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RISK ANALYSIS OF COASTAL NOURISHMENT TECHNIQUES (RIACON)

FINAL EVALUATION REPORT

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in cooperation with

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Contents

General introduction

Beach nourishment to combat coastal erosion and loss of public amenity has been a common practice in many countries having a sandy coastline. Relatively recent developments in the field of coastal protection measures are shoreface nourishment alone or a combination of shoreface nourishment and beach nourishment. An overview of shoreface nourishment project in the world is given in the report on the results of the NOURTEC project (NOURTEC, 1997).
The advantage of shoreface nourishment above beach nourishment is that the works will not directly interfere with the recreational use of the beaches. Moreover, execution of shoreface nourishment can be done largely outside the tourist season and is therefore of great economic interest. As shoreface nourishment implies deposition of a body of sand in a shallow coastal area this may have an impact on the ecological importance of the shoreface because of the occurrence of phytobenthos communities (*e.g.* seagrass beds) or rich zoobenthos communities which form the basis of a more extensive and biodiverse coastal food web including fish (commercial and non-commercial) and diving seabirds.

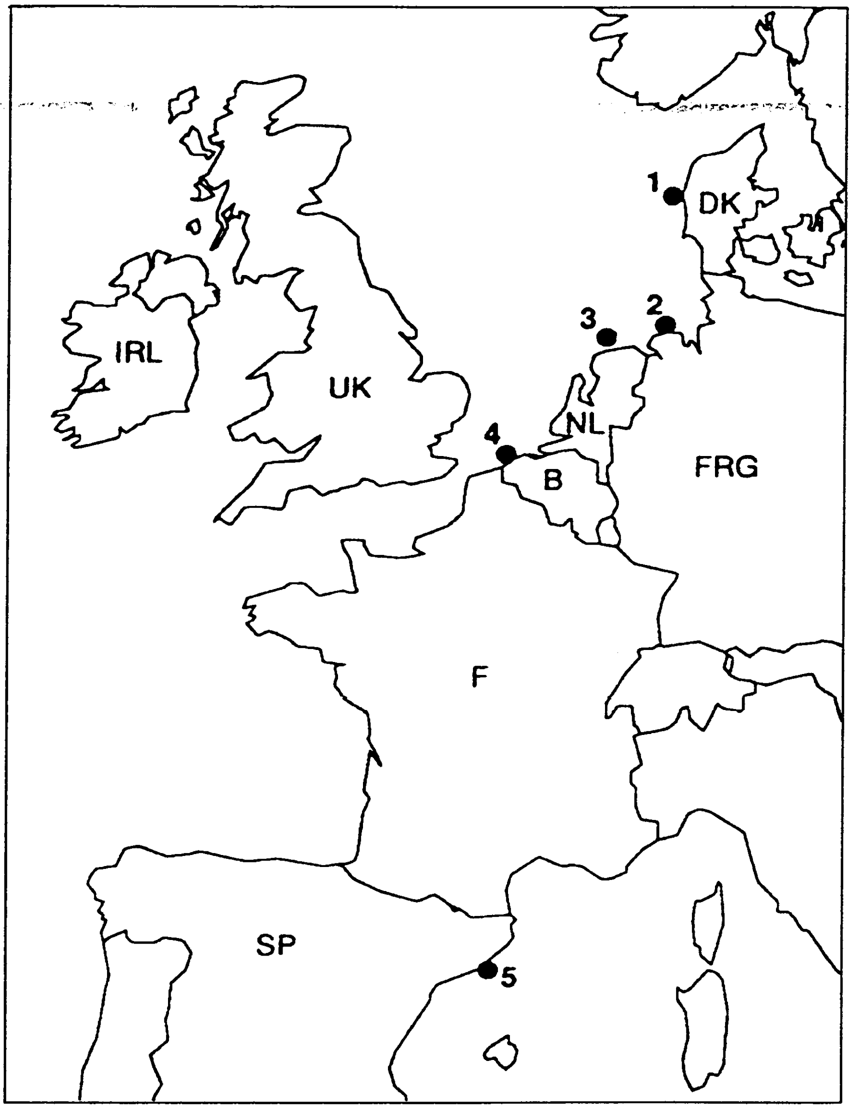
Of course, the sand necessary for the nourishment has to be borrowed from elsewhere. This may be relatively near the shore or, alternatively, more remote at greater depth. The acceptability of such subaqueous sand extraction depends on at least two factors. Firstly, nearshore extraction may interfere with the sand balance of the coast, and therefore with the maintenance of the coastline. Secondly, sand extraction will have an impact on the ecological functions of the seabed, such as habitat for benthic flora and fauna, and feeding grounds for (juvenile) fish and diving seabirds.

Within the MAST-II (1990-1994) programme of the Commission of the European Communities risk evaluation studies and research on the understanding of the underlying processes permitting prediction and avoidance of damage were stimulated. To study the ecological risks of the installation of coastal protection measures such as shoreface nourishment the RIACON-project was formulated: Risk Analysis of Coastal Nourishment Techniques.

The principal objective of the RIACON project was to evaluate the risk of shoreface nourishment and subaqueous sand extraction for the marine zoobenthic community of the foreshore, including seagrass bed communities in the Mediterranean Sea, and its consumers higher up in the food web. The risk of shoreface nourishment was evaluated through studies at the three sites of the NOURTEC project, *viz.* The Netherlands, Federal Republic of Germany, Denmark, as well as at two other sites, *viz.* Belgium and Spain (Costa Daurada, Catalunya) (Fig.1). Possibilities to include studies on the effects of subaqueous sand extraction were available in Denmark, The Netherlands and Spain.

The reason for linkage of the RIACON-project to the NOURTEC-project was obvious. The object of the NOURTEC-project was to study the behaviour of sand nourished to the shoreface, and assess the

Fig. 1.
Location of the sites studied in the RIACON project.



1. Torsminde Tange, 2. Norderney, 3. Terschelling, 4 De Haan,
5. Costa Daurada.

effectiveness of this method as an alternative to the common practice of beach nourishment. In this way, the NOURTEC-project was able to provide much of the sedimentological and hydrodynamical background information necessary for an ecological impact study such as to be carried out in the RIACON-project. Linking-up of RIACON with NOURTEC, therefore was of good cost benefit.

The general approach in the RIACON-project was
1) to study the response (decrease and recovery) of the zoobenthic community at five sites of shoreface nourishment along the coasts of the North Sea (Denmark, Germany, The Netherlands, Belgium) and the Mediterranean Sea (Spain),
2) to study the response (decrease and recovery) of the benthic community at three sites of sand extraction (borrow sites) needed for shoreface/ beach nourishment (Denmark, The Netherlands, Spain), and
3) to interpret the obtained results in terms of the risks for consumers of the (zoo)benthic community, such as juvenile fish and diving seabirds.

In Spain, special attention was given to the *Posidonia* community (seagrass beds).

In this Final Evaluation Report an integration will be presented of results as obtained in the five national studies within the RIACON-project (BIRKLUND *et al.*, 1996; MANZANERA *et al.*, 1996; LE ROY *et al.*, 1996; GROTJAHN & LIEBEZEIT, 1997; VAN DALFSEN & ESSINK, 1997). For details, the reader is referred to these national evaluation reports. This report consists of two text parts. In Part A the effects of shoreface nourishment will be presented. Part B deals with the effects of subaqueous sand extraction. In Part C the cited literature references are listed. A more extensive citation of the literature can also be found in the national evaluation reports.

Part A

Ecological risks of shoreface nourishment

A.1 Introduction

Beach nourishment to combat coastal erosion and loss of public amenity has been a common practice for long in many countries with a sandy seashore. Large amounts of sand have been nourished at an expenditure of tens of millions US dollars per year. Beach nourishment generally requires relatively calm weather to be able to bring sand on the beach, sand mostly being borrowed from the nearby seabed and pumped ashore through pipelines. Due to these practical 'calm weather' constraints beach nourishments may interfere with recreational activities at beaches in spring and summer and, therefore, with economic interests.
A recent development in the field of coastal protection is the application of shoreface nourishment or the combination of beach- and shoreface nourishment. Shoreface nourishment implies deposition of a buffer of sand on the sea floor in front of a beach that is eroding or is threatened to be eroded (*e.g.* VAN HEUVEL & HILLEN, 1991). This buffer is intended to supply the beach with sand, in this way providing compensation for erosional loss of beach over several years. The feasibility and effectiveness of shoreface nourishment has been subject of a morphological and sedimentological co-operative study (NOURTEC) within the MAST-II programme and carried out in Denmark, Germany and The Netherlands (*e.g.* KAISER *et al.* 1994).
An important advantage of shoreface nourishment is that it can be done outside the recreational season. Sand nourishments are also cheaper than building and maintenance of dikes. Nourishments also reduce the cost of coastal defence (*e.g.* maintenance of groynes). Shoreface nourishment is considered a realistic alternative for beach nourishment, except for stretches of sandy coast where deep tidal channels are close to the coast, such as at the western end of the islands in the Dutch and Lower Saxonian Wadden Sea (*cf.* ANONYMOUS, 1996).

The shoreface area along sandy coasts usually represents ecological as well as economic values. This shallow zone of the North Sea is relatively rich in benthic fauna (HOLTMANN *et al.*, 1996), providing food for juvenile demersal fish (*e.g.* plaice, sole, turbot), as well as for wintering sea birds (*e.g.* common scoter, eider). In the western Mediterranean Sea, the shoreface of sandy coasts is characterized by ecologically very important seagrass and zoobenthos communities (ROS *et al.*, 1984). Moreover, seagrass as well as zoobenthic communities support local fisheries for bivalve molluscs, *Octopus vulgaris* and fish.

To investigate the ecological risk of shoreface nourishment and shoreface beach nourishment to the coastal benthic communities and its dependent other organisms the RIACON (Risk Analysis of Coastal Nourishment Techniques) project was started in 1994-1996 under the auspices of the MAST II programme of the Commission of the European Communities.

A.2. Methods

A.2.1. Study areas

The study areas chosen are located along the eastern shores of the North Sea as well in the western Mediterranean (Fig. 1). In the North Sea study areas the benthic community mainly consists of several species of polychaetes, bivalve molluscs, small crustaceans and the sea urchin *Echinocardium cordatum*. The benthic community present in the study areas is the 'coastal assemblage' described by KÜNITZER *et al.*(1992) and HOLTMANN *et al.*(1996) which is typical along the eastern shores of the North Sea down to ca. 30 m depth.
At the study site at the Costa Daurada the benthic communities show a clear depth zonation:

0 - 5 m:	coarse sand communities with *Saccocirrus papillocercus* and *Donax* sp.
5 - 10/12 m:	fine sand communities with *Spisula subtruncata*; occasionally, patches vegetated with *Cymodocea nodosa* appear below 10 m depth.
10/12 - 20 m:	beds of the main Mediterranean seagrass species *Posidonia oceanica*, which formerly extended down to 23-24 m, but at present have regressed and narrowed its bathymetric range.

These communities can be considered typical for the sandy shores in the Western Mediterranean (ROS *et al.*, 1984).

In Table 1 an overview is presented of the major characteristics of the nourishments carried out in the different study areas. In Torsminde, Norderney and Terschelling these nourishments were also studied in the framework of the NOURTEC project (NOURTEC, 1997).

The environmental conditions present in the study areas as well as some main characteristics of the benthic communities present are given in Table 2.
The differences in Northern latitude between the study areas imply differences in extreme winter temperatures, and therefore, differences in winter mortality of species sensitive to low temperatures (BEUKEMA *et al.*, 1988).
During storms the study areas will be exposed to waves and currents causing increased along-shore and cross-shore sediment transport. Along the Costa Daurada southerly storms cause considerable along-shore sediment transport in an otherwise rather stable environment.

In the species composition of the North Sea study areas a fair amount of r-strategists are present. These species with an opportunistic life strategy can be considered as an adaptation to the relatively dynamic environment of changing position of breaker banks and troughs, especially in situations of exposure to storms. In the Costa Daurada area the long-lived seagrass species are the basis of a rather stable community, with major natural stress as a results of sand transport due to southerly storms during winter.

A.2.2. Research approach

In the North Sea nourishment studies repeated surveys of the macrozoobenthos were made, before and after nourishment, both in the actual nourishment area as well as in reference areas. Numerical densities and biomass (ashfree dry weight) of species and taxa were assessed. Additional information was obtained by determining age and/or size composition of major species (only in the Terschelling case). The structure of the benthic community and changes therein was described by means of clustering techniques.
Along the Costa Daurada emphasis was laid on repeated cartographic surveys of Posidonia beds and additional field experiments on the effects of simulated sedimentation and burial of Posidonia. Also a predictive model for the risk of sedimentation in seagrass beds was developed.

Table 1.
Major characteristics of the nourishment operations executed at the five RIACON study areas.

	Torsminde (DK)	Nordemey (D)	Terschelling (NL)	De Haan (B)	Costa Daurada (ES)
nourishment	deeper shoreface	beach shallow shoreface deeper shoreface	deeper shoreface	deeper shoreface	beach shallow shoreface
area nourished	0.24 km^2	2 km beach ca. 0.26 km^2	1.7 km^2	ca. 1 km^2	12 km beach ca. 1 km^2
volume of sand	250,000 m^3	350,000 m^3	2,100,000 m^3	525,000 m^3 (2^{nd} phase)	2,625,000 m^3
duration/time of nourishment	32 days May 1993	ca. 1 month April 1992	6 months Apr-Nov. 1993	3 periods in Feb-91 / Sep-94	3 months Oct-Dec. 1983
thickness of nourished layer	1.1 m	beach: 0 - 2 m shoreface: 2 m	max. 3 m	1 - 3 m	beach: 1.5 m shoreface: 1 m
grainsize (Md_{50})	500-600 µm	150-200 µm	180-215 µm	ca. 200 µm	215-555 µm

Table 2.
Overview of main environmental conditions and characteristics of the benthic communities in the five RIACON study areas.

	Torsminde (DK)	Nordemey (D)	Netherlands (NL)	De Haan (B)	Costa Daurada (ES)
Geogr. latitude	56° 25' N	53° 43' N	53° 25'N	51° 20' N	41° 00' N
Water depth	4 - 6 m	0 - 4 m	5 - 8 m	2 - 4 m	14 - 16 m
Grainsize (Md_{50})	400 µm	beach: 300-600 µm shoreface: 130-180 µm	165-180 µm	ca. 180 µm	215 µm
Sea floor	breaker bars and troughs	breaker bars and troughs	breaker bars and troughs	slope with sand wave	stable slope
Wind exposure	SW - N	SW - N	SW - N	NW	SW - E
Species composition of the benthic community	dominated by crustaceans and polychaetes	beach: *Scolelepis* shoreface: more k- than r-strategists	both k- and r-strategists	80% polychaetes, mainly: *Nephtys cirrosa* *Magelona pap.*	persistent seagrass *Posidonia oceanica*
Long-lived species	bivalve molluscs	bivalve molluscs	bivalve molluscs *Echinocardium*	bivalve molluscs (*Macoma balthica*)	*Posidonia oceanica*
species of commercial interest	plaice, sole	brown shrimp	brown shrimp *Spisula* sp.	brown shrimp	fish, bivalves, crustaceans

A.3. Results

A.3.1. Type of nourishment operation

With regard to the risk to the benthic communities of coastal nourishment operations, it is first of all important what type of nourishment operation we are dealing with. The following types of operation can be distinguished:

- o beach nourishment
- o shallow shoreface nourishment
- o deeper shoreface nourishment

Within the RIACON project beach nourishment was included in the studies in Germany (Norderney) and Spain (Costa Daurada). In the case of sandy beaches situated between the low and high water mark nourishment may trigger an opportunistic response of a single (or a few) species capable of rapidly colonizing the newly nourished and not yet stabilized sediment. Along the beaches of the North Sea, *i.e.* in the temperate climate zone, this may cause a rapid colonization by juvenile polychaetes with a similar life style as *Scolelepis squamata* (GROTJAHN, 1997). In the case of non-tidal sandy beaches, such as present in the Mediterranean, the beach is a terrestrial rather than a marine habitat. In this case, effects on marine benthic communities pertain only to those situations in which beach nourishment causes sedimentary changes (*e.g.* burial) in the shallow shoreface. The RIACON studies along the Costa Daurada have shown that the risk of damage to seagrass beds is very high in the 0 - 7 m depth range. Especially at the upper limit of its distribution, the seagrass biocoenosis may be at risk due to a downward spreading of sedimentation as a consequence of beach nourishment (MANZANERA *et al.*, 1996).

At the shallow and the deeper shoreface, benthic communities occur that may be affected by nourishment. The shoreface habitat studied in the North Sea sites in the RIACON project varies in depth between 0-2 m below the low water mark and ca. 8 m of mean water depth. In general, the benthic community of this shoreface habitat is relatively poor in species. This habitat is characterized by natural dynamics due to an interplay of tidal currents and (breaker)waves. Short-term effects on the benthic community were in general terms a decrease in species abundance and in zoobenthic biomass. This effect was most clear in the deeper study sites (Torsminde/DK, Terschelling/NL) (BIRKLUND *et al.*, 1996; VAN DALFSEN & ESSINK, 1997) and less clear in the more shallow sites (De Haan/B, Norderney/D) (LE ROY *et al.*, 1996; GROTJAHN, 1997), the latter being due to a high variability in the zoobenthic parameters measured which mirrors the variability and dynamics of the abiotic environment (KROON *et al.*, 1995).
In the Mediterranean, seagrass beds form a habitat of outstanding ecological importance, providing niches for a great variety of species (plants and animals) and ecological functions. In the non-vegetated areas in between the seagrass beds macrozoobenthos may be of importance to local fisheries. The studies carried out at Costa Daurada showed that the risk for seagrass beds due to beach nourishment decreases with increasing

depth. The risk of sedimentation in seagrass beds (risk of burial and consequent die-off) due to beach nourishment is strongly mediated by local hydro/sediment dynamics and can be prognotized by a predictive model that was developed (MANZANERA *et al.*, 1996).

A.3.2. Type of sediment nourished

Nourishment operations may use sand that has the same or a different grainsize composition as the original sediment present at the nourishment site. Apart from risks for the design and execution of a nourishment operation due to the use of a different (finer or coarser) sediment (ANONYMOUS, 1995) also ecological risks may be involved as a consequence of specific sediment type preferences of specific species among the macrozoobenthos. Characteristics of the original and nourished sand within the RIACON project are listed in Table 3.

Table 3.
Median grainsize (Md_{50}, µm) of original and nourished sand in the five RIACON study areas.
B = beach, S = shoreface

	Torsminde (DK)	Nordemey (D)	Netherlands (NL)	De Haan (B)	Costa Daurada (ES)
Original sand	S: 300	B: 300-600 S: 130-180	S: 165-178	S: ca. 180	B: 215
Nourished sand	550	150-200	ca. 180	ca. 200	180-520

In general, at all the RIACON study sites the nourished sand was a little coarser than the original sand. Only in the case of the beach at Norderney, having a rather coarse sand (Table 3), the nourished sand was significantly finer. Around the high water mark it took about one year for the sediment to regain the pre-nourishment grainsize composition, whereas at the lower part of the beach the fine sand remained in place until summer 1995. At the low tide level, where grainsize composition of the sediment is very variable, it is not likely that occurrence of finer grainsizes here are due to the nourishment that was carried out.
Along the eastern margins of the North Sea, being exposed to the prevailing SW-NW winds, the interplay of tidal currents and wave climate cause a fairly great morphodynamics in the shoreface area. As a consequence, the original morphological features of ridges and runnels or breaker banks and troughs can be expected to return at a relatively short time scale. This dynamics of the seabed includes sediment transport leading to an exchange of nourished sand with that of the surroundings of the actual nourishment site. The effect of this sediment transport phenomenon is clearly illustrated in the disappearance of enhanced median grainsize in the nourishment site off Terschelling (NL) within six month after completion of this nourishment operation (VAN DALFSEN & ESSINK, 1997; NOURTEC, 1997).

The benthic community of the shallow coastal zone along the eastern shores of the North Sea is composed of species that are largely adapted to the kind of seabed dynamics just described. In other words, these species have a relatively wide ecological tolerance with respect to sediment characteristics such as median grainsize, sediment sorting, mud content of the sediment and temporal variations of these environmental conditions. This is reflected in a coherent 'coastal' benthic community as described by KÜNITZER *et al.*(1992) and HOLTMANN *et al.*(1996). The consequence of this is that no significant effect of shoreface nourishment on macrozoobenthos is to be expected related to the different sediment characteristics of the nourished sand. The only possible exception may occur when the nourished sand is much coarser (or finer - what is unlikely to occur in coastal nourishments) than the original sediment. The major risk for the zoobenthic community will rather be related to the effect of burial under the body of sand nourished (see below).

In the case of nourishments as occur on Mediterranean beaches, the risk for the benthic community is greatest where seagrass beds are present at shallow depths close to those beaches. A coarse sand deposited on a beach is less likely to be transported to lower levels of the shore than a fine sand. Parallel to this are differences regarding the risk of exerting detrimental effects on seagrass beds and their associated fauna as a consequence of increased sedimentation leading to growth reduction and mortality of seagrass plants.
The risk to the benthic community will vary from place to place as different part of the coast will have a different exposition towards storms. This relates to a different 'energy content' of the prevailing southwesterly and easterly winds. In the Mediterranean study area, easterly winds are the most frequent and powerful ones. Due to the approximate East-West orientation of the coastline, however, southerly winds are the most likely cause of beach erosion, and hence of damage to seagrass beds (MANZANERA *et al.*, 1996).

A.3.3. Scale and rate of sand deposition

In terms of volume of sand deposited and surface area covered with sand the five nourishment cases do differ considerably, as is presented in Table 1. The impact on the benthos, be it flora or fauna, is first and for all determined by the thickness of the body of sand that is deposited. In the North Sea nourishment sites the layer deposited was 1-3 m thick, implying that practically all originally present benthic fauna could not survive. Only few species are known to be able to survive sediment deposition up to ca. 60 cm. Among these are Tellinid bivalves, *Ensis directus*, *Nephtys* sp. and *Asterias rubens* (see BIJKERK, 1988). Such an impact is expected to occur in all nourishment cases where the thickness of sand deposition surpasses the extent of sedimentation that may occur under natural conditions in these hydro/morphodynamic habitats.

In Mediterranean seagrass beds, however, only slight (centimetres rather than decimetres) and short lasting sand deposition in beds of *Posidonia oceanica* will cause shoot mortality (MANZANERA *et al.*, 1996). In fact, seagrass beds are much more sensitive to sedimentary events than most macrobenthic infauna living in North Sea coastal habitats.

Consequently, along the sandy shores of the North Sea the impact of shoreface nourishment will to a large extent be determined by the spatial scale of sand deposition. The larger the area covered with sand, the larger the effect will be on demersal (young) fish feeding on the bottom fauna. Where locally rich stocks of bivalves such as *Spisula subtruncata* occur, these resources for wintering common scoters and eider ducks will be put at risk by shoreface nourishment.
In the Mediterranean Sea the risk for seagrass meadows is largely determined by the design and extent of the nourishment operation. In beach nourishments as studied in the RIACON project the risk of damage is very high for any seagrass bed occurring at depths less than ca. 7 m. Local conditions of seagrass bed occurrence, beach-shoreface profile, granulometric distribution over the profile and hydro/morphodynamics due to the natural wave climate will modify the degree of impact (MANZANERA *et al.*, 1996). In any case, if one would apply nourishment of the shoreface, as done in the North Sea, along Mediterranean beaches, this would certainly imply a much greater risk to the seagrass beds, impairing the ecological and economical significance of these communities.

For neither of the cases of shoreface nourishment studied in the North Sea and Mediterranean Sea accurate information on the rate of sand deposition (*e.g.* in cm per day) was registrated. If the loads of hopper dredgers would have been deposited well spread over a large seabed area then many macrozoobenthos species would have been able to survive these conditions of more or less continuous sedimentation (*cf.* BIJKERK, 1988). The common practice of shoreface nourishment with sand hopper dredgers, however, is that these dredgers empty as quickly as possible after arrival at the nourishment site. So, gradual deposition of sand does not occur; the macrobenthos has to cope with instantaneous coverage by a body of sand. Only in the case of beach nourishments as carried out at the Costa Daurada (Spain), a more or less continuous higher sedimentation rate may occur due to wave and current induced dispersal of a part of the nourished sand towards the shoreface. There, a real risk of damage to seagrass beds is present due to the observed sensitivity of *Posidonia oceanica* to even low sedimentation rates (MANZANERA *et al.*, 1996).

A.3.4. Impact on and recovery of the benthic community

A.3.4.1. Short-term effects

The studies along the nourished beaches of Costa Daurada (Catalunya, Spain) showed no direct effect of beach nourishment on the local seagrass beds, except for a not expected slight increase of rhizome growth of *Posidonia oceanica* which may be a result of sedimentation of fines including organic matter. Experimental work, however, showed that increasing sedimentation of sand leads to a decreasing number of shoots and increasing plant mortality. A predictive model was developed using hydrodynamic, morphological and granulometric information to calculate the expected extent of increased sedimentation in seagrass bed areas resulting from nourishment operations. With help of this model the direct risk for seagrass beds due to deposition of sand can be estimated (MANZANERA *et al.*, 1996).

At the nourishment sites studied in the North Sea, the general finding was that the deposition of a body of sand on the shoreface initially led to a reduced abundance and biomass of zoobenthic species. Also the species diversity decreased and the structure of the zoobenthic community departed from the one present before the nourishment started. After completion of the nourishment, in some of the sites a strong development of opportunistic species (*e.g. Scolelepis squamata*) was observed (GROTJAHN & LIEBEZEIT, 1997).

A.3.4.2. Longer term effects and recovery

Approximately one year after nourishment at the North Sea sites recovery of the zoobenthic community was already in progress. By the end of the project, *i.e.* after two years, densities, biomass and diversity had largely regained pre-nourishment values. The community structure in the nourished areas was not longer very different from the one in the reference areas. In the reference areas of the nourishment sites the abundance, biomass, diversity and community structure showed much less changes over time. The study carried out at De Haan (Belgium), in which different consecutive phases of nourishment were involved, indicates that ca. 2 years after a nourishment the benthic community is again quite similar to the one in the reference area. In general terms, a fair recovery of abundance and biomass was achieved 1-2 years after completion of the nourishment.
In long living bivalve and sea urchin species, however, no such recovery was observed. Though recruitment occurred during the reproduction season after the nourishment operation, the population structure was unbalanced due to absence of older year classes (VAN DALFSEN & ESSINK, 1997). As these species do not reproduce successfully every year, recovery may take more time, probably 2-5 years.

In case of damage to *Posidonia* beds, recovery of this very slowly growing plant, and therefore also of its associated fauna, will take 100 years or more.

A.3.5. Risk to consumers of the benthic fauna

Along the North Sea shores the risk for consumers of benthic fauna due to shoreface nourishment mainly consists of a temporary reduction of food resources for juvenile fish (mainly eating polychaetes and crustaceans) and diving ducks (eating *Spisula subtruncata*, *Donax vittatus* and other bivalves). The risk for diving ducks which during their winter stay very much depend on these bivalve resources is dependent on whether nourishment affects one or more beds of these major bivalves occurring along the coast. This picture, however, can not simply be generalized to all shoreface areas of the North Sea. In the Belgian study area the only bivalve that could serve as food for diving ducks was *Macoma balthica*. This species showed an increase in abundance at the old feeder bar as compared to the reference area, suggesting improved settling and living conditions for *Macoma balthica* at this specific part of the shoreface (LE ROY *et al.*, 1996).

Along the Mediterranean shores the seagrass beds play an important role as feeding ground and habitat of commercially exploited species (fish, crustaceans, molluscs). Therefore, damage brought to seagrass beds due to nourishment operations would certainly have significant socio-economic impacts, not only through fishery but also through tourism (MANZANERA *et al.*, 1996).

A.4. Discussion and Conclusions

A.4.1. Shoreface nourishment in the North Sea

As a short-term effect of shoreface nourishment at the North Sea study sites a reduction of abundance and biomass of species was found. On the basis of information found in the literature (see review by BIJKERK, 1988) one would have expected an almost complete disappearance of the original benthic fauna as a result of deposition of a body of sand of 1-3 m thickness. In the first surveys after completion of the nourishment, abundance, biomass and species diversity had indeed decreased but not to a great extent. Therefore, it is concluded that recovery did proceed rather fast. One possible way of recovery is the import of live benthos with sand from the borrow site. However, this is not considered to play an important role. More important in the hydro/morphodynamic system of ridges and runnels (Belgium) and breaker banks and troughs (Netherlands, Germany and Denmark) is the immigration of specimens from the direct surroundings of the nourished area. Only in the further process of recovery settlement of recruits becomes important.

Although at the North Sea sites nourishment caused a disturbance of the sea bed sediment in the nourished area, there was not a significant development of opportunistic species, such as been observed after dredging operations in La Coruña Bay and after oil pollution in the Bay of Morlaix (SOUPRAYEN *et al.*, 1991). Only a moderate response of opportunistic species was observed, *viz. Scolelepis squamata* at the beach nourishment at Norderney (D). The reason for this may be that in the case of the disturbance due to nourishment no organic enrichment of the sea bed occurred as may occur to some extent after dredging or oil pollution.

For most of the species, abundance and biomass had largely recovered already ca. 1 year after completion of the nourishment. Long living species, such as bivalves (*e.g. Spisula subtruncata, Donax vittatus*) and sea urchins (*Echinocardium cordatum*) showed a much slower recovery. For these species, that do not reproduce successfully each year, recovery of total biomass and a normal age structure is considered to take 2-5 years.

In the North Sea coastal zone many demersal fish prey on benthic fauna. Directly after nourishment these fish experience loss of feeding habitat in the nourished area. In view of the quick recovery of the benthic fauna and of the relatively small size of nourishment areas in comparison to the coastal feeding ground habitat for demersal fish the risk of shoreface nourishment to demersal coastal zone fish is considered negligible unless the spatial scale of shoreface nourishments is much larger than in the four cases studied.

A more serious risk of shoreface nourishment relates to diving ducks, such as the common scoter (*Melanitta nigra*). These birds are known to feed especially on banks of the bivalve *Spisula* sp. Therefore, any shoreface nourishment that buries banks of these bivalves under a body of sand will during the following winters affect the food resources of these ducks. An inventory of occurrence of bivalve banks at intended shoreface nourishment sites will therefore give insight into the possible impact on wintering ducks.

A.4.2. Beach nourishment in the Mediterranean Sea

Beach nourishments such as the one carried out on the Costa Daurada that was studied within the RIACON project are not very likely to affect seagrass beds that may be present in the foreshore. If, however, a beach nourishment causes increased sedimentation at depths where seagrass beds are present then the seagrass *Posidonia oceanica* will prove to be very sensitive. The result will be shoot mortality due to burial of the leaf meristem and eventually decline of the vegetated area. Only in the case of very slight sedimentation the *Posidonia* rhizomes can counteract burial by increasing their vertical growth rate up to 2-3 cm per year.
The model that was developed to predict the probability of such burial events during and after beach nourishment may prove to be a useful tool for choosing the best design of beach nourishment, *i.e.* the design with the least possibility of affecting seagrass beds. The recovery potential of *Posidonia oceanica* after burial by sediment has to be considered as very low. Furthermore, as seagrass beds play an important role as feeding ground and habitat of commercially exploited species (fish, crustaceans, molluscs), application of the precautionary principle is of great importance to protect Mediterranean seagrass beds against possible damage due to beach nourishment operations.

A.4.3. Climatological constraints

The differences in Northern latitude between the study areas imply climatological differences, especially with regard to extreme winter temperatures. For the Terschelling and Norderney study areas, during severe winters the vicinity of the very shallow Wadden Sea may cause the water temperatures in the coastal zone to drop to values well below zero (down to -1.5°C) up to ca. 15 km off shore (BEUKEMA *et al.*, 1988). Such a strong 'cooling down' effect was not found along the Dutch mainland coast South of the Wadden Sea. This implies that for the Torsminde study area, cooling down during winter will be less extreme than along the North Sea shore of the Wadden Sea islands. In the study area at De Haan (B) winter temperatures will be higher than at Terschelling (VAN DER HOEVEN, 1984). During the last century ice occurred only once at De Haan. These latitudinal differences in winter temperature may cause significant differences in the survival of macrozoobenthic species as was shown by BEUKEMA *et al.* (1988). At the Costa Daurada low winter temperatures seldom cause problems for the benthic communities.

Part B

The ecological risks of subaqueous sand extraction

B.1 Introduction

The ecological effects of sand extraction at the borrow sites were studied in three sites, *viz.* in Denmark, The Netherlands and Spain. These borrow sites were situated at some km distance from the nourishment areas. The sand for nourishment was obtained by trailer suction hopper dredgers. In the process of sand suction dredging sand and infauna is removed from the site. In this process animals are easily damaged.
The purpose of inclusion of a study at the borrow sites in the RIACON project was to provide new information on the ecological effects of this anthropogenic activity on the local benthos. In the Spain, attention was also given to the possible effects on nearby seagrass beds.

B.2 Methods

B.2.1. Study areas

The study areas were situated at less than 10 km distance from the shoreface nourishments sites Torsminde (DK), Terschelling (NL) and Costa Daurada (ES). The sand was borrowed at a depth of 14-20 m (Spain), 16-18 m (Denmark) and 20-23 m (Netherlands).

At the North Sea borrow sites, the benthic community can be characterised as the 'coastal assemblage' described by KÜNITZER *et al.*(1992) and HOLTMANN *et al.*(1996) which is typical along the eastern shores of the North Sea down to ca. 30 m depth.

At the Costa Daurada two neighbouring borrow sites (B and C/D, see MANZANERA *et al.*, 1996) were used. The benthic communities present in this area are characteristic for the infralittoral of the western Mediterranean (ROS *et al.*, (1984; see also Part A of this report). Seagrass beds, present in the borrow area at the beginning of this century were not present any more after successive regressions during the last decades . A traditional fishing for molluscs (*Murex* sp. and *Callista chione*) is carried out, especially from the harbour of Vilanova i la Geltrú (MANZANERA *et al.*, 1996).

In Table B.1. an overview of the main characteristics of the different borrow sites is given.

Table B.1.
Main characteristics of the borrow sites studied in the RIACON project.

	Torsminde (DK)	Terschelling (NL)	Costa Daurada (ES)
area studied	1.7 km^2	4.15 km^2	
area affected	0.5 km^2	1.4 km^2	ca. 1.5 km^2
volume extracted	250,000 m^3	2,100,000 m^3	2,625,000 m^3
grainsize (Md_{50})	500 - 600 μm	183 - 213 μm	215 - 555 μm
depth	16 - 18 m	20 - 23 m	14 - 20 m
max. depth of extraction	0.5 m	0.25 - 1.5 m	ca. 2 m
sediment after extraction	same	decrease of org. matter content	finer increase of org. matter content

B.2.2. Research approach

In principle, one survey of the zoobenthos was made before the actual sand extraction took place. After the completion of the sand extraction, surveys were repeated in one year intervals.

The zoobenthos was sampled by means of Box Corer (Terschelling) and Van Veen grab (Torsminde, Costa Daurada). The sampling strategy was adapted to local conditions: samples along transects (DK), (stratified) random sampling (NL, DK) or selected stations (ES). Numerical densities and biomass (ashfree dry weight) of species and taxa were assessed. Additional information was obtained by determining age and/or size composition of

major species (only in the Torsminde and Terschelling case). The structure of the benthic community and changes therein were described by means of clustering techniques.
In Spain, at a *Posidonia* meadow in the vicinity of the borrow site, plant coverage, plant density and ligula height above the sediment as basic parameters of seagrass vitality were measured along transects and in quadrats. Measurements made before (1988) and after extraction (1995) were compared.

B.3 Results

B.3.1. Sediment response

In the North Sea borrow sites studied the sediment type at the borrow sites after sand extraction did not change very much. Only in the Torsminde borrow site a small increase in organic matter content of the sediment occurred. In the Costa Daurada borrow site, however, the sediment type had considerably changed after extraction. Here, a 5-20 cm thick layer of fine sediment (Md_{50} 16-80 μm formed on top of the original sediment which had a Md_{50} of 100-150 μm.

B.3.2. Benthic community response

In the North Sea borrow sites sand extraction caused a reduction of species abundance and biomass. An opportunistic response was observed in a quick development of the polychaete *Spio filicornis*. Recovery generally proceeded rather fast (within one year). At the end of the project, however, in the borrow site abundance and biomass of longer living bivalve species was still not fully recovered, especially in the borrow site North of Terschelling (VAN DALFSEN & ESSINK, 1997).

Around the borrow site at Costa Daurada no direct effect of sand extraction on nearby seagrass beds was observed. At the location of the borrow site itself within a few months after the extraction a dramatic development of opportunistic polychaetes (*Capitella capitata*, *Malacoceros* sp.) occurred. Information on a possible recovery of macrozoobenthos is not available. On the other hand, an important loss of the locally exploited mollusc *Callista chione* was observed (MANZANERA *et al.*, 1996).

Observations made in the Terschelling borrow site clearly showed that, although bivalve molluscs and sea urchins (*Echinocardium cordatum*) recovered in terms of numerical densities, these long living species had not yet recovered in terms of biomass. By the end of the project, ca. 2 years after sand extraction, adult specimens of these larger species were still rare (VAN DALFSEN & ESSINK, 1997).

B.4 Discussion and Conclusions

B.4.1. Direct effects

The difference in response of the sediment composition to sand extraction, as demonstrated between the North Sea and Mediterranean sites studied, seems to be strongly related to differences in hydrodynamics and associated sediment transport over the sea floor. These findings strongly relate to those of a study of borrow pits in the Dutch Wadden Sea, where in locations with high water movement (in tidal channels) borrow pits filled in quickly with approximately the same type of sediment as was originally present. In shallow locations with little influence of tidal water movement, however, borrow pits filled in slowly and with a much finer sediment in which hardly any macrozoobenthos could develop (VAN DER VEER et al., 1985). The latter phenomenon must be the case in the Costa Daurada borrow site. A similar response to mechanical disturbance of the sediment was found by LOPEZ-JAMAR & MEJUTO (1988).

The observations made around the Costa Daurada borrow site show that sand extraction does not present a risk to nearby seagrass beds as long as a minimum distance of 1-2 km is observed. The immediate results of this study imply a warning against exploitation of an other potential borrow site that is situated much closer to the same seagrass beds.

B.4.2. Recovery of the benthic community

Recovery of the natural composition of the zoobenthic community in the North Sea sites proceeds rather fast (1 - 2 years) for most species. Recovery of longer living species such as bivalve molluscs and sea urchins is dependent on good recruitment. Good recruitment does not usually take place each year. Therefore, recovery of these species may last 2-5 years.

In the borrow site at the Costa Daurada a dramatic development of opportunistic polychaetes was observed shortly after sand extraction.
A similar development of opportunistic species following sediment disturbance due to dredging was found by LOPEZ-JAMAR & MEJUTO (1988). These authors, however, found a recovery of the soft bottom fauna within 1-2 years, being about as quickly as found in the North Sea borrow sites. Nevertheless, it is assumed that recovery of macrofauna in borrow pits as made at Costa Daurada will take longer. This is postulated because of the resemblance with the slowly recovering shallow Wadden Sea pits (*cf.* VAN DER VEER *et al.*, 1988). This conclusion is further supported by fishermen's observations in other Spanish sand borrow areas where after an initial almost complete loss of commercially exploitable stocks (*e.g.* the bivalve *Callista chione*) adult specimens remained absent for at least 4 years (MANZANERA *et al.*, 1996).

B.4.3. Risk to birds and fisheries

In the North Sea, the risk for diving ducks (mainly *Melanitta nigra*) is considered small at borrow sites at c. 20 m depth as their preferred food *Spisula subtruncata* is not abundantly present there. In Danish and Dutch waters, sandeel and flatfish (*e.g.* plaice) are the major consumers of benthic invertebrates. Due to the fast recovery of benthic fauna, and remnant fauna in between the suction lanes, reduced food supply in borrow sites is not considered a real risk for these fish species (BIRKLUND *et al.*, 1996; VAN DALFSEN & ESSINK, 1997).

In the studies around the borrow site at Costa Daurada no direct effect of sand extraction on nearby seagrass beds was observed. So, no risk to this benthic community is involved as long as a minimum distance is observed. In non-vegetated sea bottoms sand extraction caused dramatic changes in the composition of the zoobenthic community, involving mainly the development of opportunistic species and an almost complete loss of commercially exploitable stocks (*e.g.* the bivalve *Callista chione*). Due to reduced water and sediment dynamics as compared to the North Sea borrow sites recovery may take 5-10 years at least, posing a risk to social and economical significance of the coastal zone.

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