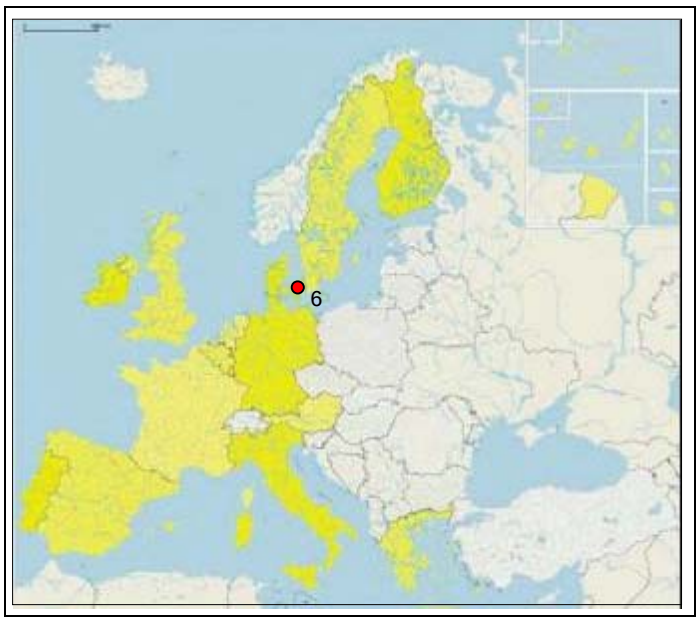
KØGE BAY
(DENMARK)



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1. GENERAL DESCRIPTION OF THE AREA

1.1 Physical process level

1.1.1 Classification

The Danish coastline is 7400 km long. There are three different types of coast in Denmark:

1. Tidal coast protected by sea dykes;
2. Highly exposed North Sea coast;
3. Less exposed coasts of Baltic Sea and Kattegat.

The Kattegat and Baltic Sea coast are moderately exposed. The case area at Koge Bay, facing shallow water, is characterized by offshore bars and barrier islands in front of lagoons.

Køge Bay is a low wave energy and low tidal energy environment. The typology according to the framework from the scoping study is:

3b. Wave dominated sediment. Plains
Baltic barrier Delta coasts, Lagoons and barrier islands.

Fig. 1: Location of case area.

1.1.2 Geology

During the Quarternary period all of Denmark was covered by ice, and the initial landforms of Køge Bay were created during the last phase of glaciation. The bay can be characterized as a central depression reflecting a large glacier lobe, advancing in a northwest direction during the last stage of the Pleistocene age. When the ice melted away, a smoothed-out till plain was left, sloping gently towards the central part of the bay. Only in the northern part of the bay the monotonous landscape is disturbed by a glacial tunnel valley, St. Vejlea Dal (see Figure 2).

6-9000 Years ago, the base level was about 18 m below present sea level, and small rivers excavated the glacial valleys. The development of the actual coastal zone is due to the transgression during the Littorina Sea (5-6000 B.P.). The river valley was submerged and large quantities of sediment were deposited; simultaneously the waves affected a wide coastal zone because of the very small gradients. As the material of the sea bottom is rather rich in clay, stones and boulders, the creation of an equilibrium profile was slow. At the transgression maximum, about 5000 year ago, the relative sea level was 3 m higher than today.

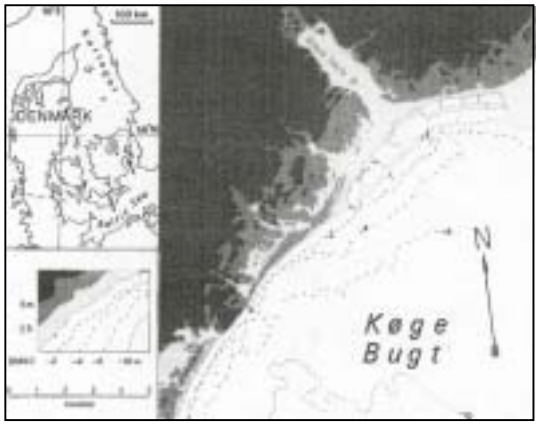

Fig. 2: Location Koge Bay Beach Park.

1.1.3 Morphology

Box 1: Distinguished situations.

Two situations are distinguished for the case area:

1. Situation before the Beach Park was built; original coastline.
2. Situation after completion of the Beach Park; coastline has been moved seaward.
These situations are illustrated by the Figures 3A and 3B.

During the last 100 years a system of barrier islands has developed. Maps of 1907 do not show offshore bars or islands. Initial barriers appeared on maps for the first time in 1909, and since then they have slowly migrated towards the shore increasing their top levels. The origin of this barrier formation is classified as barrier emergence through nearshore aggradation.

In 1972, the coastal landscape shows a single, sandy ridge- an initial barrier- in the nearshore zone (see Figure 3A). The development of the nearshore zone off the Broendby Strand (north of single ridge) differs markedly and is characterized by multiple and minor bars. Since the 70s the small temporary islands have developed into more permanent barriers.

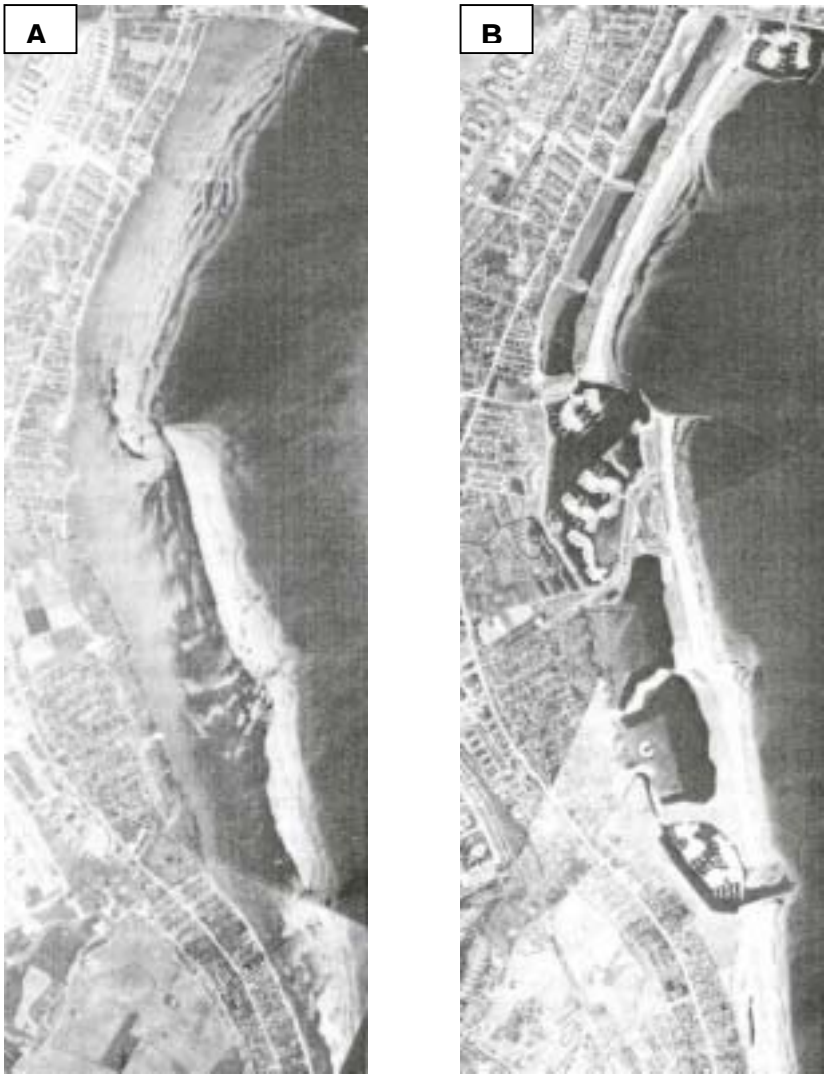

Fig. 3: (Picture 1:) Situation before (A) and after (B) completion of Beach Park.

The reason why the rate of accretion of material has been relatively slow is a consequence of the sea bottom morphology. As indicated, the sand fraction in the till is very small and the great majority of the available and mobile sediment is already concentrated in the nearshore zone. Investigations reveal that the till is covered by a thin layer of lag material (coarse gravel and stones). Separation of the sand fraction from the till by waves and current is consequently a slow process. In Picture 1 an aerial view of the coast is shown before and after the construction of the Køge Bay Beach Park. The original morphology is clearly recognized in the newly created situation.

At the northern border of the case area, an older reclamation area is present for industrial purposes. This area forms a corner of the bay area with low wave activity and thus a gathering of seaweed and sewage.

1.1.4 Physical processes

Tide

The astronomic tide is below 0.1 m, the tidal influence is therefore considered to be negligible.

Waves

According to Hayes (1979), Køge Bay must be classified as a low wave energy environment with H_{bmax}<1.5 m. The principal reason is the orientation of the coastline in relation to the dominating westerly winds combined with the limited fetches. The coast is protected from high waves because of the form of the bay. The prevailing wave energy is coming from the southeast (longest fetches).

Wind

Western winds are prevailing. Temporal wind tide may be pronounced, sea level fluctuations of –0.8 m to 1.1 m in 24 h are not uncommon and high waters near +2 m are recorded.

1.1.5 Erosion

Specific information about erosion in Køge Bay is not available, however it is clear that the net sediment transport is not high. This is caused by the fact that the coastline is directed perpendicular to the dominant wave direction, in the original situation as well as in the situation after completion of the Beach Park.

In a study from 1990 it was said that preliminary interpretations of air photos, levelling and soundings in fixed profiles did not indicate a clear net longshore transport in any direction. There were no accumulations seen at the groins. However, in PROCOAST 2001, erosion at the northern end of the island belt is mentioned because the new built harbour with jetties would hinder the sediment transport into the bay and thus cause lee side erosion. This indicates the presence of a net longshore transport in southwestern direction.

1.2 Socio-economic aspects

1.2.1 Population rate

The case area is densely populated. The suburbs of Copenhagen are located in this area, as can be seen in Figure 3. In the period from 1965-1980 the build-up of the southern part of Copenhagen was explosive. In this period 42,000 dwellings with the infrastructure required were built along the coast of Køge Bay.

1.2.2 Major functions of the coastal zone

- **Tourism and recreation:** North of Copenhagen, towards Elsinore (40 km), along most of the coastal area upper class houses prevail. Beaches for bathing and recreation for the city population are therefore restricted to the north coast of Zeeland or the Køge Bay.
- **Urbanisation (protection of life and investments)**
- **Industry:** Køge Bay is a highly industrialized area south of Copenhagen receiving wastewater from four municipal wastewater treatment plants and several industrial outlets.
- **Nature reservation:** Before and after the completion of the Beach Park, valuable salt marshes and reed swamps are present in the shallow lagoons.

Fig. 4: Urbanisation at case area.

1.2.3 Land use

Land use around the case area mainly consists of industrial and inhabited areas. The Køge Bay Beach Park self however is mainly restricted to recreational and nature functions.

1.2.4 Assessment of capital at risk

It is clear that the capital at risk is high, the suburbs of Copenhagen are densely populated and the human lives and investments at stake are very high. Furthermore, the recreational value of the area is high because this is the main possible bathing area for the city population of Copenhagen.

2. PROBLEM DESCRIPTION

2.1 Eroding sites

Original situation

Before the construction of the Beach Park, extraordinary high waters during winter gales flooded large areas around the rivers St. Vejle A and L1. Vejle A. Therefore, a coastal defence measure was needed.

After completion of Beach Park

The coastline of the artificial beach islands is quite stable because it is lying in the inner part of a shallow bay. Only at the northern end of the island belt the dunes are eroded because a new built harbour with jetties hinder the sediment transport into the bay and thus causes leeside erosion.

2.2 Impacts

Original situation

The rivers flow through densely populated areas; therefore the flooding of the areas around the river has great impact on the inhabitants of the suburbs of Copenhagen.

Furthermore, behind the naturally formed barriers, the lagoons are polluted because of the shallow water. This problem was increased by the presence of an old reclamation area at the northern border of the case area; seaweed and sewage are gathered in the corner of the bay area. The lagoons exist of swamps because they are sheltered by the natural barrier islands. The swamps do not create good recreational values but, on the other hand, valuable nature can develop in the swamps.

After completion of Beach Park

The erosion at the northern end of the island belt, affects the recreational values of the beaches at this location.

3. SOLUTIONS / MEASURES

3.1 Policy options

Original situation

The policy option for the coastal defence measure in this situation was “move seaward”.

After completion of Beach Park

The policy option for the taken measure in this situation was “hold the line”.

3.2 Strategy

In 1975, the Ministry of Environment decided to establish a beach park facility in Køge Bay, southwest of Copenhagen. The water area behind the barrier was transformed into two systems of brackish lagoons (to preserve the inherent environment, the lagoons should still contain salt water). After the establishment in 1977-1980, the area was given to spontaneous vegetation developments. Stagnant water should be avoided to combat the pollution problems in the case area.

The main purpose of the Beach Park is to give fine beaches to the population of the area (recreation function). In hot summers more than a million people visit the park. The park is situated close to a large city and therefore it is necessary that it works well for the visitors. But it is also important that the park as a nature area is protected. Therefore and because the park hopefully shall continue to be an attractive place for future generations, the intensive use is concentrated at the access points and parking lots so that large areas only are used very lightly.

Besides being a recreational area for the metropolitan area, the park functions as coastal protection for the hinterland. So the second objective was to ensure that the densely populated areas near the coast are protected against flooding. Hence, on the new beach islands an embankment of sand dunes was erected that serves as a dike. The dike continues around the harbours thus protecting the adjacent land against flooding.

3.3 Technical measures

3.3.1 Type

Original situation

- **Land reclamation area**

The beach park in the Køge Bay, south of Copenhagen, is an artificial landscape created in one of Northern Europe’s largest land reclamation projects. The park consists of 7 km of beach, dunes, parking lots, access roads and kiosks. Between the beach and the hinterland are 6 lakes, which are connected with the Køge Bay by sluice gates. The park also includes 4

small harbours. To solve the problem of flooding, dikes and sluices were built to regulate the river outlets.

The park is actually an expansion of natural barrier islands formed in the 20th century in the shallow Bay of Køge (as can be seen in previously shown Figure 3). Between the islands and the coastline shallow lagoon-like areas were formed.

The construction of the Beach Park was started in 1977, at the turn of 1977/78 in all essential it was accomplished. During the following 1.5 years details behind the dike were completed. After that only the harbour facilities still remained, this took another 1.5 years.

- **Groynes**

Three groynes were built in order to keep the sand in place. The groynes made a parallel displacement of the coastline possible. By this manipulation most of the dike length could be placed on the uppermost part of the initial barrier islands. This coastline adjustment also meant that the orientation of the new coast is perpendicular to the direction of the prevailing direction of the incident wave energy. This is very important to minimize the longshore transport of sand.

After completion of Beach Park

- **Filter tubes**

To combat the local erosion, a system of filter tubes was installed on the beach. They should enforce the drainage of the beach during low tide and thus lead to more sedimentation during high tide.

3.3.2 Technical details

Original situation

- **Land reclamation area**

Fig. 5: Land reclamation at Køge Bay.

The backbone of the park is a ca. 7 km long and 300 m wide artificial barrier, built of marine sand, pumped up mainly upon sandy barrier islands. Extensive beach nourishment took place to create the new beaches. The basic idea was to use the sediment taken from the lagoons for this purpose. However, sufficient material was not found in this way. Sample investigation showed that the necessary amount and the right quality could be quarried from the central part of the sea bottom of Køge Bay. To reduce transportation costs, the lagoon areas were extended. In total, 5 million cubic meters of sand were needed for the alteration

of the coastal profile. Of this amount, 3 million was gained from excavation in the lagoon areas and 2 million was dredged from the sea bottom of Køge Bay.

The core of the artificial new coast is a 20 m wide dike, built of sand with a top level of 3 m DNN (Danish Ordnance Datum). The beach in front of the dike was designed to have a width of 45 m with a slope from the foot of the dike to the coastline of 1:20. In Figure 6 cross sections of the original and the artificial coast are shown. The 1977 profile shows the morphology of an initial barrier. In time, the inner near shore has not changed a lot after the Beach Park was constructed.

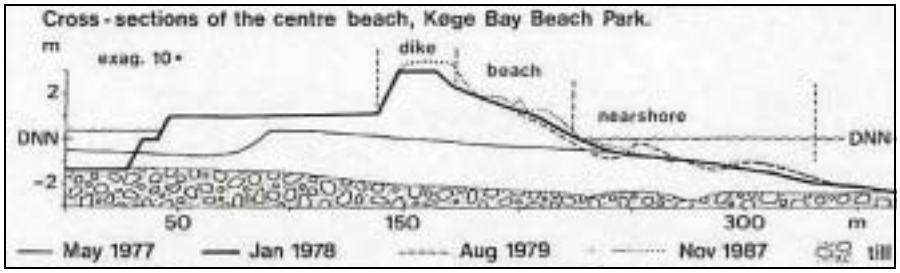

Fig. 6: Cross section of centre beach at Koge Bay Beach Park.

After the artificial new coast was finished, a covering layer of coarse sediment, dredged from the sea bottom of Køge Bay, was placed on the exposed area of both dunes and beach to reduce the marine and aeolian sand transport.

- **Dunes**

Finally, in dike sections where particularly intense traffic was expected, 1-2 m high artificial dunes were created upon the crest of the dike. The dunes provide a buffer of sand and convey some naturalness to the artificial morphology. Also, at the base of groynes and harbour piers, dune-areas were carefully shaped to offer lee-giving points to the benefit of the bathing guests. Besides the scenic values of the coastal landscape, these dunes are meant for emergency sand depots in case the sea threatens the dike system.

Fig. 7: View of Køge Bay Beach Park, towards the southwest.

The shore and the dune were built of sand; the area behind the dune row was formed of material of a finer texture, the uppermost 30 cm mixed with clay to improve growth conditions for the plants. The dunes with their slopes were planted with *Ammophila arenaria*. The area behind the dune row was partly planted with trees and shrubs, partly sown with a mixture of grasses. After the period of establishment in 1977-1980, where the planted and sown areas were fertilized and controlled, the area was mainly given to spontaneous vegetation developments. At the beach, in front of the dike and on the wide backshore, natural large dune formations have developed for example after the completion of the Beach Park.

- **Groynes**

The three groynes have a length of 175 m.

- **Lagoons**

To preserve the inherent environment, lagoons should still contain salt water after establishment of the Beach Park. To avoid stagnant water, automatic sluices were provided to force the water circulation in a one-way direction through the lagoons. The sea water is led from the central harbour area (Vallensbaek) into the lagoons both towards east and southwest during situations with higher water level in the sea than in the lagoons. Thus with water levels above +0.3 m DNN, the sluices will automatically close. To avoid inundation from river water in long periods with closed sluices, spillovers are established with top levels of +0.5 m DNN. During these events the lagoons are functioning as reservoirs.

When the sea level drops below the level of the lagoon, the lagoon water escapes through sluices located at Hundige and Broendby harbours. Recordings and calculations of the hydrography show that, with a daily sea level variation of 0.1 m, a total exchange of lagoon water would take place during a two-week period.

The waterdepth in the originally very shallow lagoons was increased in a zone parallel to the dike for the use of smaller boats like rowing boats, dinghies and wind surfers. In the three eastern lagoons, the bridges leading to the beach got an elevation of 4.4 m and a span of 12 m to allow boat-racing.

In many places the landwardside of the lagoons is preserved as salt marsh areas and reed swamps. Consciously, these areas are made difficult to penetrate to secure quietness for the wildlife, especially the birds of passage which in great numbers rest at this locality.

After completion Beach Park

- **Filter tubes**

The filter tubes consist of ca. 2 m long vertical tubes, which are perforated at their lower part. At the Strandparken beach they are installed in 5 profiles with two tubes each and a distance of 70 m between the profiles.

3.3.3 Costs

Total expenses (excluding the harbours) in 1980 prices was 20 million US dollars, also € 21 million.

4. EFFECTS AND LESSONS LEARNT

4.1 Effects related to erosion

Original situation

Investigations at the coast indicate no structural retreat of the coastline; the nearshore terrace appears relatively stable with an even positive trend in material exchange. Investigations along a transect shows, that the relief in the inner part of the dune and behind it, remained fairly unchanged, but in front of the dune the relief changed very markedly. The planned 45 m broad beach, unusual for the landscape in Køge Bay, changed into a normal beach of approximately 10-15 m width over its whole length. It is bordered by an almost continuous and marram grass covered mobile dune ridge, formed from marine deposits by aeolian transport.

Erosion was seen in the north of the island belt, where a harbour with jetties causes leeside erosion. This is a local problem.

After completion of Beach Park

A septic attitude towards the effect of the installed filter tube system to combat the leeside erosion is stated. It could not be proved that they contribute to an increased sedimentation. German delegates doubt the effectiveness of the system, because a draining effect normally can only be seen 0.5 to 1.5 m around tubes of this size. Furthermore, the tidal range of 0.1 m at this location is considered to be much too low to cause a considerable effect.

Fig. 8: Lee-side erosion and filter tube system at Koge Bay.

4.2 Effects related to socio-economic aspects

The creation of the Beach Park has effected recreation and nature functions:

Recreation

The following recreational facilities were created by the construction of the Beach Park: 5000 ha recreational area, 8 km of sandy bathing beach and 4 harbours with capacity to 5000 pleasure boats.

Nature

Nature was preserved and enhanced by the creation of the Beach Park. The salt marsh areas and reed swamps are kept quiet and reserved for nature development and wildlife. Furthermore, the dune areas are left to spontaneous natural development. The dunes on top of the dike and in the sand depots today look amazingly natural-like with their cover of aeolian-sorted sand, caught by the dense carpet of lyme grasses. The dune forms have been modeled by wind. The creation of dunes was a success. The wind-borne material did not escape into the lagoons or the sea, but remained where it belongs to: the dune area.

A precondition to preserve the original vegetation in the lagoon is a frequent addition of salt water. Here some problems have turned up, as the mean water level in the sea during the months of autumn is normally +0.3 m DNN, i.e. the level at which the sluices automatically close. Long periods with closed sluices have revealed that the river dikes are too low, and several times the water levels in the rivers have exceeded the spill-overs. In such situations the lagoons receive an undesired amount of fresh water.

4.3 Effects in neighbouring regions

A considerable accretion has taken place on a 3 km long coastal stretch southwest of the beach park. Several barrier islands and lagoons have emerged, and in some sections the coastline is displaced more than 100 m in a seaward direction. The major disadvantage from this development is that sea weeds of different kinds are swashed into the lagoons during storm situations and infect the air when rotting in the stagnant water. Another complaint from the landowners is the reduced sea-view from their houses. However, it is not known, if this results from the beach park itself or if it's a natural barrier development, just started during the time, when the beach park was built.

Of course the creation of the Beach Park must have caused a great impact on the surrounding environment, but the recreational value must be regarded so high that it was motivated. It made the coast and sea available for all the citizens in Copenhagen.

4.4 Relation with ICZM

Interesting things about this project are the planning process (the authorities, municipalities etc. that have been involved and how), how the "Strandparken" was financed (Copenhagen city and some of the surrounding municipalities etc. have contributed to the costs) and how at least two main problems (recreation facilities combined with coastal defence measure) were solved by co-operating.

In the planning phase there have been several complaints against the project by local residents as well as by environmentalists. While environmentalists feared the loss of

biotopes for sea birds, local inhabitants feared their free access to the beach. The project has been planned since the thirties and was conducted during the seventies. Maybe today more participatory planning instruments would have been used which could have avoided some complaints. Especially for such large projects like Strandparken, participatory planning tools or at least early information about the consequences of the project are recommended in order to achieve an early acceptance of planned measures.

It seems important to consider environmental aspects at an early stage in order to avoid conflicts with nature conservation goals. However - regardless if it is a result of the complaints or of wise planning - after two decades it turns out that the park has become a recreational area as well as a nature reserve with many different nesting and migrating birds.

Another interesting aspect is the management of the vegetation. Only typical vegetation from very similar locations was planted and managed in a way that keeps the park in a most nature-like manner. However, it would have been an idea to leave some parts of the park over to nature and let free succession of the vegetation take place**.** Furthermore there are good public relations activities at the Beach Park.

4.5 Conclusions

Effectiveness

Coastal defense measures and tourism development can often be combined, as shown in the example of the Beach Park at Køge Bay south of Copenhagen. The Beach Park can be seen as a good example for the combination of flood protection and the development of tourist infrastructure. It also can be seen as a perfect example of how it can be possible to work together with natural processes to create a stable and low maintenance demanding structure, but also at structure that serves to purposes - both as flood protection and as recreational area for a metropolitan area.

A very important explanation for the success of this large-scale coastal interference is due to the fact that its design was based upon the character of the original morphology. When evaluating this thorough change of coastal landscape it should finally be noticed that nature environmentalists only have had very few critical objections to the project.

Possible undesirable effects

Observed undesirable effects of the Beach Park are:

-Pollution in the lagoons when water is stagnated.
-Too much fresh water in lagoons during long periods with closed sluices, affecting the present vegetation.
-The accretion southwest of the Beach Park, causes pollution in the originated lagoons and reduce the sea-view of landowners in the area. However it is not clear whether this is a natural development or it is caused by the presence of the Beach Park.

5. REFERENCES

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Figures:

Figure 1: http://www.icm.noaa.gov/country/denmark.html
Figure 2: http://www.coastalguide.org/dune/index.html
Figure 3: http://www.coastalguide.org/dune/index.html
Figure 4: http://www.kms.dk/landetrundt/danmarkskort/d1513.html
Figure 5: http://www.coastalguide.org/dune/index.html
Figure 6: http://www.coastalguide.org/dune/index.html
Figure 7: PROCOAST Final Report
Figure 8: PROCOAST Final Report