

## **Eelgrass (*Zostera marina* L.) in the western Wadden Sea: monitoring, habitat suitability model, transplantations and communication**

Arthur R. Bos<sup>1</sup>, Norbert Dankers<sup>2</sup>, Art H. Groeneweg<sup>3</sup>, D. Carin R. Hermus<sup>1</sup>,  
Zwanette Jager<sup>4</sup>, Dick J. de Jong<sup>5</sup>, Thea Smit<sup>4</sup>, Jaap de Vlas<sup>4</sup>,  
Marco van Wieringen<sup>6</sup> and Marieke M. van Katwijk<sup>1</sup>

<sup>1</sup> Department of Environmental Science, Institute for Wetland and Water Research, Radboud University Nijmegen, PO Box 9010, NL-6500 GL Nijmegen, The Netherlands  
E-mail: a.bos@science.ru.nl

<sup>2</sup> Research Institute ALTERRA Texel  
PO Box 167, NL-1790 AD Den Burg, Texel, The Netherlands

<sup>3</sup> Directorate-General for Public Works and Water Management, Department for Geo-information  
PO Box 5023, NL-2600 GA Delft, The Netherlands

<sup>4</sup> National Institute for Coastal and Marine Management/RIKZ  
PO Box 207, NL-9750 AE Haren, The Netherlands

<sup>5</sup> National Institute for Coastal and Marine Management/RIKZ  
PO Box 8039, NL-4330 EA Middelburg, The Netherlands

<sup>6</sup> Directorate-General for Public Works and Water Management, North Holland Department  
PO Box 3119, NL-2001 DC Haarlem, The Netherlands

### **Abstract**

Eelgrass almost completely disappeared in the course of the previous century. Because of this, the Dutch authorities funded a four-year (2002-2005) project "Reintroduction of eelgrass (*Zostera marina* L.) in the western Wadden Sea". The objective of this project was to create a stable eelgrass population which would grow into a source for further recovery and expansion. Transplantations were carried out using the expertise from previous research on habitat requirements, donor suitability and transplantation techniques. Furthermore, actual eelgrass beds in the Wadden Sea were monitored, a communication strategy was implemented and a seagrass map (for both *Z. marina* and *Z. noltii*) was developed with a Habitat Suitability Model in order to select optimal locations for transplantation and protection. This paper gives an overview of these activities and their results. Transplantation depth, size and density of planting units were varied to optimize the transplantation technique. Some transplantations were carried out in proximity of a mussel bed to test facilitative effects. A chain of unfortunate events caused the transplantation in the year 2002 to fail. The transplantation in 2003 became very successful: high survival rates with abundant development of reproductive shoots, though few seeds were observed. In spring 2004 few seedlings were found, which may have been due to the low seed production observed in 2003 and/or abundant macro-algal development. The transplantations in 2004 resulted in equally high survival rates as in 2003. Fortunately, abundant seed production was measured in September 2004.

From the experimental pilot in transplanting we learned that higher density (14 vs. 5 plants·m<sup>-2</sup>) has a favourable effect on survival, except at the most sheltered locations where density had no effect. Variation in planting unit size (37 vs. 61 plants) had no effect, while variation in depth (+2 vs. +8cm MSL) only had marginal effects. Planting in open spaces within a mussel bed had a positive effect on eelgrass survival during the first growing season, indicating facilitation. At present, natural seagrass beds in the Wadden Sea cover approximately 270ha, but this figure varies from year to year. Habitat suitability was found to be 20-50% in an area of 9,490ha in the Dutch Wadden Sea and 50-80% in an area of 1,747ha. Another 200ha was highly suitable (80-100%) for seagrass growth. This, together with the small scale transplantation successes and the persistence of (dynamic) natural beds, gives hope for future seagrass recovery in the Wadden Sea.

Keywords: Facilitation; GIS-model; Seagrass; Transplantation; Wadden Sea.

## Introduction

The cosmopolitan eelgrass (*Zostera marina* L.) suffered worldwide from the ‘wasting’ disease in the 1930s (Rasmussen, 1977; Giesen *et al.*; 1990ab; de Jonge *et al.*, 2000), which wiped out hundreds of hectares. Natural recovery of eelgrass in the Wadden Sea was poor, probably due to intensive engineering activities (*e.g.* Nienhuis and de Bree, 1977; Nienhuis, 1983; Reise, 1985), poor visibility in the water column and fishery activities (Giesen, 1990ab; de Jonge *et al.*, 2000) and increased nutrient loads in the 1970s and 1980s (van Katwijk *et al.*, 1997, 1999, 2000). By that time, the abundance of eelgrass in the Wadden Sea had been reduced by more than 99% since the 1930s (de Jonge *et al.*, 2000). In the 1990s water quality improved and the visibility of the water column increased again (de Jonge *et al.*, 1996, 2000), but eelgrass did not recover in the western Wadden Sea. The seeds or seed bearing shoots of the remnant eelgrass locations in the eastern part of the Dutch Wadden Sea may not have reached the western part due to predominantly westerly winds and currents.

In 1987, the Dutch government started to support studies into options for seagrass restoration in the western Wadden Sea, in order to restore natural values. These studies were carried out by the Radboud University Nijmegen in cooperation with the National Institute for Coastal and Marine Management. Habitat suitability in the Wadden Sea was tested, suitable donor populations were identified, selection criteria for optimal habitats were defined and transplantations techniques were evaluated (van Katwijk, 2003; van Katwijk and Wijgergangs, 2004). In 2002, the Dutch government decided to put effort into the recovery of eelgrass in the Wadden Sea on a larger scale. This project was funded by the Dutch Directorate-General for Public Works and Water Management and carried out by the two above-mentioned institutes in cooperation with the research institute Alterra. The purpose of this paper is to give managers, politicians and scientists an overview of the different aspects of a reintroduction project.

### **Status of legal protection and policy regulations on eelgrass**

The elaboration of the EU Habitats Directive (1992) was a step forward in the protection of European terrestrial and marine habitats and species. Several marine habitats were identified as targets for conservation and restoration, such as sandy shore, mud flats, coastal sub-tidal sandy sediments, large shallow inlets and bays. Mudflats, shallow inlets

and bays are habitats where eelgrass could be a dominant natural inhabitant. Eelgrass, as species, was not considered to be endangered and has not been protected under this instrument. In addition to the Habitats Directive, the Oslo-Paris Commission (OSPAR - 1992) for the protection of the marine environment of the North East Atlantic recently prepared an initial list of threatened and/or declining species and habitats. The inclusion of *Zostera* beds on this list reflects the necessity of protection of these habitats and species. Some additional protection for eelgrass may also be provided by the Ramsar Convention and the EU Birds Directive.

Eelgrass (*Zostera marina*) was, together with Dwarf Eelgrass (*Zostera noltii*), incorporated in the Dutch Red List of threatened plants in March 2002. This list proceeded from the implementation of the Convention of Bern (1982), in which protection for endangered and vulnerable species was demanded. Eelgrass and its habitat have been protected by the Dutch Flora and Fauna Act since 2002. Furthermore, *Zostera* beds were chosen as a classification tool for several Dutch water bodies including the Wadden Sea under the European Water Framework Directive. In 2005 the Dutch government will decide about species and habitat protection under the *Planologische Kernbeslissing* (PKB). Results of the present project were used to support an increase of no-activity zones around eelgrass plants from 40 to 500m.

In spite the fact that eelgrass habitats are protected under the above-mentioned instruments, they are still highly endangered. It remains important to give global consideration to eelgrass habitats on a wide scale and it remains necessary to define specific conservation regulations at the level of the species or genus.

## **Transplantations**

### ***Location selection***

Location selection has been considered the most important phase in restoration practices (Fonseca *et al.* 2002) and therefore considerable attention was given to these activities. Areas considered for planting were selected according to the following criteria (van Katwijk 2003):

- eelgrass used to grow naturally in the selected area in the past;
- the area should have natural protection against prevailing wind directions;
- the area should have some freshwater input;
- no fishing activities or bait digging should be allowed in or in the proximity of the area.

As a result of the selection process Balgzand, a tidal area in the western Wadden Sea of approximately 6,000ha, was chosen to be the main area for the project as it fits all selection criteria (Fig. 1). The habitat suitability map (explained below) supported the selection of Balgzand.

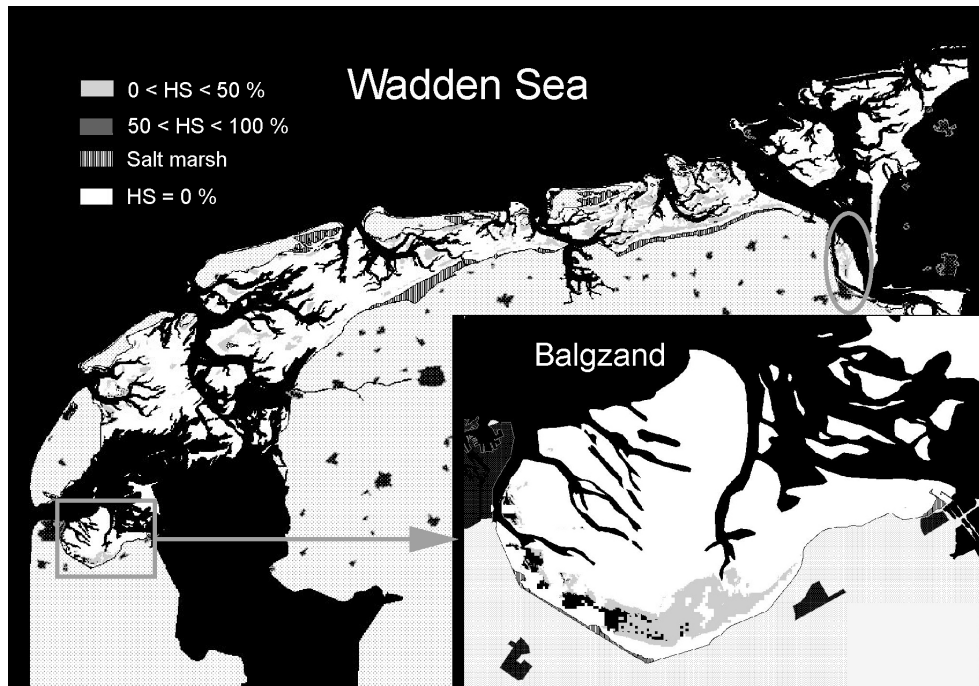


Fig. 1. Map of the Wadden Sea as a result of the Habitat Suitability Model. Habitat Suitability (HS) for seagrass is presented in three categories (%):  $HS = 0$ ,  $0 < HS \leq 50$  and  $50 < HS \leq 100$ . The grey square is enlarged and represents the Balgzand area. The grey oval encircles the donor population in the Ems Estuary.

The following criteria were used to select transplantation areas on a local scale (van Katwijk and Wijgergangs, 2004):

- sediment should be stable and not too coarse;
- depth of the location should be between +15 and -20cm MSL;
- wave exposure should be slight;
- a thin layer of water should remain during low tide.

Additionally, it was considered of vital importance to spread risks in space and in time, consistent with the apparent strategy of natural beds. Natural beds ([www.zeegras.nl](http://www.zeegras.nl), see also below), as well as transplantations (*e.g.* Bos *et al.*, 2004), show large fluctuations in cover and density.

Seedlings that were to be used for transplantation were collected at the tidal area Hond/Paap in the Ems Estuary in the eastern Dutch Wadden Sea (Fig. 1). Seedlings were dug up by hand (only one seedling per 9m<sup>2</sup> to guarantee genetic diversity) and carefully rinsed and transported to the new locations at temperature of collection.

A planting unit (PU) consisted of 37 (or 61) seedlings transplanted in a hexagon bed (Fig. 2). The mutual distance between two neighboring shoots was constant (in six

directions) by the nature of this hexagon shape. Shoot density was set at mutual distance of 30cm (high density = 14 seedlings·m<sup>-2</sup>) or 50cm (low density = 5 seedlings·m<sup>-2</sup>). High density (HD) and low density (LD) PUs were always transplanted in pairs. The imaginary line between the two center points of all pairs of PUs was fixed at 50°N to assure similar exposure to the tidal currents.

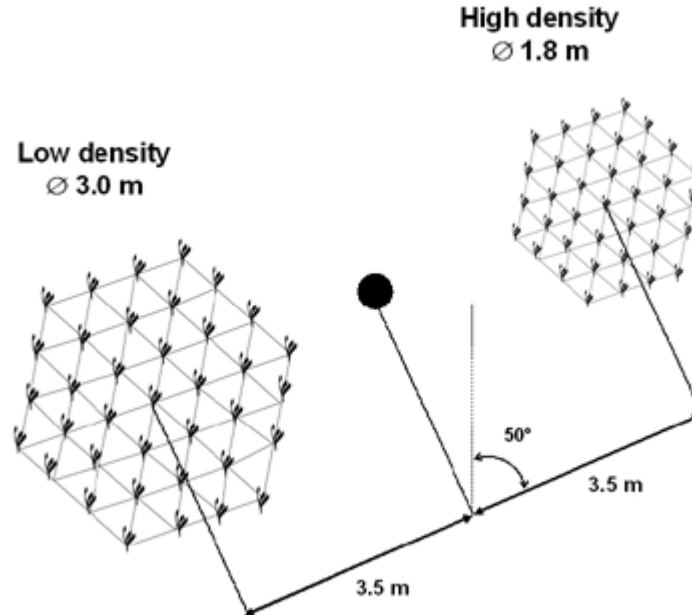


Fig. 2. Planting units (PU) with eelgrass seedlings at low density (LD = 5 seedlings·m<sup>-2</sup>) and high density (HD = 14 seedlings·m<sup>-2</sup>). Size of PU diameter is indicated. PU-pair axis was positioned at 50°N to guarantee similar exposure to the prevailing currents.

### Habitat Suitability Model

A habitat suitability map was developed for the seagrasses in the Dutch Wadden Sea (de Jong *et al.*, 2005). This map shows locations which are potentially suitable for the growth of seagrasses (Fig. 1) and is applicable to both *Zostera marina* and *Zostera noltii*: two species that often co-occur and have highly similar habitat preferences. The map is based on a GIS-model using five environmental factors: duration of exposure to dehydration, current velocity, wave exposure, salinity and ammonium load. The relationship between seagrass habitat suitability (HS) and these factors was based on own monitoring data and available literature (see below). The habitat suitability map could be used to support policy measures on protection or to determine suitable eelgrass locations for transplantation. This makes it an important policy instrument.

### *Duration of exposure to dehydration*

Upper and lower limits of seagrass zonation are determined by duration of exposure to dehydration during each tidal cycle. If the duration is too long the plants desiccate, and if the submersion period is too long exposure to waves causes continuous and harmful flip-flapping of the leaves (van Katwijk and Hermus, 2000; van Katwijk *et al.*, 2000). The relationship between duration of exposure to dehydration and HS is based on monitoring, field experiments and literature studies (Harmsen 1936; van Katwijk and Hermus, 2000; van Katwijk *et al.*, 2000; Groeneweg, 2004; Bos *et al.*, *subm.*; [www.zeegras.nl](http://www.zeegras.nl)) and was defined as follows: duration of exposure to dehydration  $\geq 65\%$ : HS 0%; 60% and 50%: HS 100%; 45%: HS 50%;  $\leq 40\%$ : HS 0%. Values in between were interpolated.

The habitat suitability map based on duration of exposure to dehydration was composed of a bathymetric chart of the Wadden Sea (2002, Ministry of Transport, Water Management and Public works [TWP]) and data on average, neap and spring tidal cycles.

### *Current velocity*

When current velocities are too high, drag forces on the leaves increase, productivity and biomass development decrease, and ultimately the leaves tear off (Conover, 1968; Fonseca and Kenworthy, 1987; Fonseca *et al.*, 1998; Schanz and Asmus, 2003; Bouma *et al.*, *subm.*). These effects occur in the range between 0.1 and 1.2 m·s<sup>-1</sup>. In the model we used the following relationship: current velocity 0-0.5 m·s<sup>-1</sup>: HS 100%; 0.7 m·s<sup>-1</sup>: HS 50%;  $\geq 0.9$  m·s<sup>-1</sup>: HS 0%. Values in between were interpolated.

The habitat suitability map based on current velocity was composed of the coastal zone model for currents SWAN, for dominant wind directions and moderate storm velocities, namely: SW 20-22 m·s<sup>-1</sup>; W 21-22 m·s<sup>-1</sup>; NW 18-21 m·s<sup>-1</sup>; NE 15 m·s<sup>-1</sup>.

### *Wave exposure*

Waves have more severe effects on seagrasses than currents. Wave action causes a continuously varying drag force on the leaves; a flip-flapping that may best be compared with metal tiredness. A relationship between eelgrass growth and duration of exposure to wave dynamics was corroborated in field experiments (van Katwijk and Hermus, 2000; Bos *et al.*, *subm.*). There is little information on critical values though. In the Wadden Sea, negative effects were detected at 0.4 and 0.6 m·s<sup>-1</sup> orbital velocity (van Katwijk and Hermus, 2000). In the model, the following relationship was used: orbital velocity 0-0.2 m·s<sup>-1</sup>: HS 100%; 0.3 m·s<sup>-1</sup>: HS 50%;  $\geq 0.4$  m·s<sup>-1</sup>: HS 0%. Values in between were interpolated. The habitat suitability map based on orbital velocities was similarly composed as the current velocity map (see above).

### *Salinity and ammonium loads*

It is generally known that seagrass productivity and vitality decrease at high salinity (*e.g.* Kamermans *et al.*, 1999; Wijgergangs and de Jong, 1999; van Katwijk *et al.*, 1999;

www.zeegras.nl). It is also known that high nitrogen loads, particularly ammonium-N, have a negative effect on seagrass and could even become toxic (van Katwijk *et al.*, 1997, 1999). Moreover, salinity and nitrogen loads interact and cause a synergetic effect on seagrass vitality. At a relatively low salinity, nitrogen stimulates growth, whereas at a high salinity growth is impaired. Nitrogen compounds cannot be used for growth by eelgrass and thus accumulate, negatively affecting the plant (van Katwijk *et al.*, 1999). On the basis of these studies the relationship between salinity, ammonium and seagrass habitat suitability was estimated (Table I).

Table I. Habitat suitability (%) for *Zostera marina* and *Zostera noltii* as function of ammonium flux and salinity (PSU, Practical Salinity Unit). Habitat suitability was optimistically estimated as to compensate for overestimation of ammonium loads by the EcoWasp model (described below)

Salinity, median period July-September (PSU)	Ammonium flux (kg·ha <sup>-1</sup> ·yr <sup>-1</sup> )			
	0-50	50-100	100-150	>150
>31	100 <sup>1</sup>	0	0	0
28-30	100	80	60	40
23-27	100	100	100	80
16-22	100	100	100	100
<16	0	0	0	0

<sup>1</sup>) A positive effect of low ammonium loads is expected, resulting in habitat suitability of 100%.

The habitat suitability map on salinity was composed of a 2D model based on water movements, water quality and local freshwater sources (Jager and Bartels, 2002). We used the calculations of spring 1988 which was a relatively wet period in a relatively wet year.

The habitat suitability map based on ammonium load was composed of ammonium fluxes from the sediment. Ammonium fluxes were calculated by the ecological model EcoWasp (Brinkman, 1993). Data from the Ministry of TWP comprising the monitoring results of abiotic parameters were all based on channel samples, and were not considered suitable to estimate tidal flat nitrogen loads. EcoWasp calculates ammonium fluxes on the basis of temperature and organic matter content. The model includes several biological processes: benthic and pelagic algae, filter feeders and mineralisation processes in the sediment (Brinkman, 1993).

Organic matter content was calculated from silt maps (fraction <16µm) according to Zwarts (1988). Silt maps were based on the SWAN wave and current model mentioned above. Values for waves and currents were calculated using a dataset of 7,000 sediment samples of 0-10cm depth (Zwarts, 1988; Zwarts, 2003; de Jong *et al.*, 2005) and correlated to sediment silt content.

A shortcoming of the ammonium prediction was that the benthic diatom activity (ammonium consumption) was underestimated, as it was based on an average light

climate. The area of interest, with an exposure period of about 50%, has a higher light availability. Ammonium tolerances were optimistically estimated to compensate for this (Table I).

### ***Results and discussion of the habitat suitability map***

The habitat suitability map correctly predicted the currently existing eelgrass locations (Fig. 1). However, some locations were considered to be too large, especially in the eastern Dutch Wadden Sea. Wave energy was estimated using a wave energy model and this may have resulted in an underestimation for particular areas. Wave energy predictions in shallow areas have a relatively large uncertainty and the SWAN model cannot be tested due to the unavailability of wave measurements on tidal flats. The habitat suitability model has its drawbacks, but can be considered to be a policy instrument, using the best available scientific, technological and monitoring information. In the Dutch Wadden Sea, the model predicts high habitat suitability (80-100%) for seagrasses in about 200ha, whereas another 1,800ha are moderately suitable (50-80%). The model confirms that the Balgzand area is a suitable location for reintroduction of seagrass.

### ***Transplantation results***

Field activities started in June 2002 with the transplantation of about 1,500 eelgrass seedlings. Survival was low and soon it was discovered that incorrect depth data had been provided. The eelgrass seedlings had been transplanted at -20cm MSL and deeper, rather than between depths of -10 and +10cm MSL, as was planned (Jager *et al.* 2002). Previous studies had shown that transplanted eelgrass hardly survived at these depths (van Katwijk and Hermus, 2000).

In June 2003 about 1,800 eelgrass seedlings were transplanted to three new locations in the Balgzand area. About 50% of the originally transplanted shoots had grown into eelgrass plants by the end of the growing season at one location (Fig. 3A). The plants developed reproductive shoots but no seeds were observed. Moreover, no seedlings were found to develop in spring 2004, probably due to the low seed production (pers. obs.).

The locations, where survival of transplants had been high in 2003 were selected to be enhanced with 1,400 seedlings in June 2004. Again about 40% had survived by the end of the growing season (Fig. 3A) and produced reproductive shoots. An intensive study into seed production proved that seeds were present, which supported expectations that developing seedlings were to be found in spring 2005.

### ***Seedling density, depth and quantity***

The success of transplantation could be affected negatively by local disturbances and therefore it was considered important to simultaneously work in different microhabitats during the eelgrass transplantations. Apart from transplanting at different locations, transplant density, transplant depth and number of shoots per planting unit were varied.



High density PUs supported survival of transplants at those locations exposed to waves and currents, whereas planting density had no effect on survival of transplants in sheltered habitats (Bos *et al.*, submitted).

Shoots were transplanted at different depths in the safe range (see above). However, none to locally small differences in survival of transplants were observed between depths of +2 and +8cm MSL (Bos *et al.*, 2004; Bos *et al.*, 2005).

As mutual protection was expected to affect survival of transplants, the size of PUs was varied (37 or 61 plants). No significant differences were observed though.

#### *Interaction between eelgrass and the blue mussel*

Eelgrass and blue mussels have been observed to occur together in tidal habitats (reviewed in van Katwijk, 2003). Eelgrass grows at greater depth if the blue mussel is present. This possible facilitation may be based on the capacity of the blue mussel to reduce the velocity of the current (Bouma *et al.*, submitted). A natural mussel bed located in relatively shallow water in the Balgzand area was selected to study this interaction. 444 seedlings were transplanted within the mussel bed, whereas 111 seedlings were transplanted to an open mudflat adjacent to the mussel bed at similar depth of -50cm MSL.

Although transplants disappeared before the end of the growing season (Fig. 3B), it was observed that plants growing in the mussel bed survived significantly longer (Kaplan-Meier,  $P < 0.01$ ) than those growing on the exposed mud flat (Bos *et al.*, submitted).

#### *Long-term successes*

Experiments with eelgrass seeds and reproductive shoots carried out in the Balgzand area in the year 1999 resulted in fluctuating numbers of between 26 (2002) and 800 plants (2003) distributed over circa 5ha (Bos *et al.*, 2004). In 2004, only 50 plants were found. The number of eelgrass plants seems to be inversely related to macro-algal development in the preceding year. Massive decay of macro-algae that drift ashore is an often observed threat to eelgrass (Hauxwell *et al.*, 2001, Cardoso *et al.*, 2004). A longer period of monitoring is required to support evidence for this relationship.

### **Communication**

In 2002, a communication plan was developed in which the Ministry of TWP formulated the following objectives:

- creation of public support for the reintroduction project;
- visualization of the project;
- information of interested persons;
- transferring of knowledge.

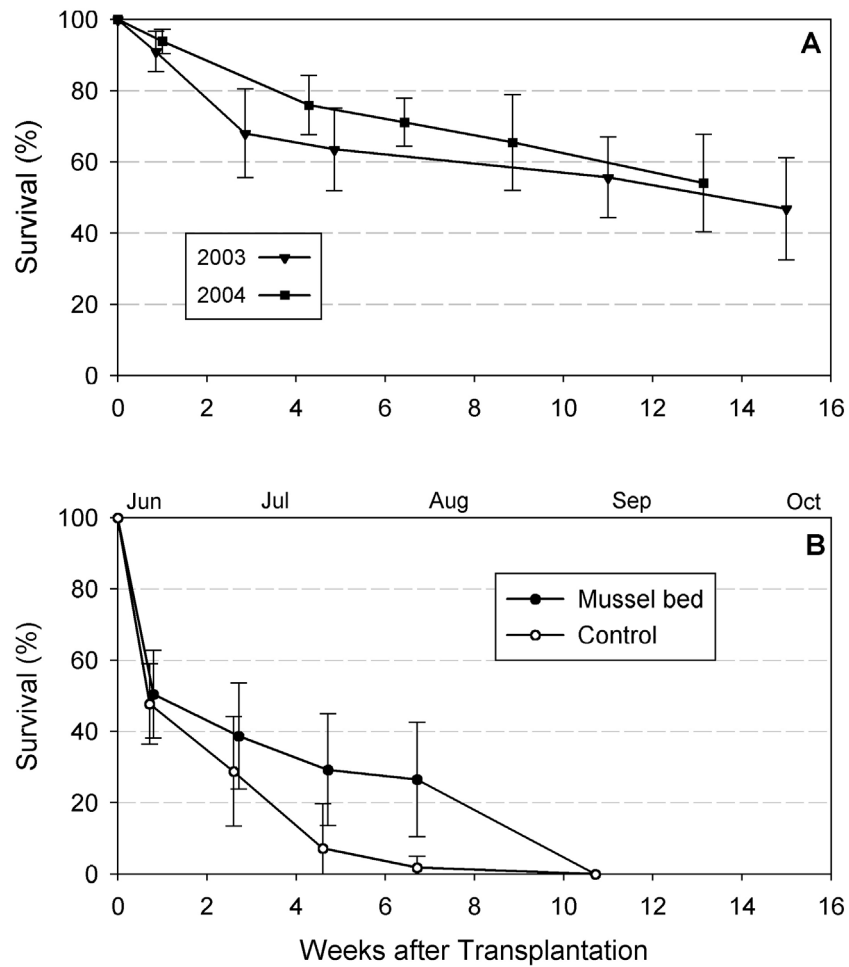


Fig. 3. Survival of eelgrass transplants at two locations in the Balgzand area. A: Relatively high survival at a location in two successive years 2003 and 2004. B: Survival of eelgrass transplants in a mussel bed and at a control location at a relative deep site.

Target groups are all the stakeholders of the Wadden Sea area, including politicians, civil servants, managers, interested citizens, NGO's and the press. Employees of museums and local tourist centers (Zuiderzeemuseum Enkhuizen, Ecomare Texel, Center for Nature and Landscape Terschelling, Information Center 'Noordwester'

Vlieland and Visiting Center ‘t Kuitje’ Den Helder) were interviewed to elaborate the type of information needed for the different stakeholders. Furthermore, employees of the Ministry of TWP advised on the level and type of information required for professional target groups.

The museums and tourist centers unanimously advised that information for interested citizens should not contain any explanations about policy decisions. The representatives of the Ministry suggested that professionals however should be informed about the policy decisions. Next, it was decided to develop a brochure for interested citizens. The information presented did not go into unnecessary detail and the text/figure ratio was set at about 50%. The brochure presented information about the ecology of eelgrass, the importance of the restoration of viable populations, the results of restoration so far, the aims for future restoration and also referred to the project website [www.zeegras.nl](http://www.zeegras.nl). This website was primarily set up as a communication tool for monitoring data and general knowledge of the species to both interested citizens and professionals. Later it was supplemented with information about the transplantations, policy backgrounds, technical information as well as with actual developments. Photographs with explanatory captions, as suggested by the museums and tourist centers, illustrate the restoration activities. Through hyperlinks the professional and interested visitor is able to find background information and information on related subjects. The website is set up in the Dutch and English languages and provides the option to order a brochure in either language.

## Discussion and conclusions

The area covered by eelgrass in the Dutch Wadden Sea roughly measured about 270ha in 2003 (Table II). However, the yearly fluctuations of eelgrass coverage are relatively high. Therefore, it is extremely important to have an estimation of the total area of potential eelgrass habitat. This shows the importance of the habitat suitability map. By protecting the potentially suitable eelgrass habitats, this species may recover at a higher rate than when only currently existing eelgrass habitats are protected.

Table II. Eelgrass area presented for three locations in the Dutch Wadden Sea in the year 1995, 1999 and 2003. The average area and standard deviation are calculated with data from 1988-2004. All values are in ha. “0” represents only a few plants whereas “-” represents no data available ([www.zeegras.nl](http://www.zeegras.nl), Groeneweg 2004)

Location	Year			Average	STD
	2003	1999	1995		
Hond/Paap	256.2	92.3	63.6	117.3	86.5
Terschelling	0	5.8	19.2	6.4	6.5
Voolhok	6.3	-	-	7.8	2.1

The high dynamics in natural beds and the variations in transplantation survival (*e.g.* Bos *et al.*, 2004) stress the importance of spreading risks when transplanting eelgrass. Changes in local environmental conditions may cause transplants to be wiped out. This can probably be avoided by simultaneously planting at different locations. An important

observation during the present study was that it may be useful to spread risks in more than one dimension. Optimal survival of transplants depends on several factors. Therefore, the risks should be spread in space (location), and also in *e.g.* depth or density of transplants. The results of such activities could additionally help to adjust the methodology and optimize the transplantation strategy.

Transplantation of seagrasses has been carried out and studied for decades all over the world (*e.g.* Phillips, 1980; Worm and Reusch, 2000; Short *et al.*, 2002; van Katwijk, 2003). It is a common phenomenon in transplantation experiments that the total number of plants in a PU logarithmically decreases towards a stable number. Survival of transplants was calculated to fluctuate around a median of 35% in 53 North American seagrass transplantation studies (Fonseca *et al.*, 1998). During the present study, survival ranged from 28 to 68% seven weeks after transplantation. Although these surviving plants produced reproductive shoots, winter survival and seedling growth were low. Seed maturation may have been poor during these observations. Nevertheless, an intensive study on seed maturation in 2004 showed the existence of relatively high numbers of ripe seeds (Bos *et al.*, 2005). Hopefully this will result in the development of seedlings in 2005.

Co-occurrence of blue mussels (*Mytilus edulis*) and eelgrass has often been described with special emphasis to the protective function of the blue mussel (*e.g.* van Katwijk and Hermus, 2000). Experiments by Bouma *et al.* (subm.) showed that the blue mussel facilitates eelgrass by reducing the drag force on eelgrass shoots when exposed to currents. We tested this relationship at a relatively exposed location and found that transplanted eelgrass shoots had a significantly higher survival in mussel beds than without mussel bed protection (Fig. 3B; Bos *et al.*, submitted). However, all plants disappeared towards the end of the growing season. This suggested that a protective mechanism of the mussel bed was present, but not strong enough to support long-term survival. Similar observations were done by Reusch and Chapman (1995), who found that mussel beds protect eelgrass during moderate storms, but not during strong storms. For future transplantations, it might be useful to plant adjacent to or within mussel beds or other naturally present objects that provide shelter.

Although locations were carefully selected, local environmental conditions may vary and highly influence the results of transplantation activities. Therefore, an ample period of time should be reserved for location selection and the fine-tuning of the methodology. Loss of transplants is unavoidable, but may result in knowledge that helps to develop the methodology and to increase survival in the years to follow.

## **Acknowledgements**

We acknowledge the *Stichting Landschap Noord-Holland* for their support and cooperation during the field activities.

## References

- Bos A.R., D.C.R. Hermus and M.M. van Katwijk. Submitted to the Journal of Applied Ecology. Interactive effects of planting density, exposure and mussel bed protection on transplantation success of eelgrass (*Zostera marina* L.).
- Bos A.R., D.C.R. Hermus and M.M. van Katwijk. 2004. Herintroductie van *Zostera marina* in de westelijke Waddenzee (2002-2006); Resultatenrapportage 2003. Afdeling Milieukunde, Radboud Universiteit, Nijmegen. 57p.
- Bos A.R., D.C.R. Hermus, P. Vugteveen and M.M. van Katwijk. 2005. Herintroductie van *Zostera marina* in de westelijke Waddenzee (2002-2006); Resultatenrapportage 2004. Afdeling Milieukunde, Radboud Universiteit, Nijmegen. 49p.
- Bouma T.J., W. Suykerbuyk, A.R. Bos, M.M. van Katwijk and P.M.J. Herman. Submitted to Functional Ecology. Is facilitation relevant to stress avoiders: linking community-level interaction strength to individual-level stress coping strategy.
- Brinkman A.G. 1993. Biological processes in the EcoWasp ecosystem model. Report 93/6. Institute for Forestry and Nature Research. Wageningen, The Netherlands. 111p.
- Cardoso P.G., M.A. Pardal, A.I. Lillebo, S.M. Ferreira, D. Raffaelli, J.C. Marques. 2004. Dynamic changes in seagrass assemblages under eutrophication and implications for recovery. Journal of Experimental Marine Biology and Ecology 302:233-248.
- Conover J.T. 1968. The importance of natural diffusion gradients and transport of substances related to benthic marine plant metabolism. Botanica Marina 11:1-9.
- Fonseca M.S. and W.J. Kenworthy. 1987. Effects of current on photosynthesis and distribution of seagrasses. Aquatic Botany 27:59-78.
- Fonseca M.S., W.J. Kenworthy and G.W. Thayer. 1998. Guidelines for the conservation and restoration of seagrasses in the United States and adjacent waters. NOAA Coastal Oceans Program Decision Analysis Series No. 12 NOAA Coastal Ocean Office, Silver Spring MD.
- Fonseca M.S., W.J. Kenworthy, B.E. Julius, S. Shutler and S. Fluke. 2002. Seagrasses. p.149-170. In: Handbook of ecological restoration; Restoration in practice. Vol. 2. Perrow M.R. and A.J. Davy (Eds), Cambridge University Press. 618p.
- Giesen W.B.J.T., M.M. van Katwijk and C. den Hartog. 1990a. Temperature, salinity, insolation and wasting disease of eelgrass (*Zostera marina* L.) in the Dutch Wadden Sea in the 1930's. Netherlands Journal of Sea Research 25:395-404.
- Giesen W.B.J.T., M.M. van Katwijk and C. den Hartog. 1990b. Eelgrass condition and turbidity in the Dutch Wadden Sea. Aquatic Botany 37:71-85.
- Groeneweg A.H. 2004. Verslag macrofytobenthos and zeegraskartering in Oosterschelde en Waddenzee 2003, deels op basis van false colour-luchtfoto's schaal 1:10.000. Rijkswaterstaat, Adviesdienst Geo-informatie en ICT. Delft, the Netherlands. 15p.
- Harmsen G.W. 1936. Systematische Beobachtungen der Nordwest-Europäischen Seegrassenformen. Nederlands Kruidkundig Archief 46:852-877.
- Hauxwell J., J. Cebrian, C. Furlong, and I. Valiela. 2001. Macroalgal canopies contribute to eelgrass (*Zostera marina*) decline in temperate estuarine ecosystems. Ecology Washington DC, 82:1007-1022.
- Jager Z. and W. Bartels. 2002. Optimale zoetwateraanvoer naar de Waddenzee. Werkdocument RIKZ/AB/2002.604x. Haren, the Netherlands.

- Jager Z., M. van Wieringen, M.M. van Katwijk and S. van Pelt. 2002. Transplantation of eelgrass (*Zostera marina*) to the western Dutch Wadden Sea. *Wadden Sea Newsletter* 2:23-25.
- Jong D.J. de, A.G. Brinkman and M.M. van Katwijk. 2005. Kanskaart zeegrass Waddenzee. report RIKZ. Middelburg, the Netherlands.
- Jonge V.N. de, D.J. de Jong and J. van den Bergs. 1996. Reintroduction of eelgrass (*Zostera marina*) in the Dutch Wadden Sea; review of research and suggestions for management measures. *Journal of Coastal Conservation* 2:149-158.
- Jonge V.N. de, D.J. de Jong and M.M. van Katwijk. 2000. Policy plans and management measures to restore eelgrass (*Zostera marina* L.) in the Dutch Wadden Sea. *Helgoland Marine Research* 54:151-158.
- Kamermans P., M.A. Hemminga and D.J. de Jong. 1999. Significance of salinity and silicon levels for growth of a formerly estuarine eelgrass (*Zostera marina*) population (Lake Grevelingen, the Netherlands). *Marine Biology* 133:527-539.
- Katwijk M.M. van, L.H.T. Vergeer, G.H.W. Schmitz and J.G.M. Roelofs. 1997. Ammonium toxicity in eelgrass *Zostera marina*. *Marine Ecology Progress Series* 157:159-173.
- Katwijk M.M. van, G.H.W. Schmitz, A.M. Gasseling and P.H. van Avesaath. 1999. The effects of salinity and nutrient load and their interaction on *Zostera marina* L. *Marine Ecology Progress Series* 190:155-165.
- Katwijk M.M. van and D.C.R. Hermus. 2000. Effects of water dynamics on *Zostera marina*: Transplantation experiments in the intertidal Dutch Wadden Sea. *Marine Ecology Progress Series* 208:107-118.
- Katwijk M.M. van, D.C.R. Hermus, D.J. de Jong, R.M. Asmus and V.N. de Jonge. 2000. Habitat suitability of the Wadden Sea for restoration of *Zostera marina* beds. *Helgoland Marine Research* 54:117-128.
- Katwijk M.M. van. 2003. Reintroduction of eelgrass (*Zostera marina* L.) in the Dutch Wadden Sea, a research overview and management vision. p.173-197. In: Challenges to the Wadden Sea area. Wolff W.J., K. Essink, A. Kellermann and M.A. van Leeuwe (Eds). *Proceedings of the 10<sup>th</sup> International Scientific Wadden Sea Symposium*.
- Katwijk M.M. van and L.J.M. Wijgengangs. 2004. Effects of locally varying exposure, sediment type and low-tide water cover on *Zostera marina* recruitment from seed. *Aquatic Botany* 80:1-12.
- Nienhuis P.H. and B.H.H. de Bree. 1977. Production and ecology of eelgrass (*Zostera marina* L.) in the Grevelingen Estuary, the Netherlands, before and after the closure. *Hydrobiologia* 52:55-66.
- Nienhuis P.H. 1983. Temporal and spatial patterns of eelgrass (*Zostera marina* L.) in a former estuary in the Netherlands, dominated by human activities. *Marine Technology Society Journal* 17:69-77.
- Phillips R.C. 1980. Transplanting methods. p.41-56. In: *Handbook of seagrass biology: an ecosystem perspective*. Phillips R.C. and C.P. McRoy (Eds). Garland Press, New York.
- Rasmussen E. 1977. The wasting disease of eelgrass (*Zostera marina*) and its effect on environmental factors and fauna. p.1-51. In: *Seagrass ecosystems, a scientific perspective*. McRoy C.P. and C. Helfferich (Eds). Marcel Dekker, New York.
- Reise K. 1985. Tidal flat ecology. An experimental approach to species interactions. *Ecological Studies* 54. Springer-Verlag Berlin. 191p.

- Reusch T.B.H. and A.R.O. Chapman. 1995. Storm effects on eelgrass (*Zostera marina* L.) and blue mussel (*Mytilus edulis* L.) beds. *Journal of Experimental Marine Biology and Ecology* 192:257-271.
- Schanz A. and H. Asmus. 2003. Impact of hydrodynamics on development and morphology of intertidal seagrasses in the Wadden Sea. *Marine Ecology Progress Series* 261:123-134.
- Short F.T., R.C. Davis, B.S. Kopp, C.A. Short and D.M. Brudick. 2002. Site-selection model for optimal transplantation of eelgrass *Zostera marina* in the northeastern US. *Marine Ecology Progress Series* 227:253-267.
- Wijgergangs L.J.M. and D.J. de Jong. 1999. Een ecologisch profiel van zeegras en de verspreiding in Nederland. Department of Aquatic Ecology and Environmental Biology, University of Nijmegen.
- Worm B. and T.B.H. Reusch. 2000. Do nutrient availability and plant density limit seagrass colonization in the Baltic Sea? *Marine Ecology Progress Series* 200:159-166.
- Zwarts L. 1988. De bodemfauna van de Fries-Groningse Waddenkust. *Flevobericht* 294, Rijksdienst voor de IJsselmeerpolders. Lelystad, the Netherlands. 195p.
- Zwarts L. 2003. Bodemgesteldheid en mechanische kokkelvisserij in de Waddenzee (concept). RIZA rapport 2003. Lelystad, the Netherlands. 123p.