Journal of Coastal Conservation 2: 149-158, 1996
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Reintroduction of eelgrass (*Zostera marina*) in the Dutch Wadden Sea; review of research and suggestions for management measures

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Abstract. Eelgrass (*Zostera marina* L.) in the Dutch Wadden Sea historically covered an area varying from 65-150 km^2 in the eulittoral as well as the sublittoral zones. At present, this area comprises less than 1 km^2 eulittoral eelgrass stands, with an associated decrease in habitat diversity. The causes for this decline are presumably connected with the 'wasting disease' and the closure of the former Zuiderzee in the early 1930s resulting in increased tidal range and increased currents. After a slight recovery of the eelgrass populations on the intertidal flats a definite decline started in the early 1970s, possibly connected to increased turbidity. The present water quality and turbidity do not negatively influence eelgrass growth up to a depth of at least 0.6m below Mean Sea Level. Based on mesocosm experiments and field experiments it is concluded that re-establishment of eelgrass should be possible in sheltered bays and on unexposed tidal flats. The most suitable depths for a reintroduction are those between 0 and 20-40 cm below mean sea level.

Keywords: Eulittoral; Sublittoral; Tidal range; Water quality.

Introduction

In the past, a sublittoral area of 65 - 150 km^2 and an eulittoral area of unknown size in the western Dutch Wadden Sea were covered with *Zostera marina* (Fig. 1: 1869, 1930). This situation changed drastically in the early 1930s when all the sublittoral eelgrass and presumably most of the eulittoral eelgrass disappeared, which then was believed to be caused by the 'wasting disease' (den Hartog 1987). The sublittoral populations never returned and the eulittoral eelgrass vegetation never recovered to its former extent. After some increases and decreases in the 1940s and 1950s, the eulittoral eelgrass has declined to less than 1 km^2 at present since the 1960s.

In coastal environments eelgrass contributes to the variety in biotopes. Ecologically, eelgrass beds function as a spawning place and a hiding-place for several fish species and for large invertebrates such as the cuttle-fish (van Goor 1919; Reise et al. 1989). Typical fauna in eelgrass beds are the sea stickleback, several species of pipe-fishes and the snail *Rissoa membranacea*. Eelgrass is grazed by birds of which the brent-goose is one of the most important species and an important grazer is the isopoda *Idotea chelipes* (Nienhuis & van Ierland 1978).

Recently, the Dutch government adopted for the coastal areas, including the Wadden Sea, the strategy of 'sustainable use' as presented by the Brundlandt Commission. This has led to a policy of improvement of environmental conditions, where necessary. To measure changes in the different ecosystems a number of indicators, 'ecotargets', visualized in a so-called 'radar plot' were selected by Rijkswaterstaat (Directorate-General for Public Works and Water Management). Eelgrass was one of the selected indicators. The status of the coastal environment was assessed to find the causes for the deterioration of the eelgrass populations as well as to find ways to increase the eelgrass population in the Dutch Wadden Sea.

In this paper a review is presented on the decline in eelgrass in the Dutch Wadden Sea and the actual condition of the remaining stands is reported. Possible causes that may have contributed to this decline are indicated. Finally, some conclusions are presented based on the research commissioned by Rijkswaterstaat to investigate possibilities of a reintroduction of eelgrass beds.

Development of eelgrass distribution in the western Dutch Wadden Sea

Before 1930

In 1869 a map was published showing the distribution of eelgrass stands that were of economic value (Oudemans et al. 1870). Given the information presented on the maximal depth occurrence (Martinet 1782; Oudemans et al. 1870; van Goor 1919; Harmsen 1936), it has generally been accepted that in these days the most important eelgrass stands were found in the sublittoral zone. However, a careful study of the map of Oudemans et al. (1870) (Fig. 1: 1869) indicates that a substantial part of these beds were actually situated in the littoral zone. The precise elevation of these eelgrass beds is now under investigation through application of GIS techniques. Actual information on the depth distribution of eelgrass is only available for the northern part of the former Zuiderzee near the former island of Wieringen (cf. Fig. 1: 1930; Feekes 1936; cf. also de Jonge & de Jong 1992), where eelgrass was present to nearly 2 m below Mean Sea Level (MSL) with a local optimum at ca. 1m.

1930 - 1990

In the early 1930s a dramatic decline in eelgrass occurred all over the north Atlantic (see e.g. Short et al. 1988). In general, the cause of the decline was ascribed to a parasitic infection by a protozoan (van der Werff 1934, 1938; Reigersman 1939) but hard evidence for this was never obtained. In the Dutch Wadden Sea this decline coincided with the closure of the Zuiderzee and the decline has been, at least partially, ascribed to this closure (de Jonge & de Jong 1992). In most of the international Wadden Sea, which covers the North Sea coast of Germany and part of the coast of Denmark and the Netherlands, eelgrass partly recovered over a period of decades, except in the western Dutch Wadden Sea (den Hartog & Polderman 1975). The eelgrass population declined again (possibly as the result of ice-scour) from 1936 to 1947. The population then increased in the Balgzand area from 1947 to ca. 1965. This was presumably caused by less exposure to currents and waves after the Den Helder harbour was extended. Since 1965, the population has been declining, both in density and in area, and is now at its lowest point.

The reason for the recent decline is unclear. Den Hartog & Polderman (1975) mention pollution, eutrophication, changing turbidity due to the engineering works, changing irradiance and infections. Changes in light climate (see below) have most likely been the primary factor in the decline (Giesen et al. 1990a, b; de Jonge & de Jong 1992).

Present situation

At present, *Zostera marina* is only known from two locations in the Dutch Wadden Sea: in the harbour of the island of Terschelling, and on the 'Paap' tidal flat in the Ems estuary (Fig. 1: 1990). It has completely disappeared from the Dutch Wadden Sea proper. In the remaining locations eelgrass consists mainly of perennial plants that grow in a narrow zone of 20-30 cm at MSL.

In the dynamic and turbid Ems estuary the eelgrass vegetation looks very healthy with plants that reach a length of over 2 m and that flower abundantly. This Ems population is extending despite intense dredging and deposition of spoil in a channel adjacent to the eelgrass bed.

Possible causes of the decline in the Dutch Wadden Sea

'Wasting disease'

In the early 1930s research was initiated to find the cause for the destruction of the eelgrass beds during that time. This investigation was started because of the economic importance of the beds. However, the investigators failed to explain the phenomenon (van der Werff 1934, 1938; Reigersman 1939). It was concluded that except in brackish inland waters, the Irish Sea, and the brackish part of the Baltic Sea, the decline caused by 'wasting disease' was a very common phenomenon in the entire northern Atlantic area. The disappearance of the sublittoral populations of *Zostera* in the early 1930s (van der Werff 1934; Reigersman 1939) was initially solely ascribed to the parasite *Labyrinthula macrocystis* Cienkowski (van der Werff 1934, 1938). Based on the excellent growth of submerged populations of *Zostera* in the salt Grevelingen in the southwestern Netherlands after this estuary was closed off from the sea, van den Hoek et al. (1979) suggested that in the Dutch part of the Wadden Sea increased turbidity, due to the closure of the Zuiderzee could have caused the complete die-off. Later, Short et al. (1988) and den Hartog (1987) suggested that more than one factor was responsible for the decline in the North Atlantic eelgrass populations.

Calculations on the maximal potential growth depth of eelgrass, (see below) strongly suggest that the 'wasting disease' is not necessary to explain the decline in eelgrass in the Dutch Wadden Sea. Poor light conditions caused by cloudy weather and increased turbidity (Giesen et al. 1990a) may have initially weakened the eelgrass, allowing 'wasting disease phenomena' to occur.

Human impact

Closure of the Zuiderzee

In the late 1920s and early 1930s a dam (Afsluitdijk) was built separating the former Zuiderzee from the western Dutch Wadden Sea (Fig. 1: 1990). The construction of this dam caused dramatic changes in the tides and currents in this part of the Wadden Sea.

Tide. Due to the construction of the dam the original tidal range of ca. 1.2 m suddenly increased by 15 - 25 cm

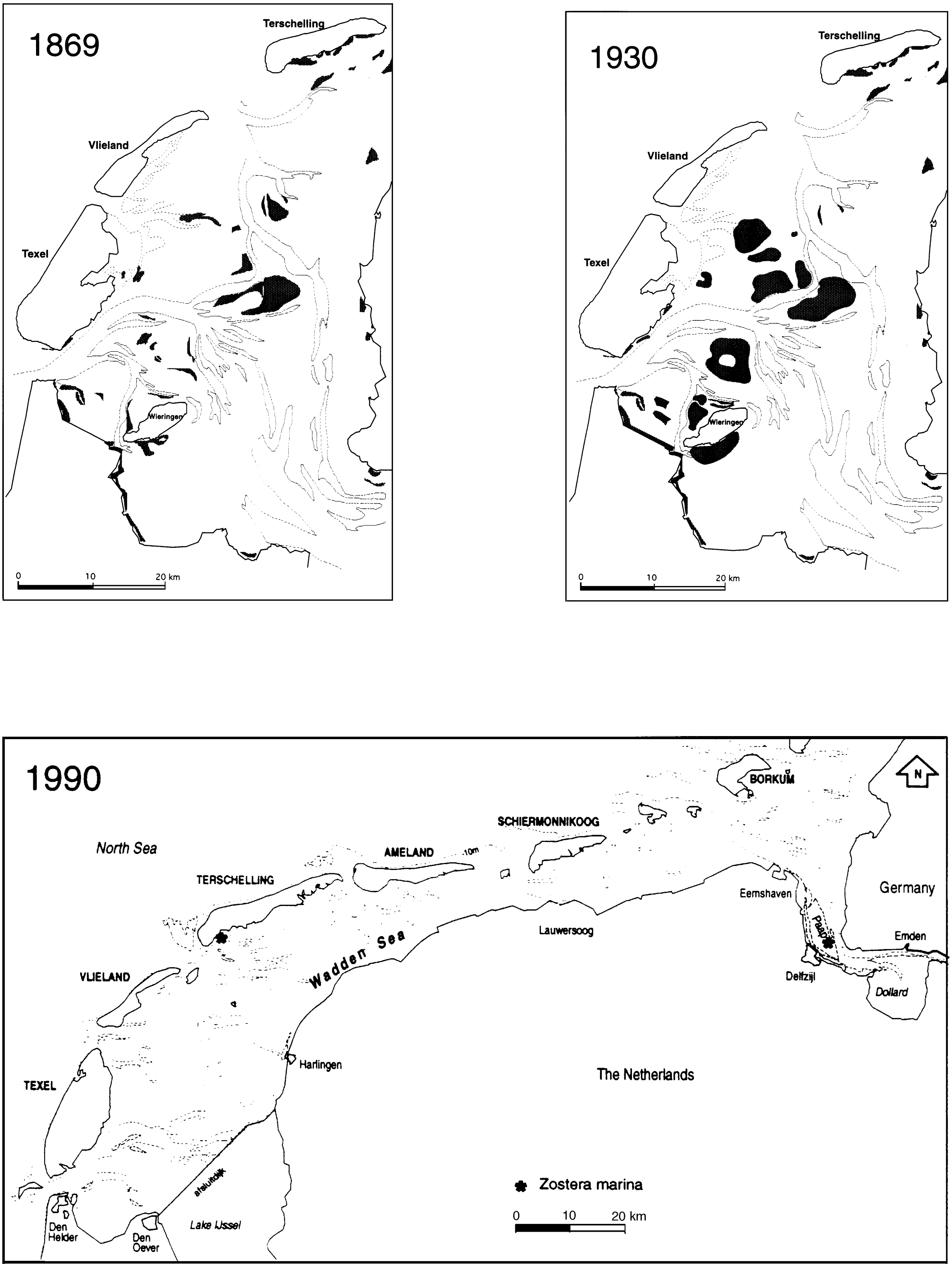

Fig. 1. Distribution of eelgrass (*Zostera marina*) beds in the Wadden Sea area in 1869 (Oudemans et al. 1870) and 1930 (Reigersman 1939), and the distribution of eelgrass in 1990.

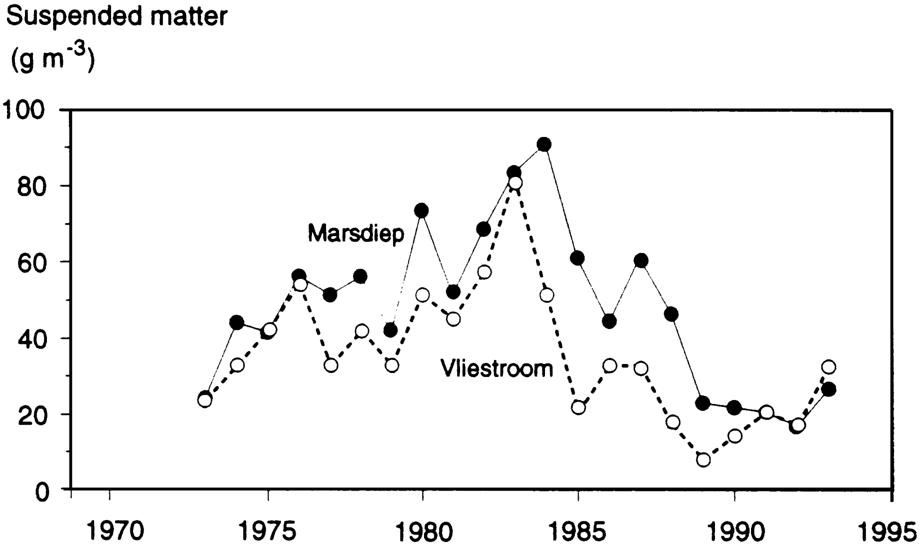

Fig. 2. Variation in mean annual concentration of suspended matter in the Marsdiep and the Vlie (de Jonge & de Jong 1992).

in the tidal inlets and by 30 - 50 cm at the upper ends of the Marsdiep tidal basin (de Jonge & de Jong 1992).

Currents. Increased tidal range has resulted in increased water transport. In some channels the velocity of the currents have decreased to 30 % of the original value. In general, however, velocities increased by 1.2 to 2.9 (Thijsse 1972). The position of several locations where eelgrass flourished in the past corresponds well with the greatest changes in current velocity, both increases and decreases (de Jonge & de Jong 1992). Although not reported in the early 1930s, this increase in current velocity must, at least temporarily, have been responsible for increased turbidity due to erosion and transport of the original bottom sediments.

Studies by Rijkswaterstaat revealed a strong sedimentation in the entire Marsdiep tidal basin over the period 1932-1950 (Glim et al. 1987; Misdorp et al. 1989). This may also serve as an indication of the increased turbidity since the construction of the closure dam.

Turbidity. As shown in Fig. 2, there is a strong interannual variation in the time series of the light extinction coefficients as calculated from mean annual suspended matter concentrations in the Marsdiep tidal inlet. It is difficult to explain this variation. It may have been caused by human activities (e.g. dumpings of harbour sludge, fisheries, extraction of bottom deposits), but it may also be due to natural variations in the tidal range (de Jonge & de Jong 1992).

Together with insolation, water turbidity and water depth (in relation to tidal range) are important factors determining the growth potential of eelgrass. Data on these factors allow the calculation of the maximum growing depth for eelgrass. This was done in the western Dutch Wadden Sea relative to MSL, as a function of solely **light attenuation** calculated from suspended matter concentrations (de Jonge & de Jong 1992). The calculated maximal grow depths correspond well with the depth distribution given by Feekes (1936). Moreover, the calculations show that changes in the tidal range hardly influence the maximum potential depth, and that even small changes in turbidity may have a big impact (de Jonge & de Jong 1992).

Due to the recorded variations in water turbidity, the maximum potential growth depth of eelgrass in the Dutch Wadden Sea varied from depths close to 1m below MSL in the 1970s to a zone around MSL in the early 1980s to again 1 m below MSL in the early 1990s (Fig. 3). In the pre-1932 period eelgrass even reached a dept of ca. 1.7 m below MSL (Martinet 1782; Oudemans et al. 1870; Harmsen 1936).

Land reclamation

Due to land reclamation (which has a long history in The Netherlands) and coastal defence the Dutch coastal area has been changed over the centuries (Fig. 4). Relatively shallow sea arms and salt marsh systems were reclaimed from the sea. Large-scale engineering works followed in the present century. In the early 1930s, the afore-mentioned closure of the Zuiderzee took place. In 1969, a second large engineering work concerned the closure of the Lauwerszee (Fig. 5). All these interventions have led to a situation where sheltered areas in the Dutch Wadden Sea are hardly available any longer.

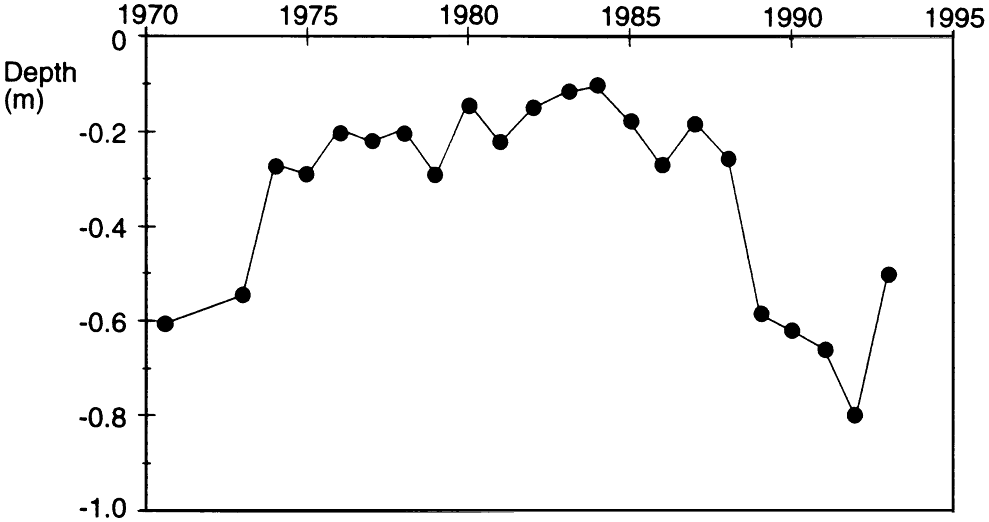

Fig. 3. Time series of the maximum depth for potential eelgrass growth, calculated from mean annual suspended matter concentrations.

Fisheries

Strong negative effects on eelgrass beds were exerted on 'mussel seed' by mechanical fishery and on edible cockles (*Cardium edule*) by cockle fishery. The effects of mechanical fishery on eelgrass are not well documented for the Netherlands. On the basis of field observations, de Jonge & de Jong (1992) briefly described effects that vary from cutting eelgrass shoots – fishery on 'seed mussels' (young mussels collected on natural mussel beds to be seeded on culture lots for further and improved growth)– to the total destruction of the vegetation – fishery on edible cockles by suction dredging. The cutting-off of shoots due to mussel seed fishery may seem less harmful, but in an annual eelgrass population, cutting in May could be as drastic as the immediate destruction due to cockle fishery. This is caused by the shortening of the growing season, which makes it difficult for plants to produce enough seed necessary for next year's populations, as was observed in the late 1980s on a tidal flat in the Ems estuary.

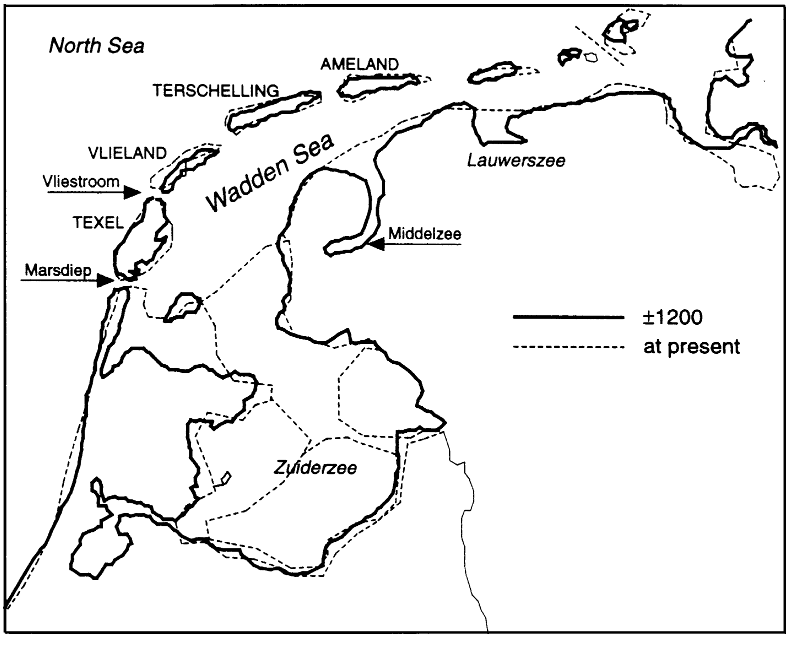

Fig. 4. Changes in the coastline of the northern Netherlands since ca. 1200 as a result of land reclamation and coastal defence works.

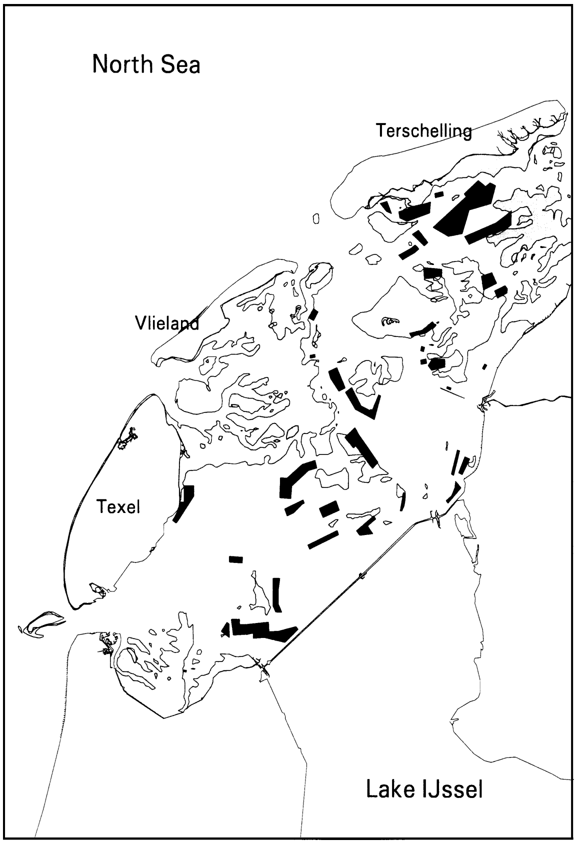

Fig. 5. Distribution of mussel culture lots (indicated in black) in the western Dutch Wadden Sea.

Water quality

Eutrophication

The occurrence of macroalgae such as *Ulva* spp. and *Enteromorpha* spp. has increased since the 1960s (pers. observ.). Although for the Wadden Sea hard evidence is lacking, it seems that the areas where these algae accumulated coincide with former stands of eelgrass on the Wadden Sea side of the islands Terschelling and Ameland (den Hartog & Polderman 1975; cf. Fig. 1: 1990). There are indications for light competition favouring the algae (Reise 1992) and for mortality due to permanent coverage of eelgrass by algal mats, as was observed elsewhere (den Hartog 1994).

Toxicants

It is difficult to indicate which chemicals have a negative effect on the growth of eelgrass in the Wadden Sea. However, from the present stands and the experiments conducted, it is clear that at the moment the water quality is not a main harmful factor in this area. According to the present Dutch water-quality policy negative side-effects of eutrophication and the input of harmful substances in this area will be reduced.

Restoration experiments

In order to find ways to re-establish eelgrass in the Dutch Wadden Sea several experiments have been carried out by the University of Nijmegen, both mesocosm (see below) and field experiments. Some important conclusions from these experiments will be presented here.

Mesocosm experiments. Under semi-natural conditions, and using 6m ×50m concrete basins, five different populations were tested for growth, overwintering, and seed production by van Katwijk (1992). These tests were also used to indicate the present water quality in the Wadden Sea with respect to the growth of eelgrass. The general results (Table 1) show that three populations were labelled as suitable for an eventual transplantation experiment and that the general water quality in the western Dutch Wadden Sea was sufficient for the plants to grow.

Field experiments. To find the proper strategy for the re-establishment of eelgrass populations in the Wadden Sea, transplantation experiments were carried out using seeds and sprouts.

Seeds were planted just south of the island of Terschelling in the autumn of 1989 (cf. Fig. 1: 1990). Using a pincet, eelgrass seeds from the population at the Wadden island of Sylt were introduced into the sediment to a depth of ca. 2 cm in a well-defined matrix determined by holes cut in a PVC plate. Nearly 10 000 seeds were placed in the sediment by hand. To prevent disturbance by winter gales the experimental area was protected by a screen of willow twigs.

Ca. 0.5 % of the seeds germinated during the subsequent spring. Only a single plant developed well during the first growing season. The conclusion was that seeding was not the best approach for restoration. Therefore, it was decided to focus further on transplantation of sprouts, to be carried out in early summer.

Transplantation of sprouts. Several experiments with transplantation of sprouts were carried out. Some remarkable results were obtained from an experiment south of the island of Terschelling that started in early June 1994 (Hermus 1995; for location see Fig. 1: 1990). The results are expressed as the percentage of shoots still present after four days, when shoot decline had stopped, indicated as 'definite settlement'.

The first series (Fig. 6) is the reference series for six depths compared to Dutch Ordnance Level (DOL) which is about MSL. Between mean sea level and – 10 cm the planted individuals develop many new shoots; after 100 days the shoot number is 4 × that of the 'definite settlement'. Growth at a depth of –20 cm MSL was less pronounced but still 3 × that of the 'definite settlement'.

Table 1. Ranking of test results for restoration based on growth, overwintering and seed production of five different populations (based on van Katwijk 1992).

Sampling place	Development first growing season	Overwintering success	Seed production	Final score
Sylt (Germany)	good	good	very good	suitable
Grevelingen (The Netherlands)	good	very good	moderate	suitable
Terschelling (The Netherlands)	moderate	moderate	good	suitable
Roscoff (France)	moderate	bad	bad	unsuitable
Yderfjorden (eastern Denmark)	bad	bad	bad	unsuitable

At depths of 40 and 60 cm below MSL complete individuals (shoots and rhizomes) disappeared quickly, apparently through disturbance by hydrodynamics, grazing or because of bad light conditions.

In a second planting series plants were caged. However, at all depths, the cages were undermined by the formation of small pools which was apparently due to currents and/or waves. So, the cages had to be fixed and sediment had to be replaced regularly around the cages. At MSL no extension occurred until the moment that the cages were removed. At a depth of –40 cm MSL nothing happened initially, but after the removal of the cages the plants disappeared. At a depth of –60 cm MSL some extension was visible suggesting that the cages functioned as a protection against some disturbing factor. However, after removal of the cages the plants disappeared within a short time.

From both experimental series the conclusion was drawn that water turbulence was the key factor responsible for the disappearance of complete plants –including their rhizomes. Thus, even very locally, turbulence may have a dramatic influence on the vegetation on a tidal flat. Also, light did not limit the growth of eelgrass on these locations.

Management perspectives

Habitat restoration

In agreement with the recommendations from the Brundtland Commission, the Dutch government has decided to develop management plans in which habitat restoration is an important goal. One seriously threatened habitat type is that of eelgrass. From our experiments we conclude that another study is required to select suitable locations where the physical conditions allow eelgrass to grow. This is currently being investigated; preliminary results, based on factors such as sediment composition, turbidity, current velocity and wave action, are promising. It seems that, although physical habitat conditions in the Dutch Wadden Sea have changed drastically, there are still opportunities for *Zostera marina* to develop locally in the eulittoral zone.

Population dynamics

Improving the present situation for eelgrass may be difficult because its population in the Dutch Wadden Sea mainly consists of perennials; consequently, seed production is low (Keddy 1987). Thus, an extension of the present population will occur relatively slowly, this in contrast to the situation in the Eastern Scheldt where annual populations predominate. The low seed production may be one of the reasons why the eelgrass population has not responded positively to the recently improved light conditions in the Wadden Sea.

Reintroduction measures

1. Because the last eelgrass beds in the Dutch Wadden Sea are near to extinction, they must enjoy total protection against any harmful activity.
2. Since mussel and cockle fisheries have a strong negative impact on eelgrass stands, they must be banned from both areas with eelgrass beds and localities where conditions are judged favourable for re-establishment. As a matter of fact, 26 % of the Dutch Wadden Sea area has recently been closed to the above-mentioned fisheries. Further, part of the Ems estuary has also been closed to the same fisheries, due to a convenant between the German and Dutch authorities. The recent positive developments of the eelgrass bed in the Ems estuary may be partly the result of these actions.
3. There should be no further expansion of the area of mussel culture lots. Instead work should be done on improving culture methods and techniques of ‘seed fishing’ and transport in order to achieve a higher production with less seed mussels and fewer harmful effects. This is now under investigation by the fishery branch.

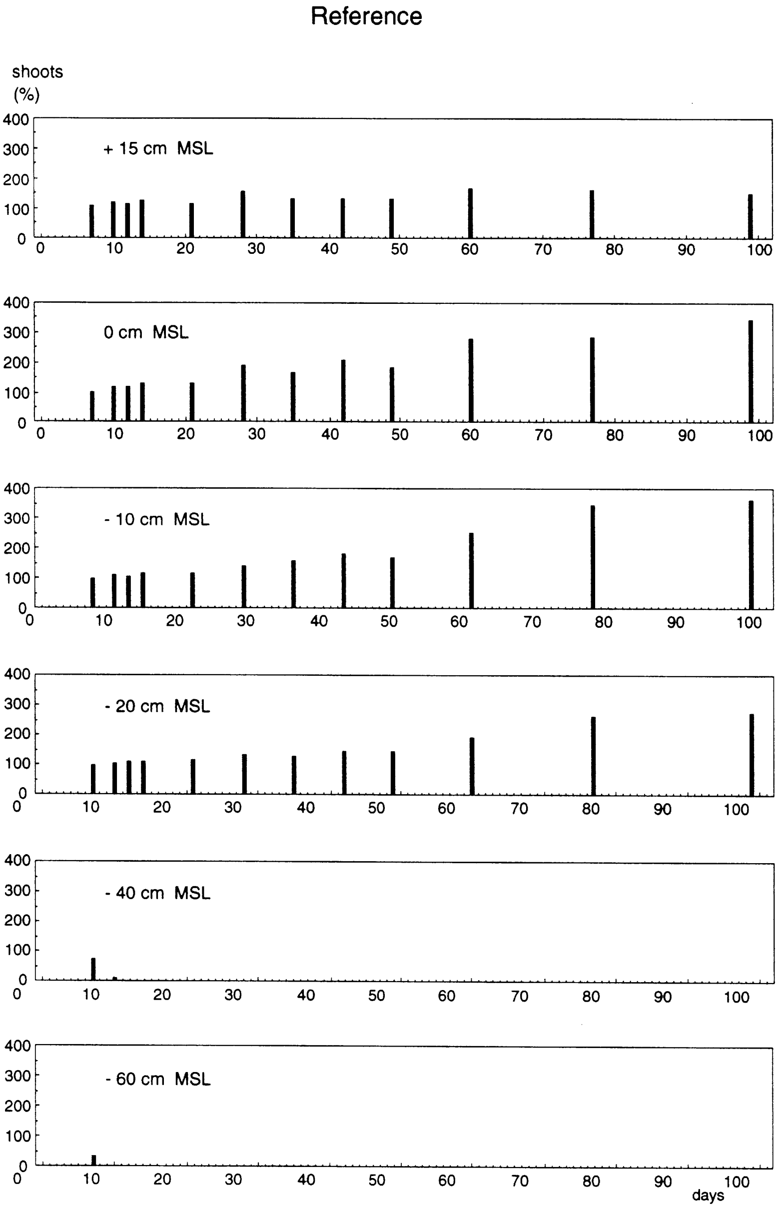

Fig. 6A. Shoots surviving from transplantation experiments at different depths south of the island of Terschelling 1994. (Based on Hermus 1995.)

4. Special small areas of eelgrass vegetation should be established, which can act as resources for further extension. Based on the work done so far, we believe that transplantation of eelgrass into sheltered tidal flats and sheltered bays in the Wadden Sea, such as the Mok bay on Texel, will be successful.

Conclusions

1. In the past *Zostera marina* (eelgrass) covered (sub)-littoral areas varying from 65-150 km^2 in the Dutch Wadden Sea. At present this area is less than 1 km^2. The causes for this decline are presumably connected with the closure of the former Zuiderzee resulting in an increase in tidal range and velocity of currents.
2. In the Dutch Wadden Sea, the present environmental conditions, notably water quality, does not negatively influence eelgrass growth down to a depth of at least 60 cm below mean sea level.
3. The direct effects of mussel and cockle fisheries are catastrophic for the eelgrass stands.
4. Reintroduction of eelgrass beds in sheltered areas and bays, by means of inocculation of sprouts, seems a realistic option.

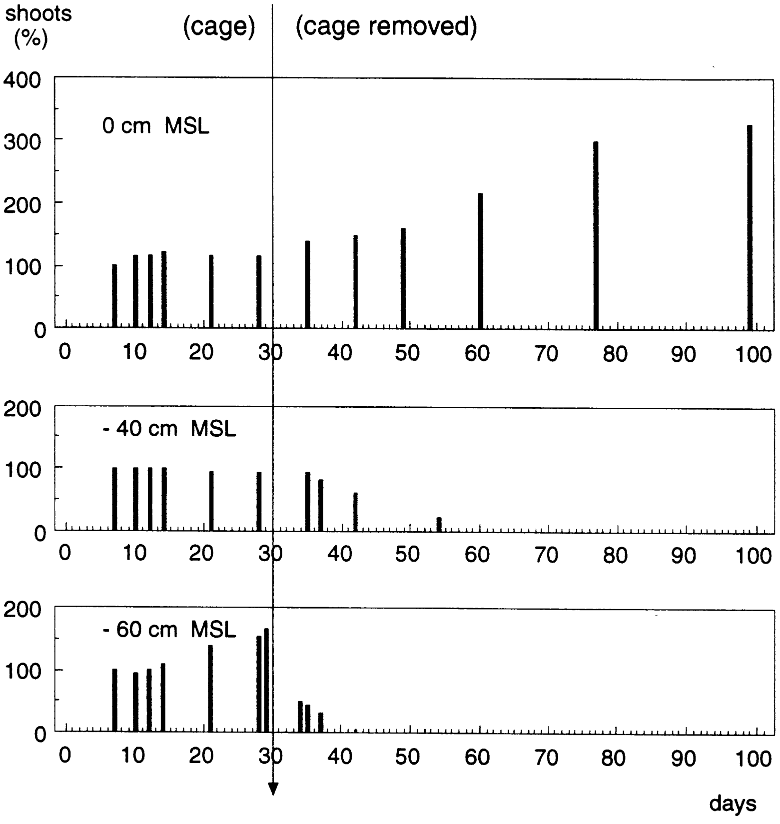

Fig. 6B. As Fig. 6A, shoots surviving from transplantations in cages and after removal of the cages. (Based on Hermus 1995.)

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Received 27 November 1995;
Revision received 12 September 1996;
Accepted 15 October 1996.