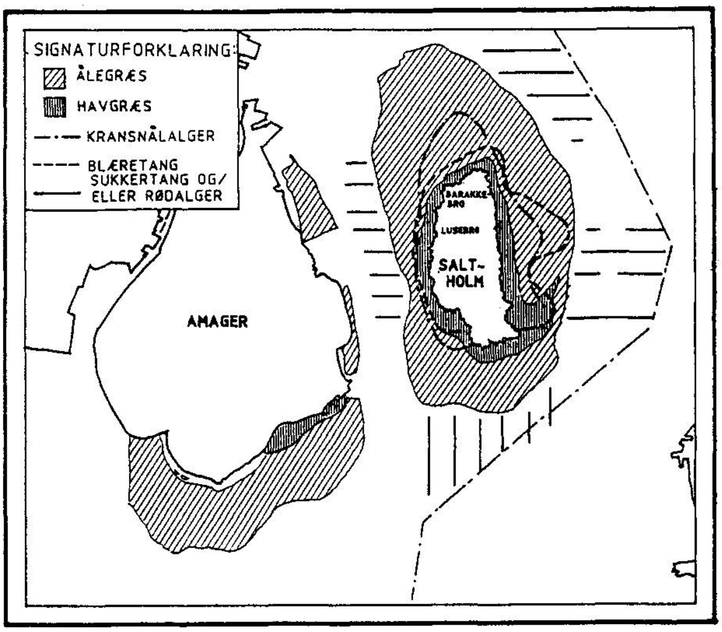

Fig. 6. Distribution of types of vegetation in the area of the bridge/tunnel route.

For certain species of birds and especially for the fish stock the grasswrack areas are considered important. This is because lumpfish and garfish, among others, spawn in the grasswrack, and the grasswrack is home to the fry of eel, cod, herring, garfish and lumpfish. The grasswrack area around Saltholm in Fig. 6 makes up 58% of the entire grasswrack area in the Øresund. It should finally be noted that the Øresund is an important migration passage for, among others, the herring which provides the backbone of Danish fishing of industrial herring in the Kattegat or Skagerak.

Lasting changes in the Øresund and the Baltic Sea as a consequence of the bridge/-tunnel link without compensatory removal of earth

Assessment of the effects of the Øresund bridge/tunnel were based on model calculations, in some cases supplemented by estimates. Two hydro-dynamic models were made, based on the DHI model systems MIKE 21 and MIKE 12. The former is a two-dimensional one-layer model, the latter a two-layer model with one dimension.

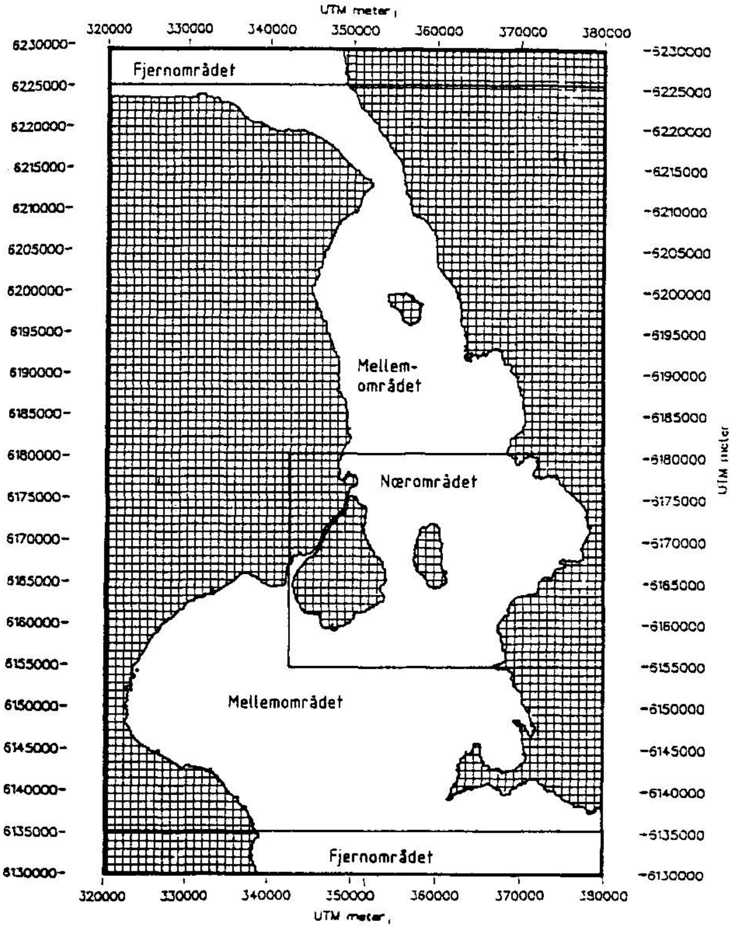

Fig. 7. Division between near, medium distance and remote areas in the models.

The near area (Fig. 7) was assessed with MIKE 21, and a 250 metre grid in the topographical database was used.

The medium distance area (Fig. 7) was modelled with both types of model, the selection of each investigation parameter being based on resource requirements and necessary degree of detail. As a topographical background for MIKE 12 a grid of 1000 metres was used.

The remote area was assessed with a special Baltic Sea model.

As the result of the assessments the following lasting effects can be pointed out:

The bridge/tunnel without compensatory removal of earth will increase resistance to the current in the Øresund by 2-3%. This will lead to a reduced through-flow of water and therefore to reduced salinity and oxygen content in the Baltic Sea. However, the model calculations only indicate a very small reduction, as shown in Fig. 8. The reduction is small whether route 1 or route 2 across the Drogden channel is chosen, and it is expected that it can be made smaller by adjusting the design of certain details of the construction in the projection phase. Finally, it should be noted that the effects in the Baltic Sea from the Øresund bridge/tunnel are of the same magnitude as the uncertainty of the 0 solution for the bridge/tunnel across the Great Belt, which is now under construction.

Conditions	Route	Salinity upper layer %	Salinity bottom layer %	Division level depth Metres	Division level stability %	Oxygen supply bottom layer %
Without CM 4.2 Present situation		0.770	1.330	49.77	100	100
With CM 4.2 after flat area earth removal	1	0.770	1.330	49.77	100	100
With CM 4.2 after channel deepening	1	0.770	1.332	49.80	100.15	99.70
With CM 4.2 without compensatory earth removal	1	0.768	1.329	49.80	100.06	99.63
With CM 4.2 without compensatory earth removal	2	0.767	1.328	49.81	100.05	99.47

Fig. 8. Key figures for effects of Øresund bridge/tunnel with and without compensatory earth removal

Fig. 9 demonstrates that brackish water areas generally contain fewer species than fresh and salt water areas. Considering that the salinity of the Baltic Sea is about 1.3% in the bottom water and 0.7-0.8% in the surface water, it can be deduced from Fig. 9 that reduction of the salinity will lead to a reduction in the number of species. The following sections will describe that the reduction in salinity in the Baltic Sea as a consequence of the construction of the Øresund bridge/tunnel without compensatory earth removal will be very moderate, but at the same time it should be noted that there is uncertainty about the assessment of the effect that this minimal reduction will have on the distribution limits of the species in the very sensitive Baltic Sea. Particular fear has been expressed that the distribution limits for the cod in the Baltic Sea will be disturbed by the effects of the construction. Nonetheless, changes in the salinity should still be seen in connection with the natural changes registered in the Baltic Sea, see Fig. 4.

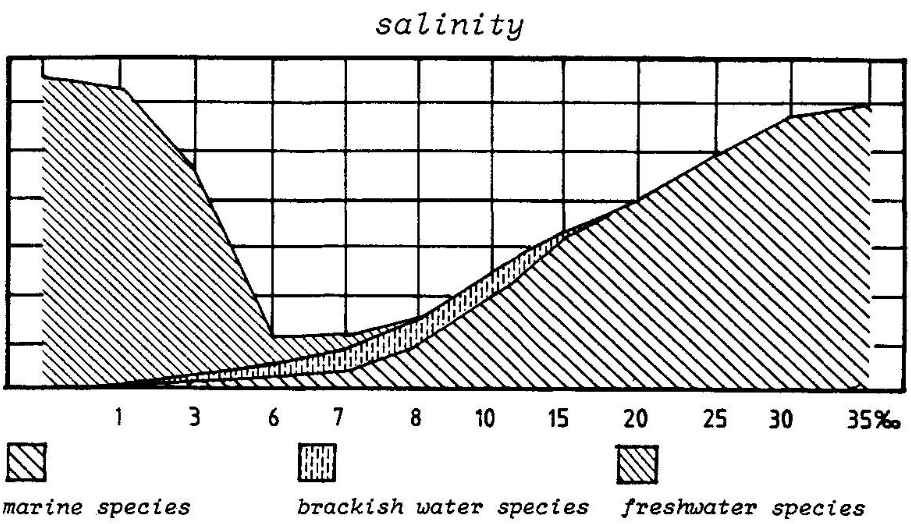

Fig. 9. Relations between number of macroscopic animal species and salinity in a normal sea area.

In the Øresund the man-made island and peninsula cover an area of roughly 3 square kilometres. Part of this area today is common mussel beds and grasswrack meadows.

In the area south of Drogden it is expected that the salt balance will be changed moderately whether the bridge/tunnel is built with or without carrying out compensatory earth removal.

The models were not used for showing effects in the near environment of the construction without compensatory earth removal, but qualified assessments point to the following effects:

* The velocity of the current in the Drogden channel will be slightly increased.
* In the area by the root of the man-made peninsula conditions will become calmer, and the result will be a bottom sediment of more organic content and consequent risk of unpleasant smell in the area.
* Ice conditions in the area will be altered. West and partly south of the man-made island and between this and Saltholm an ice sheet will form more rapidly and stay longer in cold winters. An increased frequency in episodes of pack ice must also be foreseen.
* There will be a great risk that the channel between Saltholm and the man-made island will sand up so that periodical dredging will be necessary. If neglected it will be difficult to prevent foxes and rats from reaching Saltholm, and this will be damage the bird life.
* The small population of seals at the south-east point of Saltholm will probably disappear.
* The number of moulting swans in the area will possible be reduced.

Compensation possibilities

If it is desired to entirely remove or to reduce the described effects of the construction on the Baltic Sea, this is possible. One can choose to remove earth from the bottom in the area around the route. This solution will ensure unaltered flow through the Øresund. The necessary volume of removed material will depend on whether route 1 or route 2 is selected, and on the tunnel length and depth to the tunnel top. Fig. 10 gives an idea about necessary volumes to be removed by the investigated construction of route 1 and by various lengths and depths for route 2. Locations of the removals are shown in Fig. 11.

		Length		
Route	Level for top side of tunnel	1800 metres	2000 metres	2400 metres
1	- 10 metres	9.2	-	-
2	- 10 metres	14.5	12.1	15.5
2	- 11 metres	11.5	9.0	-
2	- 12 metres	9.3	-	-

Fig. 10. Volumes, in millions of cubic metres, necessary to be removed for full compensation for effects of the construction on salinity and oxygen contents in the Baltic Sea by route 1 and by various lengths and depths for the submerged tunnel in route 2.

Another possibility is to deepen the channel. By expanding channels and making moderate deepenings totalling about 1.3 million (route 1) or 1.65 million cubic metres (route 2) in the areas shown in Fig. 10, unaltered salinity in the Baltic Sea can be achieved. However, the water through-flow and thereby the contents of oxygen in the Baltic will be reduced slightly (about 0.3%) by the bridge/tunnel after channel deepenings.

Temporary effects in the Øresund caused by the bridge/tunnel

Temporary effects in the Øresund depend a great deal on the waste from foundation digging and possible compensatory removal of flat area earth. If it proves possible to keep this waste down to 5% the investigations predict only relatively moderate temporary effects as follows:

* Some reductions in the bio-mass for both fauna and vegetation may be caused by a cover of sediment and by the light being temporarily reduced by sediment vanes and algae. But the analyses do not point to significant reductions in fauna and vegetation if waste is kept within the target percentage.
* Some of the waste sediment will consume oxygen. It is, however, estimated that the increase in oxygen consumption will be so moderate that it cannot in itself cause occurrences of lack of oxygen but perhaps aggravate already occurred lacks of oxygen.
* Algae may flourish because of increased quantities of nutritive salts in the water emanating from waste sediments containing nutritive salts. However, the analyses indicate that it will be a question of relocation of these areas of water with increased nutritive salt contents rather than an extension of the areas.
* Waste of sediment containing heavy metal. With the actual knowledge of the earth type distribution in the area it is expected that the waste sediment will contain a smaller proportion of heavy metal than the present bottom sediment.

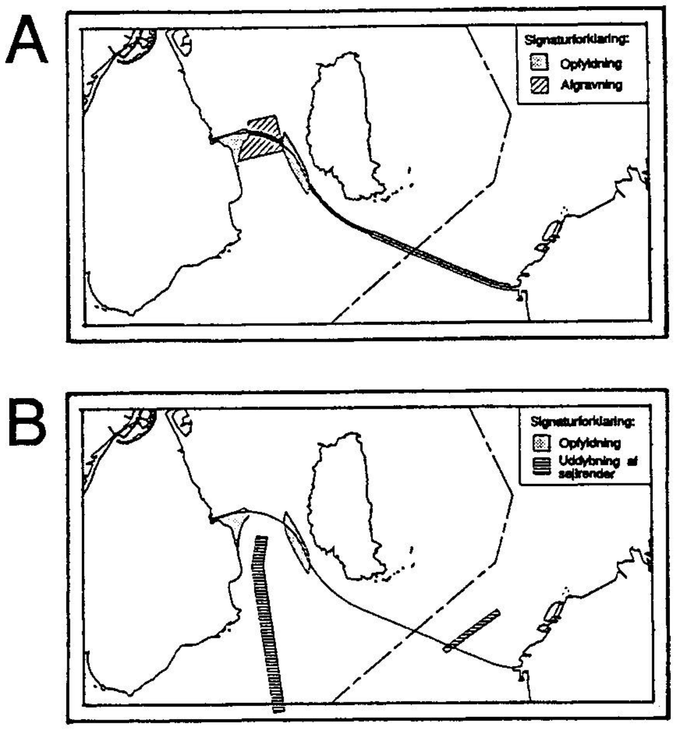

Fig. 11. Localization of earth removals when deepening flat area and channel respectively.

In all circumstances the danger of serious effects from the digging will be increased in step with the extension of the digging, i.e. in proportion with the size of the chosen compensatory removals of earth.

Other investigations

Besides the analyses of the effects of the bridge/tunnel on the marine environment, assessments have been carried out of the geological situation in the area, of noise and emission consequences of traffic across the bridge/tunnel, and of possible conflicts between the bridge/tunnel and marine-archaeological interests. Finally, a series of preliminary reflections have been made on the architectonic design of the construction.

The geological analyses included assessments of the bearing strength and diggability of the various types of earth in relation to foundation digging and possible compensatory removals of earth, of raw material reclamation prospects, of groundwater problems as a consequence of the constructions on land in Denmark, and of earthquake risks, if any, to the bridge/tunnel.

Summarily it can be concluded that none of the investigations carried out has lead to results which in any way suggest that the bridge/tunnel will be a serious strain on the environment in the area.