

ORIGINAL ARTICLE

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Policy plans and management measures to restore eelgrass (*Zostera marina* L.) in the Dutch Wadden Sea

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Abstract The Dutch Wadden Sea has been changed dramatically over the last centuries by human activities like land reclamation and different forms of fishery. This has, amongst other things, led to changes in the number of biological communities. One of the changes was the near extinction of eelgrass (*Zostera marina* L.) in the Dutch Wadden Sea. The deterioration of the area led to policy plans in the late 1980s that aimed at restoring the original natural communities of which the eelgrass community was one. This paper presents a restoration strategy which contains a selection procedure for suitable transplantation sites. The selection procedure is based on factors such as sediment composition, exposure time, current velocity and wave action. These were combined in a GIS-based map integrating these factors. One important action in the restoration process is to increase the number of freshwater discharge points to meet the requirements of the brackish water community in general and the growing conditions for eelgrass in particular.

Key words Policy plans · Management measures · Eelgrass · *Zostera marina* · Wadden Sea

Introduction

The presence of eelgrass (*Zostera marina* L.) increases biotope diversity and accompanying species (e.g. Heck et al. 1995) and increases sediment stability (e.g. Gambi et al. 1990). The disappearance of eelgrass may cause large-scale geomorphological changes as was observed in the Danish Wadden Sea during the 1930s (Jespersen and Rasmussen 1994).

Seagrass communities in the coastal zones of the world are under stress (Short and Wyllie-Echeverria 1996). This is mainly due to the presence of eelgrass in coastal areas which are also of interest to man, viz. shallow, sheltered locations. Human activities which are harmful to seagrasses are, for example, dredging of navigation routes and harbours, resulting in increased turbidity (de Jonge 1983), reclamation works for agriculture or living areas, coastal defence, changes in the number of freshwater outlets and discharge schemes (Kamermans et al. 1998; van Katwijk et al. 1999), fisheries (de Jonge and de Jong 1992), recreation and pollution, for instance by pesticides like azines (Derksen et al. 1994) and eutrophication, especially by ammonia and nitrates (van Katwijk et al. 1997).

In the Dutch Wadden Sea, the eelgrass has almost completely disappeared from 90–150 km^2 of area covered in the period prior to the early 1930s to less than 1 km^2 in the 1970s and later. Three factors, the “wasting disease”, the construction of a huge dam, and dull summers, have contributed to the decline. The decline in eelgrass around 1930 is only one of many changes that have taken place in the Dutch Wadden Sea. During past centuries, human intervention has resulted in a series of cumulative detrimental changes in the Wadden Sea system. The main changes are summarised below.

- Land reclamation shortened the coastline significantly starting in 1200 A.D. and caused the disappearance of shallow and sheltered areas (Dijkema 1987). As a result nearly all the natural salt marshes and many suitable sites for eelgrass have been lost.
- Oyster fishing flourished in the Wadden Sea for centuries. Around 1845, overfishing led to the extinction of the oyster (van Ginkel 1995). The former oyster fishers, particularly those on the island of Texel

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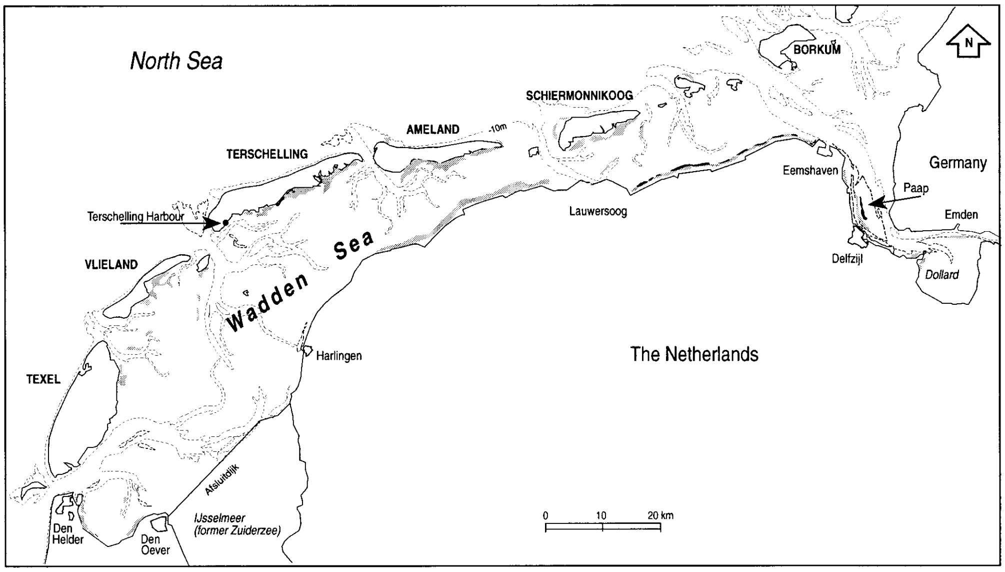

Fig. 1 Composite map with areas that are suitable as eelgrass habitat (0.8–1.0). Map is based on the factors: sediment composition, exposure time, current velocity and wave action. Further indications of situations and locations are given, which are referred to in the text

(Fig. 1), looked for new possibilities which were found in eelgrass fishery and in fishery for shrimps, herring, anchovy, flounder, eel, sea-pike and ray (van Ginkel 1995).

- For several centuries there has been a flourishing eelgrass fishery in the Dutch Wadden Sea (van Ginkel 1993). The complete disappearance of eelgrass had dramatic effects on the eelgrass fishers who were forced to change to the fishery of blue mussel and whelk.
- Increased turbidity and eutrophication possibly caused the decrease in abundance of brown algae and red algae in the Wadden Sea (Reise et al. 1994).
- Since 1960, mussel fishery and mussel culturing in The Netherlands have been concentrated entirely in the Wadden Sea. This concentration was mainly related to the preparation of a master plan in the early 1950s to protect the south-western part of the country against flooding by closing most of the estuaries there.
- Due to the intensive fishing of seedling mussels and mussels for consumption, the intertidal mussel beds in the Wadden Sea have completely disappeared.
- The extinction of beds formed by the blue mussel resulted in a decrease in the abundance of *Fucus vesiculosus* and accompanying species such as *Elachista fucicola*, *Littorina mariae* and *Jaera albifrons* (Reise et al. 1994).
- The flourishing whelk fishery industry in the Wadden Sea was terminated in the early 1970s. One of the causes for the total disappearance of this species was the introduction of tributyltin (TBT) (Cadée et al. 1995).
- During recent decades, cockle fishing has been developed into an extremely modern and efficient fishery industry by the application of a combination of trawling and suction dredging. Today, cockle fishery is regulated because it competes strongly with the waders and some duck species. The authorities are aware of the fact that this fishery is capable of destroying every benthic community, including eelgrass stands, completely.

In the late 1980s, the deterioration of the Dutch and German coastal environment was widely acknowledged. It became a political issue and the improvement of this environment was put high on the political agenda. In agreement with the recommendation of the “Brundtland Commission” policy, strategies and management plans were produced that should result in the improvement of the natural resources against the background of the strategy of “sustainable use”. The most important Dutch document stressing the deteriorated situation and mentioning the need for restoration, was the “Derde Nota Waterhuishouding” (Third Report on Water Management) produced by the Ministry of Transport, Public Works and Water Management (Anon. 1989).

The re-establishment of eelgrass populations is considered an important issue because they form a characteristic natural component of the Wadden Sea ecosystem. Eelgrass beds have a positive local effect on the reduction of water turbulence while their rhizome systems give additional stability to sediments (Gambi et al. 1990; Jespersen and Rasmussen 1994). Moreover, the stands play a role as a breeding area and nursery for many species, among them economically-important fish and invertebrates (Heck et al. 1995). Eelgrass forms a major food source for brent geese (*Branta bernicla*) and ducks (e.g. *Anas penelope*). Finally, eelgrass contributes positively to habitat diversity and the attractiveness of these areas to mankind because eelgrass is an aesthetic addition to the landscape during low tide due to variations in the colour and roughness of the surface of the intertidal flats.

In this paper, the state-of-the-art and future developments of the eelgrass restoration strategy in the Dutch Wadden Sea are presented. Composite Geographical In-

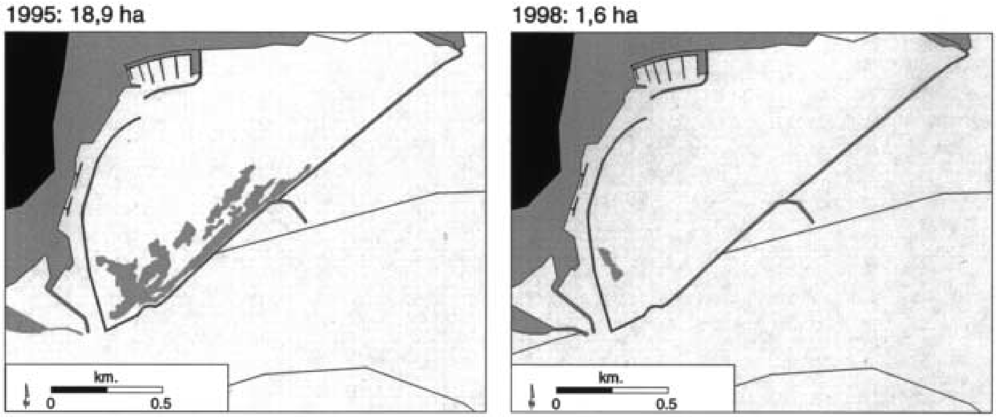

Fig. 2 The only location (Terschelling harbour) in the Dutch Wadden Sea with permanent eelgrass beds. Shown is the local distribution in 1995 and in 1998.

formation System (GIS) maps and Decision Support Systems are useful tools in formulating policy plans and management measures. A start has been made in using these tools in the restoration programme for eelgrass (*Z. marina* L.) in the Dutch Wadden Sea. Some preliminary results are presented.

Restoration strategy

Problem analysis

The current Dutch situation is alarming because in the Wadden Sea itself less than 0.02 km^2 (1.5 ha) of eelgrass is still present (Fig. 1), exclusively in the harbour of Terschelling (Fig. 2). In the early 1970s in the Ems estuary only a few solitary eelgrass plants were found by the first author (den Hartog and Polderman 1975).

The occurrence of the "wasting disease" in the late 1920s and early 1930s affected eelgrass communities over the entire northern hemisphere, including the Dutch Wadden Sea. Apart from this disease, the populations were suffering from the construction of a 30 km-long dam in 1932 that separated the former brackish Zuiderzee (now IJsselmeer) from the Wadden Sea and North Sea (de Jonge and de Jong 1992; de Jonge et al. 1993, 1996b; Fig. 1). In addition, two subsequent years with a considerable deficit of sunlight occurred (Giesen 1990).

From theoretical studies, it was concluded that a combination of factors could have been responsible for the decline in eelgrass in the Wadden Sea in the early1930s. Cloudy summers, relatively high temperatures in the early 1930s (Giesen et al. 1990a,b) and the construction of the "Afsluitdijk" in which *Labyrinthula* could have destroyed the weakened eelgrass populations, are some serious options. The recovery of the *Labyrinthula*-infected populations was subsequently hindered by the long-term hydraulic effects caused by the construction of the "Afsluitdijk" (de Jonge and de Jong 1992).

The complete licensing of the fishery of the edible cockle and the improvement of the light climate by decreased turbidity (de Jonge et al. 1996a) were good prerequisites for eelgrass restoration. It was, however, recognised that despite all the available studies little was known about the ecology of the eelgrass populations that once covered considerable parts of the Wadden Sea and the former Zuiderzee. The available field information was mainly restricted to two relevant maps showing the geographical distribution of eelgrass in 1869 (Oudemans et al. 1870) and in 1930 (Reigersman 1939). Feekes (1936) also provided some information about the elevation of eelgrass within the tidal range before 1932.

To obtain information about the vertical distribution of eelgrass before its large-scale decline, a re-evaluation of the old maps of 1869 and 1930 was made using a GIS technique (de Jonge and Ruiter 1996). It appeared that both in 1869 as well as in 1930 about 50% of the former stands were located in the low littoral zone and another 50% in the sublittoral zone.

Van Katwijk et al. (2000), indicated that two different populations may have been present in the littoral zone between mean high water and mean low water, separated by a bare zone (cf. also Harmsen 1936). Presumably, the middle and high littoral populations consisted mainly of annual plants, while the low littoral and sublittoral populations were perennial.

Experimental and field work was carried out to find suitable conditions and suitable donor populations for possible transplantation schemes (van Katwijk 1992; Hermus 1995; van Katwijk et al. 1997, 1998, 1999, 2000; Kamermans et al. 1998). The results of these studies showed that hydrodynamic processes caused by wind-induced waves play a decisive role in the success of any transplantation scheme (Hermus 1995). There were indications that fresh water stimulates the development of eelgrass (Kamermans et al. 1998; van Katwijk et al. 1999), and that eutrophication (particularly ammonium) negatively influences eelgrass development (van Katwijk et al. 1997 and references therein). Furthermore, eelgrass can easily be outcompeted by opportunistic algae like *Enteromorpha* species and *Ulva* species, which prosper under eutrophication (e.g. den Hartog 1994). These possible key factors are currently under study by several scientists at different institutes.

Table 1 Class ranges of several factors used to make the GIS maps per factor from which the composite map and later a habitat map was made

Parameter	Range	Chance of occurrence (%)	Reference
Orbital velocity in waves (m·s^{-1})	0–0.15	100	Best estimates based on field observations and model calculations
	0.15–0.2	100–50	
	0.2–0.3	50–0	
	>0.3	0	
Current velocity of flowing water (m·s^{-1})	0–0.5	100	Fonseca et al 1983
	0.5–0.9	100–5	Fonseca and Kenworthy 1987
	0.9–1.2	5–0	
	>1.2	0	
Sediment composition (% <64 µm)	0–2.5	0	DJ de Jong, personal observation
	2.5–5	0–100	
	5–60	100	
	60–75	100–50	
	75–100	50–10	
Emersion time(% day^{-1})	100–70	0	de Jonge and de Jong 1992
	70–65	0–100	Feekes 1936
	65–40	100	Harmsen 1936
	40–28	100–50	Hermus 1995
	28–17	50–10	van Katwijk et al 2000
	17–12	10–0	
	<12	0	
	Below MLW=0		

First integration step: towards a habitat map

As a first integration step, a composite map was prepared using a GIS technique to indicate the relative suitability of different locations in the Dutch Wadden Sea for the growth of eelgrass (Fig. 1). The map is based on the factors of sediment composition, exposure time, current velocity and wave action (Table 1). Information on suitability of sediment composition was obtained from field observations in the south-western part of The Netherlands. The influence of exposure time on eelgrass occurrence was obtained from field observations in the south-west Netherlands, on data concerning the tidal curve in the different parts of the Wadden Sea (de Jonge and de Jong 1992) and on the vertical distribution of eelgrass in the past (Feekes 1936). Influence of current velocity on eelgrass occurrence was derived from data published by Fonseca et al. (1983) and Fonseca and Kenworthy (1987). The effect of wave activity on eelgrass occurrence was established by field observations mainly in the south-west Netherlands in combination with results from available wave models and our own field expertise. The relative influence (chance of occurrence) of these four growth-condition determining factors for eelgrass are presented individually (Table 1).

Based on these four factors, four separate maps were made representing a two-dimensional (geographical) distribution of the chance of occurrence per growth condition. When these maps were amalgamated into a GIS-based composite map, the lowest chance of occurrence per grid cell (with geographical units of 500×500 m) over the four factors dictates the overall chance of occurrence for eelgrass within that grid cell. For technical reasons the map in Fig. 1 shows only one specific category (0.8–1.0 chance of occurrence) for eelgrass. This map is still at a preliminary stage. A detailed technical description of the creation and application of habitat maps like the present one is given by de Jong (1999).

Preparing the second integration step: combining policy and management

A map with potentially suitable areas for eelgrass establishment is not only valuable to the management and planning of the Dutch Wadden Sea policy, it can also be used as an input for an integral (ecosystem and socio-economic) dynamic model.

In The Netherlands, the bird watchers' lobby has initiated a more structured analysis of historical developments in human use of the Wadden Sea than was previously available. Due to this pressure, an increasing knowledge on natural variations in stocks or populations is now available. New inventories provide the basis for detailed discussions about the future of the Wadden Sea area between all the stakeholders involved. We are now ready to openly discuss the real problems connected with human use. In this discussion, knowledge systems, for instance Decision Support Systems begin to play a prominent role. It is up to the scientists to report on the possible consequences of human use and the possibilities for restoration measures (de Jonge et al. 1996b), and to the politicians to make the decisions.

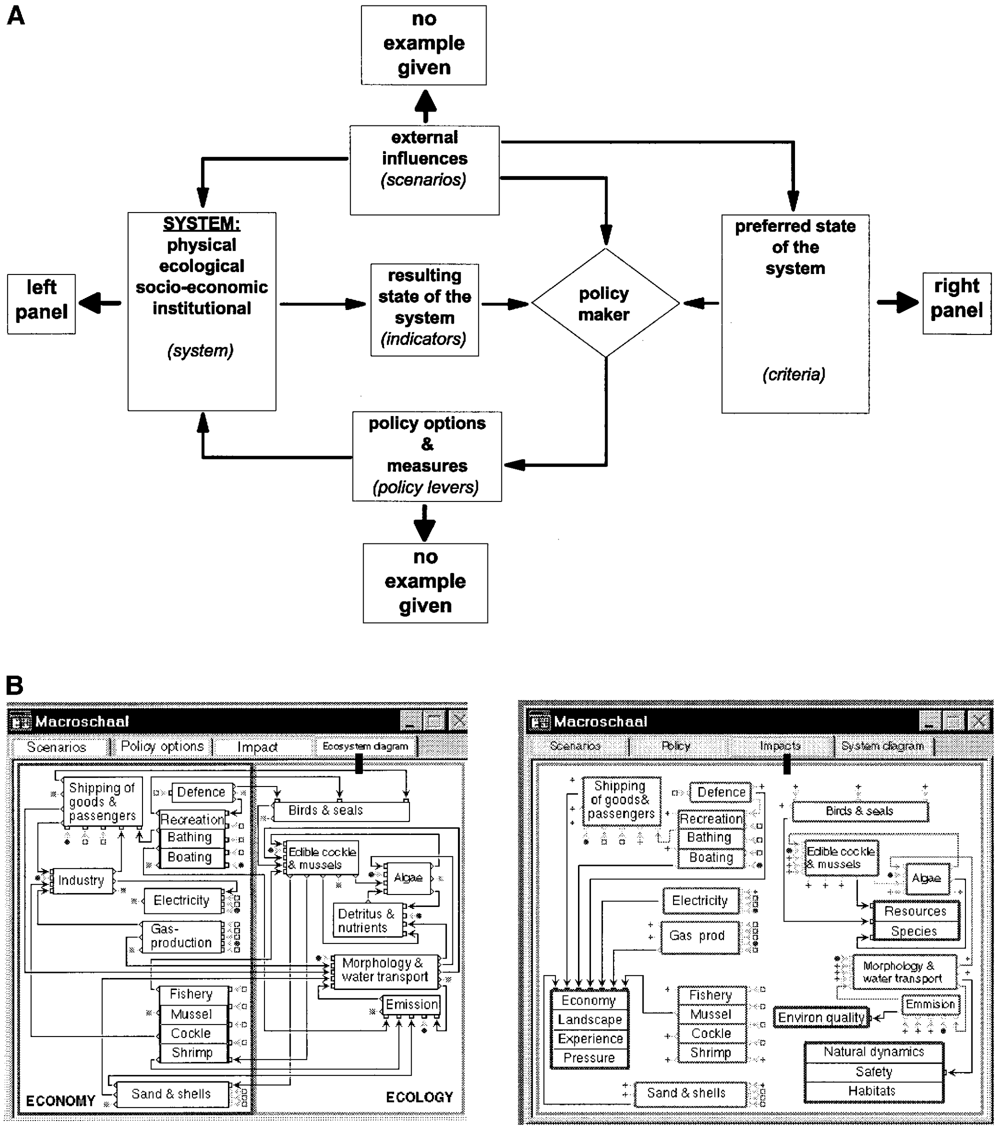

Fig. 3 Diagrams presenting: **A** the main structure of the Decision Support System, the integrated decision process informed by exploring several policy options and the role of the policy maker; and **B** examples of part of the model system showing connections between the socio-economic part and the natural and ecological part of the modelled integral system of the Wadden Sea and the impacted items

For the integration of the socio-economic and ecological aspects of the entire Wadden Sea system, the Wadden Sea Policy Supporting System (WADBOS) has been developed. The system has a dynamic structure, using feedbacks and connections between all relevant factors and processes at every (micro- or macro-) level. This has been done in order to structure the relationships between human activities and ecosystem mechanisms, and to explore the effects of different policy options in terms of engineering works, type and intensity of fishery, boating, pollution, eutrophication, and so on, on both the socio-economic and the natural parts of the integral system (Fig. 3). The first panel gives the general structure of the described relationships between ecosystem and socio-economic system while the second panel gives some of the impacts of activities in the first panel on items such as "environmental quality" and "economy, landscape, experience and pressure".

The WADBOS model roughly resembles the model published by Engelen et al. (1995), and is based on the use of constrained cellular automata for high resolution modelling as developed by Engelen (1988) and White et al. (1997). An interesting option of the WADBOS is the possibility of modelling features at different levels (cf. Engelen et al. 1995). The highest level refers to the entire Wadden Sea, and the second level to one of the 12 geographical compartments. The third level refers to the individual cells of 500×500 m. Macro-level and micro-level of the economic and ecological systems are tightly coupled in the model. This system guarantees a geographical (thus two-dimensional) modelling of the relevant parameters.

Structuring the relationships between human use and nature will facilitate discussion between the stakeholders when a new policy option becomes available. The qualitative and, if possible, quantitative structuring of relationships also helps in estimating the effects of different policy options and consequently facilitates the process of decision-making.

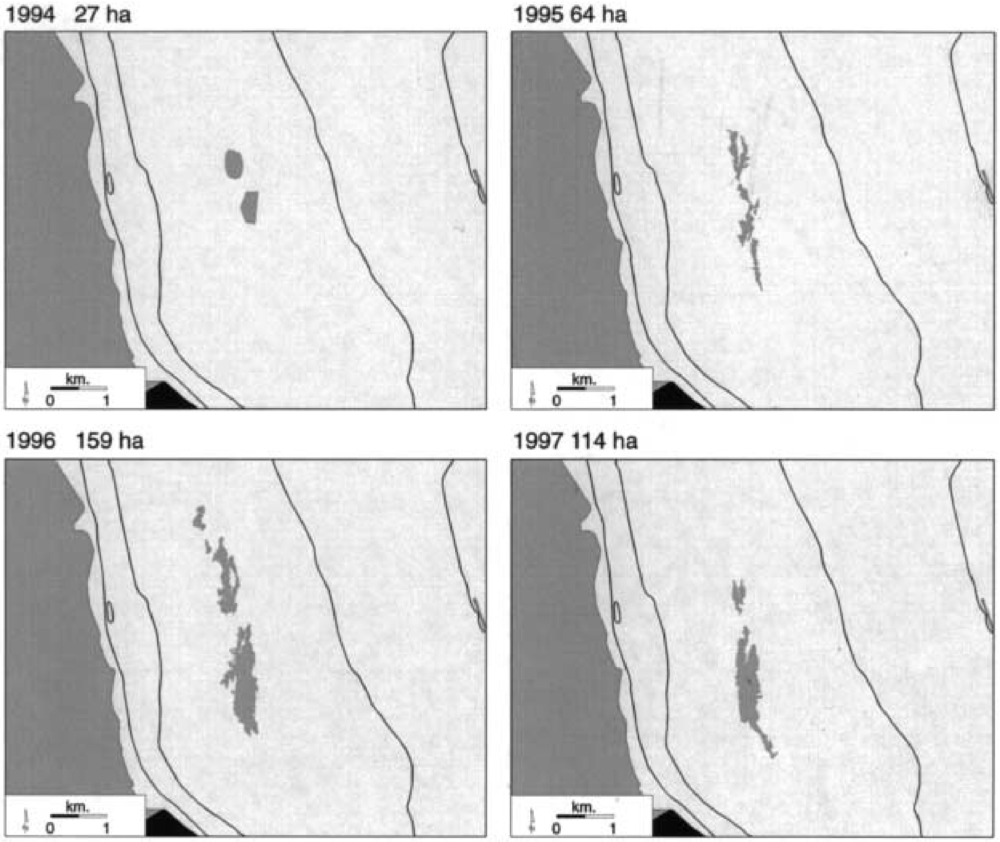

Fig. 4 Development of the eelgrass stand on the Paap-Hond tidal flat in the middle reaches of the Ems estuary over the period 1994–1997. Until the late 1970s no eelgrass was present there

Future developments

Locality selection

The most critical factors in the process of eelgrass re-establishment are the selection of a suitable locality, and the availability of a suitable donor population. Salinity and ammonium are factors which still need to be added to the GIS-based model because of their possibly decisive effect on eelgrass establishment potential (see above). In addition, the factor "wave action" should include wind directions other than the prevailing southwestern direction that is employed in the present version of the model.

To select a suitable locality, it is necessary to know (1) the growth requirements of eelgrass and (2) the present conditions in the Wadden Sea.

1. Most of the relevant growth requirements of eelgrass are already known (van Katwijk et al. 2000). However, further quantification of nutrient requirements, nutrient toxicity and of the role of wave action as a stress factor need to be investigated in more detail.
2. Information about the conditions in the Wadden Sea is present in large data files, but not yet in an accessible form.

A start has been made in combining (1) and (2) in the composite GIS map presented in Fig. 1. Information about salinity and nutrients has to be added to the GIS model, and wave action has to be adjusted. When suitable locations are indicated by the model, field visits are then required, as the microrelief is an important factor for eelgrass (van Katwijk et al. 2000) that cannot be assessed by the GIS model.

On the basis of our present knowledge, a suitable location was found along the dike that borders the Balgzand area (between Den Helder and Den Oever in Fig. 1), and probably also in the Mokbaai, a very shallow and small bay on the south-eastern part of the island of Texel (Fig. 1).

The composite map is not yet incorporated into the WADBOS system but will be added as soon as the GIS model has been adjusted in the ways suggested above.

Scale of reintroduction

The continuous cultivation and exploitation of the Wadden Sea by man for centuries has resulted in great losses of potentially suitable locations for eelgrass. In particular, the sheltered areas have been lost (see "Problem analysis"). Nutrient loads have increased (e.g. de Jonge et al. 1993; van Katwijk et al. 2000) and a large reduction in the number of fresh water discharge points has occurred. Therefore, a constructive human intervention to increase the number of suitable eelgrass locations may be desirable in order to counteract the destructive human interventions.

To make this happen, the building of constructions to reduce wave action and enhance shelter is recommended on a temporal and local scale. Eutrophication, particularly nitrogen load, has to be reduced. Furthermore, from an ecological point of view it is necessary to increase the number of freshwater discharge points again. This is necessary to meet the requirements of eelgrass and the brackish water community in general. Until then, suitable locations can only be found where freshwater influence is present (van Katwijk et al. 2000).

On the Paap in the Ems estuary, eelgrass has been developed in a positive way from less than 30 ha in 1994 to nearly 160 ha in 1996 (Fig. 4). Although a causal relationship could not be established, this development took place after measures had been taken to prevent any shellfishery on this intertidal flat. This estuary is further connected to an area in Germany (Fig. 1) where eelgrass stands are still available. This means that active reintroduction is possibly not necessary here.

The situation in the Dutch Wadden Sea is, however, quite different. Here the active reintroduction of eelgrass plants (transplantation) may be a possible constructive human intervention because of the complete absence of local donor populations. Such an active transplantation involves the collection of seed and/or culturing of suitable donor populations and the subsequent transplantation of seedlings. Direct sowing is under consideration as an alternative. Suitable mid-littoral donor populations are already available (van Katwijk et al. 1998).

To select a suitable donor population for low littoral and sublittoral eelgrass re-establishment, more insight is required into the reproductive and expansive potential of the rhizomes, the plasticity of the species to different environmental conditions (particularly nitrogen and salinity), the (lack of) sensitivity to wasting disease and the genetic diversity of potential donor populations.

References

Anon. (1989) Water now and in the future (in Dutch). Derde Nota Waterhuishouding, 's-Gravenhage, The Netherlands

Cadée GC, Boon JP, Fischer CV, Mensink BP, Ten Hallers-Tjabbes CC (1995) Why the whelk (*Buccinum undatum*) has become extinct in the Dutch Wadden Sea. Neth J Sea Res 34:337–339

Derksen AMCE, Jonge VN de, Peletier H, Rensen JJS van, Snel JFH (1994) Effects of atrazine and simazine on photosynthetic parameters of eelgrass (*Zostera marina* L.). Report Landbouwuniversiteit Wageningen, The Netherlands

Dijkema KS (1987) Changes in salt-marsh area in the Netherlands Wadden Sea after 1600. In: Huiskes AHL, Blom CWPM, Rozema J (eds) Vegetation between land and sea. W Junk, Dordrecht, pp 42–49

Engelen G (1988) The theory of self-organization and modelling complex urban systems. Eur J Operational Res 37:42–570

Engelen G, White R, Uljee I, Drazan P (1995) Using cellular automata for integrated modelling of socio-environmental systems. Environ Monit Assess 34:203–214

Feekes W (1936) The development of the natural vegetation in the Wieringermeerpolder, the first significant reclamation of the Zuiderzee (in Dutch). Ned Kruidk Arch 46:1–295

Fonseca MS, Kenworthy WJ (1987) Effects of current on photosynthesis and distribution of seagrasses. Aquat Bot 27:59–78

Fonseca MS, Zieman JC, Thayer GW, Fisher JS (1983) The role of current velocities in structuring eelgrass (*Zostera marina* L.) meadows. Estuarine Coastal Shelf Sci 17:367–380

Gambi MC, Nowell ARM, Jumars PA (1990) Flume observations on flow dynamics in *Zostera marina* (eelgrass) beds. Mar Ecol Prog Ser 61:159–169

Giesen WBJT (1990) Wasting disease and present eelgrass condition. Laboratory of Aquatic Ecology, University of Nijmegen, The Netherlands

Giesen WBJT, Katwijk MM van, Hartog C den (1990a) Temperature, salinity, insolation and wasting disease of eelgrass (*Zostera marina* L.) in the Dutch Wadden Sea in the 1930s. Neth J Sea Res 25:395–404

Giesen WBJT, Katwijk MM van, Hartog C den (1990b) Eelgrass condition and turbidity in the Dutch Wadden Sea. Aquat Bot 37:71–85

Ginkel R van (1993) Between Scylla and Charybdis: an ethnic history of the fisherfolk of the Island of Texel, 1813–1932 (in Dutch). Het Spinhuis, Amsterdam

Ginkel R van (1995) Green-black: the heart of the Texel people. Reflections on an island culture (in Dutch). Het Spinhuis, Amsterdam

Harmsen GW (1936) Systematische Beobachtungen der Nordwest-Europaeischen Seegrasformen. Ned Kruidk Arch 46: 852–877

Hartog C den (1994) Suffocation of a littoral *Zostera* bed by *Enteromorpha radiata*. Aquat Bot 47:21–28

Hartog C den, Polderman PJG (1975) Changes in the seagrass populations of the Dutch Waddenzee. Aquat Bot 1:141–147

Heck KL, Able KW, Roman CT, Fahay MP (1995) Composition, abundance, biomass and production of macrofauna in a New England estuary: comparisons among eelgrass meadows and other nursery habitats. Estuaries 18:379–389

Hermus DCR (1995) Reintroduction of seagrass in the Wadden Sea (in Dutch). Rapport Laboratorium voor Aquatische Oecologie, Katholieke Universiteit, Nijmegen, The Netherlands

Jespersen M, Rasmussen E (1994) Koresand – Die Entwicklung eines Aussensandes vor dem dänischen Wattenmeer. Die Küste 52:79–91

Jong DJ de (1999) Ecotopes in the Dutch marine tidal waters. Report RIKZ 99.017, Haren, The Netherlands

Jonge VN de (1983) Relations between annual dredging activities, suspended matter concentrations, and the development of the tidal regime in the Ems estuary. Can J Fish Aquat Sci 40 [Suppl 1]:289–300

Jonge VN de, Jong DJ de (1992) Role of tide, light and fisheries in the decline of *Zostera marina* L. in the Dutch Wadden Sea. In: Proceedings of the 7th International Wadden Sea Symposium, Ameland, The Netherlands. (Publication series no 20, Netherlands Institute of Sea Research) Casparie, Heerhugowaard, The Netherlands, pp 161–176

Jonge VN de, Ruiter JF (1996) How subtidal were the 'subtidal beds' of *Zostera marina* L. before the occurrence of the wasting disease in the early 1930s? Neth J Aquat Ecol 30:99–106

Jonge VN de, Essink K, Boddeke R (1993) The Wadden Sea: a changed ecosystem. Hydrobiologia 265:45–71

Jonge VN de, Bakker JF, Stralen MR van (1996a) Possible change in the contribution of the river Rhine and the North Sea to the eutrophic status of the western Dutch Wadden Sea. Neth J Aquat Ecol 30:27–39

Jonge VN de, Bergs J van den, Jong DJ de (1996b) Reintroduction of eelgrass (*Zostera marina*) in the Dutch Wadden Sea: review of research and suggestions for management measures. J Coast Conserv 2:149–158

Kamermans P, Hemminga MA, Jong DJ de (1998) The significance of salinity and silicate concentrations in Dutch coastal waters for the eelgrass area (in Dutch). BEON report no 98–5

Katwijk MM van (1992) Reintroduction of seagrass in the Wadden Sea. 1. Mesocosm experiments with eelgrass (*Zostera marina* L.) (in Dutch). Rapport Laboratorium voor Aquatische Oecologie, Katholieke Universiteit, Nijmegen, The Netherlands

Katwijk MM van, Vergeer LHT, Schmitz GHW, Roelofs JGM (1997) Ammonium toxicity in eelgrass *Zostera marina*. Mar Ecol Pro7g Ser 157:159–173

Katwijk MM van, Schmitz GHW, Hanssen LSAM, Hartog C den (1998) Suitability of *Zostera marina* populations for transplantation to the Wadden Sea as determined by a mesocosm shading experiment. Aquat Bot 60:283–305

Katwijk MM van, Schmitz GHW, Gasseling AM, Avesaath PH van (1999) Effects of salinity and nutrient load and their interaction on *Zostera marina.* Mar Ecol Prog Ser 190:155–165

Katwijk MM van, Hermus DCR, Jong DJ de, Jonge VN de (2000) Habitat suitability of the Wadden Sea for *Zostera marina* restoration. Helgol Mar Res 54:117–128

Oudemans CAJA, Conrad JFW, Maats P Jr, Bouricius LJ (1870) Appendix V. Report on the State Commission on the mowing of eelgrass. In: Report to the King on the Public Works in the year 1869 (in Dutch). Algemeene Landsdrukkerij, ‘s-Gravenhage, The Netherlands, pp 199–231

Reigersman CAJ (1939) Report on the influence of the wasting disease on the decline in the eelgrass population (in Dutch). Mimeograph

Reise K, Kolbe K, Jonge VN de (1994) Makroalgen und Seegrasbestände im Wattenmeer. In: Lozán JL, Rachor E, Reise K, Westernhagen P von, Lenz W (eds) Warnsignale aus dem Wattenmeer–Wissenschaftliche Fakten. Blackwell, Oxford, pp 90–100

Short FT, Wyllie-Echeverria S (1996) Natural and human-induced disturbance of seagrasses. Environ Conserv 23:17–27

White R, Engelen G, Uljee I (1997) The use of constrained cellular automata for high-resolution modelling of urban land-use dynamics. Environ Planning B 24:323–343