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Seagrass

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1. Introduction

Narrow-leaved *Zostera noltii* and broader-leaved *Z. marina* on a tidal flat near Sylt (Photo: K. Reise).

Seagrasses occur worldwide in shallow coastal waters. In the Wadden Sea these periodically submersed flowering plants are represented by two species of the genus *Zostera*. The small and very narrow-leaved *Z. noltii* is the most common. It grows in the intertidal zone and is usually perennial. It is often accompanied by a mostly annual, narrow-leaved, small morph of the large *Z. marina*, growing particularly in puddles which remain filled with water at low tide. Around the low-water line and deeper, beds of a large and perennial *Z. marina*, with rigid bases and broad leaves, once occurred in the western and northern Wadden Sea. In the course of a wasting phenomenon in the early 1930s these beds vanished and never came back. The primary cause of the decline of the perennial *Z. marina* beds might have been anomalously cloudy and/or warm years in the 1930s, and the conspicuous infestation with the pathogenic protist *Labyrinthula zosterae* – which may have come up as a response to the already weakened seagrasses (den Hartog and Phillips, 2001).

In spite of this historic decline, a high allelic diversity was observed in the Wadden Sea, indicating a confluence of populations in this region (Olsen *et al.*, 2004). *Z. noltii* also shows a high genetic diversity (Coyer *et al.*, 2004).

Zostera beds, when growing in dense stands, protect the sediment against erosion and facilitate deposition during summer. They provide a substrate for fouling algae, which in turn are grazed by snails and other invertebrates. The canopy offers protection for small animals. The now vanished subtidal beds of *Zostera marina* offered shelter for small fishes that utilized the beds as a nursery. *Zostera* beds constitute a food resource for brent geese and wigeon. In the Wadden Sea at present, most beds are to be found in the mid to upper tidal zone along the leeside of islands and high sand bars as well as along sheltered parts of the mainland coast. A conspicuous decline of the intertidal beds of *Z. noltii* and *Z. marina* has occurred since the 1950s or 1960s, suspected to have been caused by human impacts, as outlined in the QSR 1999. This situation led to the target of 'an increased area and a more natural distribution and development of *Zostera* fields' agreed upon in the Trilateral Wadden Sea Plan (1997) (http://www.waddensea-secretariat.org/management/Plan.html).

1.1 Findings of the QSR 2004

In 2004, this target was evaluated for the first time. It was concluded that the target of an increased area of *Zostera* beds had not yet been met in all sub-regions of the Wadden Sea. However, it was noted that the decline of intertidal seagrass in the southern and central Wadden Sea had come to an end and that some recovery was evident. In 2004, more than 80% of the seagrass area in the Wadden Sea occurred in the Northern Wadden Sea. At all locations both species showed considerable fluctuations between years in the size and shape of local beds.

Eutrophication and hydrodynamics were defined as the overall variables determining seagrass distribution in the Wadden Sea, while positive effects of low salinity and negative effects of shellfish fishery and land reclamation works were seen as more locally relevant.

Recommendations were made for a complete and concerted survey of seagrass in the Wadden Sea, avoidance of disturbance of seagrass by shellfish fishery and land reclamation works, further reductions in nutrient loads, restoring of ebb-sluices with continuous freshwater runoffs and reintroduction of seagrass.

1.2 Method and data sources

A revised TMAP guideline with common definitions and a classification of seagrass beds was developed in 2006 to enable a common interpretation of monitoring results of the entire Wadden Sea (http://www.waddensea-secretariat.org/TMAP/Handbook/guideline9.html). Because of the extremely uneven distribution of intertidal seagrass, different monitoring methods are in use.

For all regions, seagrass areas are divided into three categories: (1) areas with scarce seagrass, less than 5% coverage, (2) areas with scattered seagrass, 5-20% coverage, (3) seagrass beds with more than 20% coverage. Furthermore the type of seagrass bed is noted (only *Z. noltii*, only *Z. marina*, mixed *Zostera* or *Ruppia*)

1.2.1 The Netherlands

In The Netherlands, monitoring has been focusing on areas where seagrass beds have already occurred in the past. Additionally a map with potential occurrence of seagrass from model calculations has been used. Monitoring is carried out annually or bi-annually by aerial photographs in combination with field surveys. There was a good consistency when comparing results from aerial photographs and field surveys. In addition to this mapping program, a system is set up in which people in the field are asked to pass on observations on presence of seagrass in other parts of the Wadden Sea. In areas with low density of seagrass (e.g. Groningen coast), groups of plants are mapped individually. Seagrass fields with a density of less than 5% are not included in the overall calculations. In addition to seagrass, *Ruppia maritima* is also monitored in the site where it is present (on Balgzand).

Reports of the mapping exercises as well as maps of the seagrass distribution are published on a website http://www.zeegras.nl.

1.2.2 Germany

In 2000-2002, the entire Lower Saxonian Wadden Sea was mapped using field surveys, supported by aerial surveys. The border of seagrass beds as well as areas with small seagrass stocks were mapped. In summer 2008, a new survey of the total intertidal *Zostera* stock was conducted. It was the first almost synchronous survey of the total Lower Saxonian stock since the beginning of the regular monitoring in the 1990s. Again, the seagrass beds were mapped by field surveys. In addition, aerial photographs (colour photographs; scale: 1:20,000) were analyzed with the aim to gain additional information about locations of seagrass beds. Beside the completion of the monitoring program and therewith, the gaining of necessary data about the stock development, these investigations aim at the further development of remote sensing techniques for the mapping of seagrass beds. The following parameters were determined:

- position and spatial extent of seagrass beds (GPS-measurement of 5%- and 20%-border);
- cover (area of seagrass-covered patches in relation to the total seagrass bed area [%]) and proportion (area covered by seagrass within the patches in relation to the total area of seagrass patches [%]) according to the definitions of cover and proportion for mussel beds (Herlyn, 2005). On the basis of these variables, the total coverage can be calculated, which is equivalent to the coverage of NL and SH. Cover and proportion were divided into five %-classes: <1; 1-5; 5-20; 20-60; 60-100;
- additionally, the biomass of seven beds was measured as ash-free dry weight (10 random samples each of 181.46 cm² area and approx. 30 cm depth per bed).

With as much as 100 km², the largest extent of seagrass beds abounds in the Schleswig-Holstein Wadden Sea. Because of this large areal size, aerial mapping has been the main method of assessment, and has been carried out three times annually (June, July and August) since 1994. This rapid assessment method provides a good overview on the spatial pattern, seasonal development and interannual variation of seagrass beds with a coverage of 20% or more. A rough distinction is made between coverage < and ≥ 60%. However, ground-truthing is essential to (a) include beds with a coverage between 5 and 20%, (b) distinguish between seagrass species, and (c) estimate density of macroalgal cover within seagrass beds.

Particularly, green algal mats may give rise to confusion. These are therefore mapped from the air concurrently, and in some cases it is necessary to verify on the ground whether it is a seagrass bed, a field of macroalgae or both mixed together. Ground surveys in the Schleswig-Holstein Wadden Sea are carried out from mid July until mid September. In addition to visiting beds of uncertain composition, the survey consists of 12 permanent sites spread evenly along the coast. Included are areas where seagrass actually occurs, used to occur or where it could potentially thrive.

Furthermore, 1/6th of the Schleswig-Holstein Wadden Sea area is completely mapped for seagrass beds by field surveys each year since 2007. The aim is to map the entire area once until 2012. Thus, all seagrass beds in the Schleswig-Holstein Wadden Sea area will be surveyed gradually within 6 years to obtain a comprehensive ecological inventory. In the first year of this six-year interval (2007), the area around the island of Sylt was mapped while all seagrass beds between the cities Husum and Büsum were recorded in 2008. The tidal flat areas in the Meldorfer Bucht and south of the Hindenburgdamm down to and including the islands Amrum and Föhr were surveyed in 2009. While monitoring the spatial extent and position, the inner core of a seagrass bed (≥ 20% coverage) and the outer fringe (≥ 5% coverage) are recorded. Furthermore, seagrass cover (5 classes), seagrass species composition, epiphyte cover (4 classes), macroalgal cover (6 classes) and the two most dominant macroalgal taxa and the substrate are noted.

1.2.3 Denmark

In the Danish Wadden Sea, seagrass is monitored on a regular basis. Simple aerial mapping is carried out in the entire area every year. Additionally field survey is carried out in large seagrass beds near the islands of Fanø and Rømø and near Jordsand and Ballum about every second year. In these areas percentage cover of *Z. marina, Z. noltii*, *Chaetomorpha* sp., *Ulva* sp., blue mussels and Pacific oysters is registered on several transects of 4 m width.

1.3 Relation to the EU Water Framework and Habitats Directives

With respect to the EU Water Framework Directive (WFD), the status of seagrass is regarded as an important indicator for the effects of eutrophication in coastal waters and transitional water bodies and is requested to be monitored at least every six years. In general, for a good ecological quality within the Wadden Sea, the presence of both species, *Z. marina* and *Z. noltii*, is required while the areal share of seagrass beds in the intertidal zone is considered to be specific for the sub-regions of the Wadden Sea.

In the Habitats Directive's goals for the Wadden Sea, seagrass is mentioned in the description of the habitat type 1140. It calls for an expansion of seagrass beds in the Wadden Sea.

Low intertidal bed of *Zostera marina* in the northern Wadden Sea (Tonnenlegerbucht at the island of Sylt, August 2007) (Photo: T. Dolch).

2. Status

2.1 Distribution of seagrass beds in the Wadden Sea

The occurrence of seagrass beds on intertidal flats in the Wadden Sea is rather uneven. From a rough aerial survey in 1998 with a total of 5,100 ha of seagrass beds recognizable from a plane, it is estimated that more than 90% of the beds occur in the northern Wadden Sea between the Eiderstedt and Skallingen peninsula (Reise, 2001).

In 2002/03 the total area of seagrass beds (all types of bed densities for all sub-regions) was about 7,300 ha with 82% in the northern part (combination of aerial and ground surveys). In 2007/2008, the total area of seagrass beds increased to about 13,000 ha with 77% in the northern part (Table 1). The real figure may be even higher, with an even higher percentage in the northern part because beds with densities lower than 20% are not recorded in Schleswig-Holstein.

In 2008, seagrass beds with coverage of more than 20% spanned an area of about 10,000 ha, with about 95% occurrence in the northern part (Table 1; Figure 1). In the southern part, coverage is generally much lower: in Niedersachsen, half of the seagrass beds have a coverage of 5-20%, in The Netherlands, 95% of the seagrass beds have a coverage lower than 5%.

It has to be recognized, however, that differences in methodology can render different results. In particular, data from air and ground surveys tend to differ in the lower limit for the density that is included. As a rule of thumb, aerial surveys with a lower limit of 20% cover are lower by one third compared to ground surveys with 5% as lower limit.

No new knowledge has become evident on seagrass occurrence in the shallow subtidal region of the Wadden Sea in recent years. There may still be no subtidal occurrence, but a systematic survey has not been attempted so far. However, prior to their collapse in the 1930s, the subtidal beds were found at and just below spring low tide level. If present, encounter by chance of such subtidal stands, or even detection from the air, would have been rather likely. For example, near the island of Sylt, subtidal kelp forests composed of the invasive *Sargassum muticum* were readily seen from 500 m above (Reise and Buschbaum, personal observation). The following description of seagrass status is confined to the intertidal zone of the Wadden Sea.

In The Netherlands, seagrass beds occur mainly along the Groningen coast and in the outer part of the Ems estuary. Some smaller beds are found on the leeside of the island of Terschelling and along the southwesterly border of Balgzand. In Niedersachsen, the largest seagrass beds occur within the sheltered Jade bay. Smaller beds can be found in other sheltered regions along the mainland coast. They are the remains of a former coherent belt. The most dominant species is *Z. noltii*; beds with dominance of *Z. marina* are rare (*e.g.* on Eversand and Knechtsand in 2008). In the North Frisian region, seagrass beds predominantly occur at sites sheltered against the prevailing surf from the southwestern direction. The largest seagrass beds in this region are found east and north of Pellworm, at Südfall, Gröde, Hooge, Langeness, Oland and Sylt (Figure 2). Both species of *Zostera* are present. *Z. noltii* dominates but mixed beds with *Z. marina* are also common. Beds dominated by *Z. marina,* however, are small and rare. Similarly, in Denmark, large beds occur at the leeside of Rømø and Fanø as well as between Jordsands Flak and Koldby. Both *Zostera* species are present.

Figure 2 also nicely illustrates that seagrass fields are less constant than we usually assume. There is a core where seagrass is always present and around that a zone where it occurs regularly.

Table 1: Seagrass coverage in 2007/2008, as recorded in the TMAP database
* Area with coverage 5-20% has been calculated by total area minus area with coverage < 5% minus area with coverage >20%
** In Schleswig-Holstein only areas above 20% coverage are monitored.

Region	Total Area (ha)	Area (ha) with coverage < 5%	Area (ha) with coverage 5-20%	Area (ha) with coverage >20%
The Netherlands (2007)	303	285	14	4
Germany / Niedersachsen* (2008)	2928	1051	1452	425
Germany / Schleswig-Holstein** (2008)	9621	not detected	not detected	9621
Denmark (2008)	932	no data available	no data available	no data available

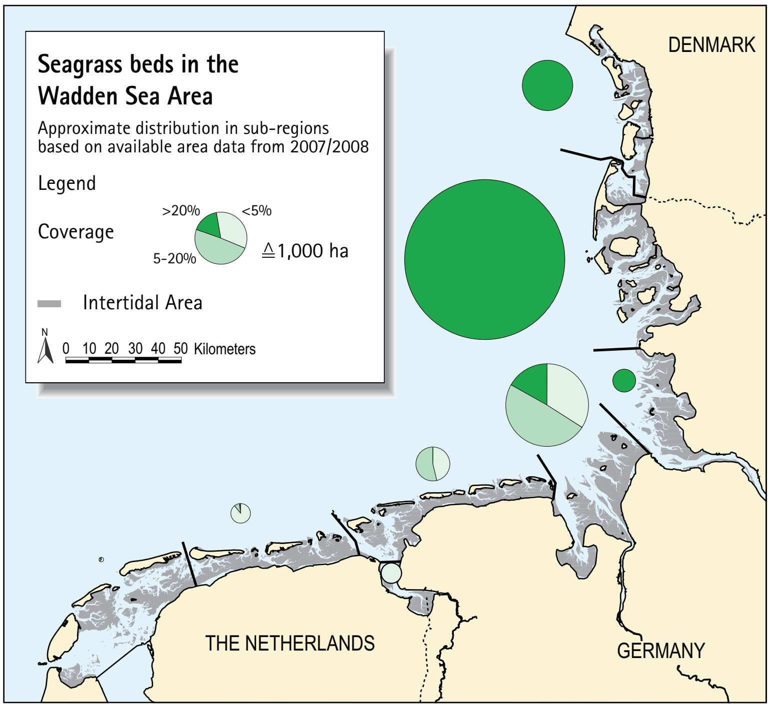

Figure 1: Distribution of intertidal seagrass beds (with various densities) in the Wadden Sea (in ha) in different sub-regions in 2007/2008.

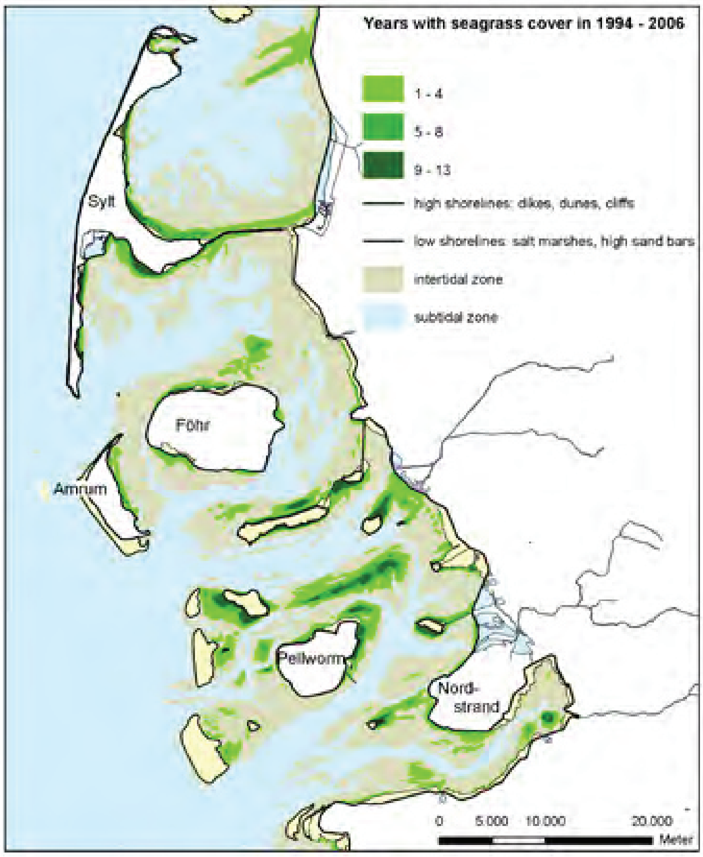

Figure 2: Occurrence of seagrass (*Zostera noltii* and *Z. marina*) in the intertidal zone of the North Frisian Wadden Sea in August/September 1994–2006. Intensity of shading refers to the number of years seagrass has been observed by aerial survey. Beds with <20% coverage are not included (from Reise and Kohlus, 2008).

2.2 Long term trends

2.2.1 Southern and central Wadden Sea

The region from Den Helder to the Elbe estuary has been subject to a continuous decline in number and size of seagrass beds in the tidal zone since about the 1960s (Den Hartog and Polderman, 1975; de Jonge *et al.*, 1993; Michaelis *et al.*, 1971; Kastler and Michaelis, 1999).

In the Dutch part of the Wadden Sea, *Z. marina* was in 2004-2007 confined to a few small patches along the Terschelling coast, the Groningen coast and the Ems estuary. On the tidal flat Hond-Paap in the Ems estuary, the bed of *Z. marina* remained. However, both the total area as well as the cover has been decreasing continuously since 2004. In 2007 cover was nowhere higher than 5%. Since 2003, a low-density seagrass location was found at the adjacent Groningen coast, probably colonised by seeds originating from the Hond-Paap. This location has remained more or less stable. The decrease of the seagrass bed at Hond-Paap might be caused by an increased turbidity of the Ems through continuous deepening and dredging techniques.

Elsewhere, *Z. noltii* is more common than *Z. marina* and was observed in 2000-2007 at Terschelling and along the Groningen coast with a total area of about 30 ha (cover >5%), with a maximum of 100 ha in 2006. Along the Groninger coast, the area of *Z. noltii* increased since the year 2000, whereas the beds at Terschelling decreased in size. This increase is particular notable along the Groningen coast since the year 2000 (Figure 3). In a 2007 study (van der Graaf and Wanink, 2007), the information on the location of seagrass beds in the Dutch Wadden Sea was reviewed using a GIS model. It compared wave intensity, turbidity and sedimentation rates with location and growth of seagrass. Along the Groninger coast *Z. noltii* only occurs in places where sedimentation was low. This might also be the reason for the absence of *Z. noltii* along the Frisian coast, where sedimentation is generally much higher.

In the Niedersachsen part of the Wadden Sea, more seagrass is present than in the Dutch part. It was estimated that seagrass beds (5%-border) occurred on 1,880 ha in 2008 (Adolph, 2009). For the period 2000-2003 the estimate was 960 ha. With a total bed area of about 1,450 ha, *Z. noltii* is the dominant species, whereas beds of *Z. marina* covered 420 ha. Regarding the 20%-border, the total seagrass bed area reached 710 ha, whereof *Z. marina* dominated beds occurred on 80 ha. *Z. marina* is generally sparse, not forming dense beds with the exception of the two beds along the Wurster Küste (on Eversand and Knechtsand) which have increased considerably since the last survey in 2000-2003. Increases of beds of *Z. noltii* were noted on the Randzel (south of Borkum) and along the mainland shore between Norddeich and Hooksiel, particularly as well in the Jadebusen. In this embayment the largest beds, in total roughly 60% (respectively 1,090 ha) of the total seagrass bed area, was recorded. Although seagrass has been continuously present with both species in Jadebusen since at least the 1930s, conspicuous changes in sizes and positions of beds and species dominance occurred in the long term. An almost coherent belt of *Z. noltii* along large parts of the shore in the 1930s was converted to singular large

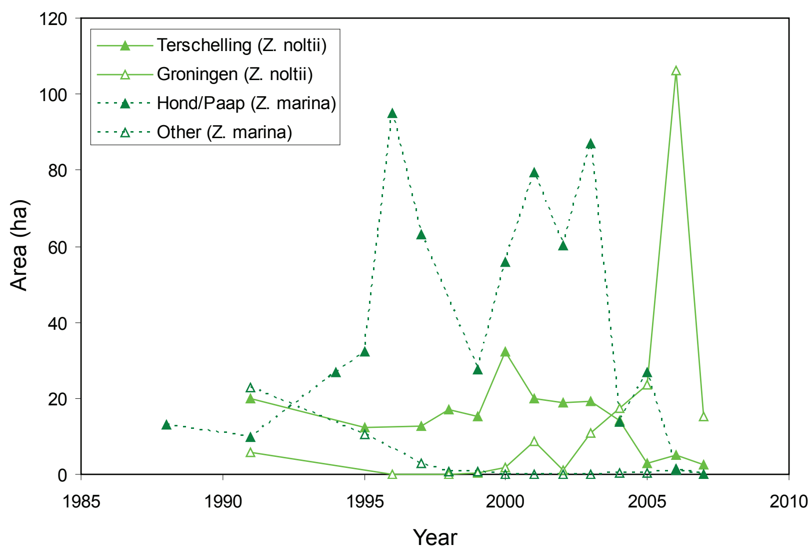

Figure 3: Total area of seagrass (cover >5%) in The Netherlands in ha.

beds. Also, the *Z. noltii* beds in the Weser estuary showed an increasing trend compared with the situation in 2000-2003. As already mentioned, two *Z. marina* beds have developed along the coast between the Weser and Elbe (Wurster Küste) covering a combined total of 420 ha.

In the tidal area between the Elbe and Eider estuary, only *Z. noltii* is present. A recurrent bed is found on the leeside of a high sand bar (Blauort), along a tidal divide in the Wesselburener Watt and a few small beds occur inside brushwood groins along the southern shore of Eiderstedt peninsula. This Dithmarschen area was visited for ground verification in 2008, and 165 ha of seagrass beds with >20% cover and 250 ha when including beds of 5-20% cover were recorded, respectively (Dolch *et al.,* 2009).

2.2.2 Northern Wadden Sea

In contrast to the southern and central Wadden Sea, no general decline in seagrass beds has been observed in the region between the Eiderstedt and Skallingen peninsulas over the last decades. Aerial surveys on seagrass between Eiderstedt and the Danish/German border indicate a three to fourfold increase in bed area from 31.7 km^2 in 1994 to up to 100.2 km^2 (or 11% of the total intertidal flat area with seagrass beds of >20% cover) in 2006, observed by aerial surveys at the seasonal maximum in August 2006 (Reise and Kohlus, 2008). A notable increase took place since 2001 (Figure 4). The trend in seagrass area development in this region may well be explained by a decrease in strength of storm surges since the 1990s (Weisse and Plüß, 2006). Considering winter periods (November-March) in the German Bight; an increase in storm activity since the 1960s with highest levels around 1990-1995, was followed by a decrease in storm activity. Storm surge water levels in summer (April to October) showed a slight decrease over the entire period. A small decrease in seagrass area after an anomalous storm frequency observed in November-December 2006 seems to support this explanation.

The spatial distribution of these large seagrass areas in the North Frisian Wadden Sea shows extensive beds at the leeside of the islands and high sand bars as well as along tidal divides on the elevated flats between adjacent tidal basins. However, there is a conspicuous scarcity of seagrass along the mainland shore. This is assumed to be the result of diking tidal flats in the course of the 20th Century and of ongoing land claim works with brushwood groins and ditches (Reise and Kohlus, 2008). These have probably eliminated or perpetually disturbed seagrass beds. At some sites where land claim works have been phased out (*i.e.* Dagebüll), recovery seems to be on its way (see Figure 2).

The development of seagrass in the Danish Wadden Sea seems to be similar to the adjacent North Frisian tidal area. Aerial surveys in the northern Lister Dyb and in the Juvre Dyb tidal area revealed 527 ha of seagrass beds in 2002 and approx. 750 ha in both 2005 and 2006, which in 2008 had increased to 836 ha. The increase in seagrass area in Lister and Juvre Dyb was mainly seen along the west coast of Jutland and the northern part of Rømø. However, the increase in seagrass area since 2002 should be considered with caution as the mapping method was changed in 2004. In 2008 the seagrass area was also mapped in Grådyb and Knude Dyb, where the total area was 85 ha.

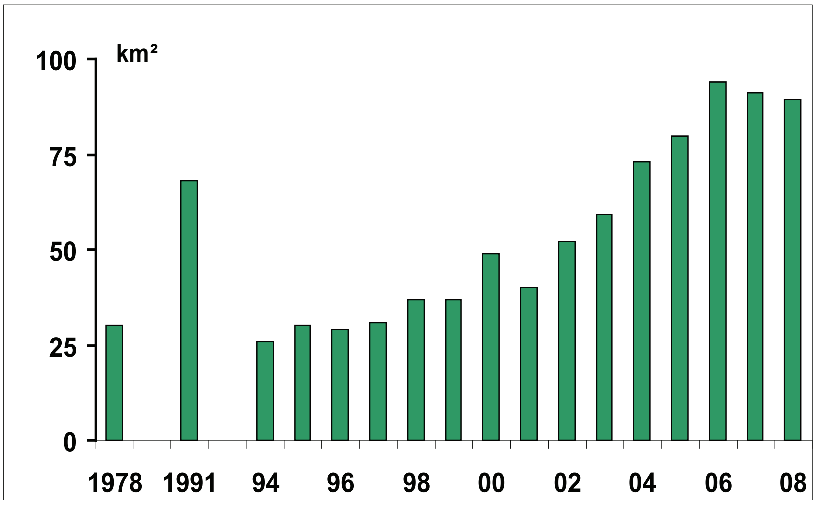

Figure 4: Seagrass bed (>20% coverage) area (km²) in the North Frisian Wadden Sea in August/ September from aerial surveys in 1978, 1991 and 1994-2008 (from Reise *et al.*, *unpubl.*).

3. Discussion

3.1 Threats to seagrass

In the QSR 2004, eutrophication and hydrodynamics were regarded as the overall variables determining seagrass status, while salinity, shellfish fishery and land claim works were seen as of more local relevance. As nothing can be done on hydrodynamics, recommendations were made to further decrease direct and indirect nutrient discharge into the Wadden Sea, to restore natural freshwater inflows, refrain from shellfish fishery and land claim at sites with actual and potential seagrass beds, and to explore further the feasibility of intertidal and subtidal seagrass reintroductions.

3.1.1 Eutrophication

The observed signs for a gradual recovery of seagrass in the Wadden Sea are in line with declining loads in phosphorus and nitrogen over the last two decades and concomitant declines in phytoplankton in the Wadden Sea (Philippart *et al.,* 2007; van Beusekom *et al.,* 2009). However, the present state of eutrophication is still assumed to be well above pre-industrial loads of phosphorus and nitrogen (van Beusekom, 2005). Seagrass is well known to be adapted to low nutrient conditions, and one may expect the status of seagrass beds to improve further if nutrient discharges into the Wadden Sea continue to decline. However, other changes in environmental conditions and their interactions need to be considered as well when attempting to project seagrass development into the future (see below).

3.1.2 Sediment stability

Considering the spatial pattern of intertidal seagrass in the North Frisian Wadden Sea (Figure 2) it is apparent that seagrass predominantly occurs at sites sheltered against prevailing storms. In this region, where more seagrass grows than in all the other regions of the Wadden Sea, the largest seagrass beds are found where surface sediments are underlain by solid peat and clay in which seagrass rhizomes and roots get a fair hold (Reise and Kohlus, 2008). From field experiments it is known that seagrass is highly susceptible to sediment turnover, as may happen during storm surges (Cabaço and Santos, 2007).

Elevated sand accretions with a generally oblong structure are called sand waves or megaripples and are widely observed on the tidal flats of the Wadden Sea. These large sandy bedforms may be formed by strong currents during storm surges and occur in extensive fields. These may be regarded as indicators of increased sediment mobility. Long-term studies near the island of Sylt have shown that fields with sand waves have expanded and replaced seagrass beds (Dolch and Reise, 2009).

Also, land claim works or maintenance works at the outer salt marshes that increase sedimentation rates may have a negative effect on the occurrence and the establishment of seagrass. A conflict with coastal protection measures arises when this is done by setting up brushwood groins in an existing seagrass bed (as is done in the North Frisian region). However, the effects of brushwood groins seem to vary with the hydrodynamic regime. They either stabilize the nearshore zone to the benefit of seagrass (Figure 5, Photo A) or enhance sedimentation to such an extent that seagrass is displaced. Fields with brushwood groins often trap green macroalgae which then smother the seagrass underneath (see below). When fields of brushwood groins are drained by ditches, the maintenance of these land claim works exterminates the seagrass from such sites (Figure 5, Photo B).

Figure 5: Depending on the hydrodynamic regime, seagrass can benefit from brushwood groins when they cause stable sediment conditions (A; south of Eiderstedt peninsula). However, severe damage can be done to a seagrass bed when drainage ditches are dug as happened at Hamburger Hallig (B) (Photos: T. Dolch, August 2008).

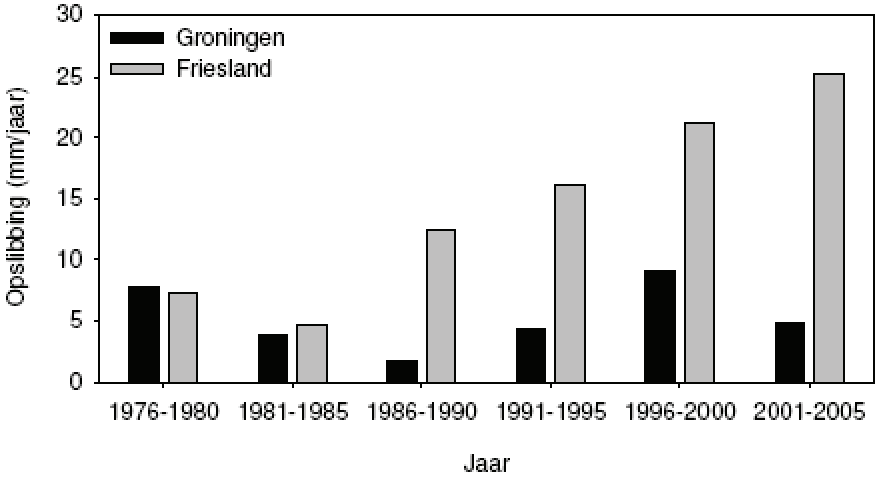

Figure 6: Sedimentation rates along the Groninger coast (where seagrass has been increasing) and the Frisian coast (where no seagrass beds have established) from 1975-2005 (van der Graaf and Wanink, 2007).

For the Western Wadden Sea it was suggested (van der Graaf and Wanink, 2007) that seagrass predominantly occurs on places with a low sedimentation rate and therefore does not occur at the Frisian coast where sedimentation rates are very high (Figure 6).

3.1.3 Turbidity

An increasing concern is the state of the former expanded seagrass bed at the Hond-Paap in the Ems-estuary. This bed has been decreasing in size and cover since 2004. In summer 2007 and 2008, this *Z. marina* stock was near to extinction. A possible cause for this is the increased turbidity of the Ems, caused by repeated deepening of the riverbed and continuous dredging in the river and especially in harbors. Dredging is carried out by means of re-suspending the mud by air injection, in this way bringing the sedimentated mud into the water column where it can reach high concentrations. The turbidity in the sea grass area in the Ems estuary has increased by about 20% from 1990-2000 (Merkelbach and Eijsink, 2001). However, although turbidity was increased in the 1990s, nevertheless the seagrass field at Hond-Paap increased in size in this period. Turbidity may, therefore, not be the (only) reason for the recent decline. More research into the effect of these dredging techniques on turbidity and on the growth of seagrass is necessary. Turbidity in the Dutch part of the Wadden Sea may also be influenced by sediment input from Rotterdam Harbour and the location of dredge disposal sites (de Jonge and de Jong, 2002).

3.1.4 Macroalgae smothering seagrass

High nutrient supply may either facilitate epiphyte growth on seagrass leaves or weedy green algae ('green tides'). The latter often accumulate in sheltered bays or between brushwood groins and other coastal defenses. At such localities green algal cover may replace seagrass beds. For a bay near Sylt this has been documented by historic comparison of benthic assemblages in 1932 and 2002 (Figure 7; Reise *et al.*, 2008). As green tides are assumed to be triggered by an excess of nutrient supply, this threat may also be seen as an effect of eutrophication. Another important factor for the growth of macroalgae are light conditions (Colijn and Cadee, 2003). Improved light conditions may have contributed to the increased growth of macroalgae. At least for the Dutch part of the Wadden Sea there are signs that light conditions have improved (D. de Jong, *pers comm.*, see also de Jonge and de Jong, 2002). Similarly, in the Dutch Oosterschelde estuary it was concluded that the growth of macroalgae increased strongly through improved light conditions, while the nutrient status of this estuary is meso/oligotrophic (Stapel and de Jong, 1998).

3.1.5 Global warming

Global warming may have direct effects on *Zostera marina* and *Z. noltii* in the Wadden Sea in the future. However, so far no mortality caused by heat stress has been described from this region. The extremely warm summer 2003 did affect *Z. marina* in the more stagnant waters of a lagoon in the Baltic Sea (Reusch *et al.*, 2005). *Z. noltii* in Portugal may have responded to that same extremely warm summer, but probably more to the associated drought event (Cardoso *et al.*, 2008). Both species of *Zostera* occur along the entire length of the European Atlantic coast but fall into genetically distinct groups (Olsen *et al.*, 2004; Coyer *et al.*, 2004). Thus, rapid warming or extreme heat events may worsen the conditions for *Zostera* in the Wadden Sea in spite of heat

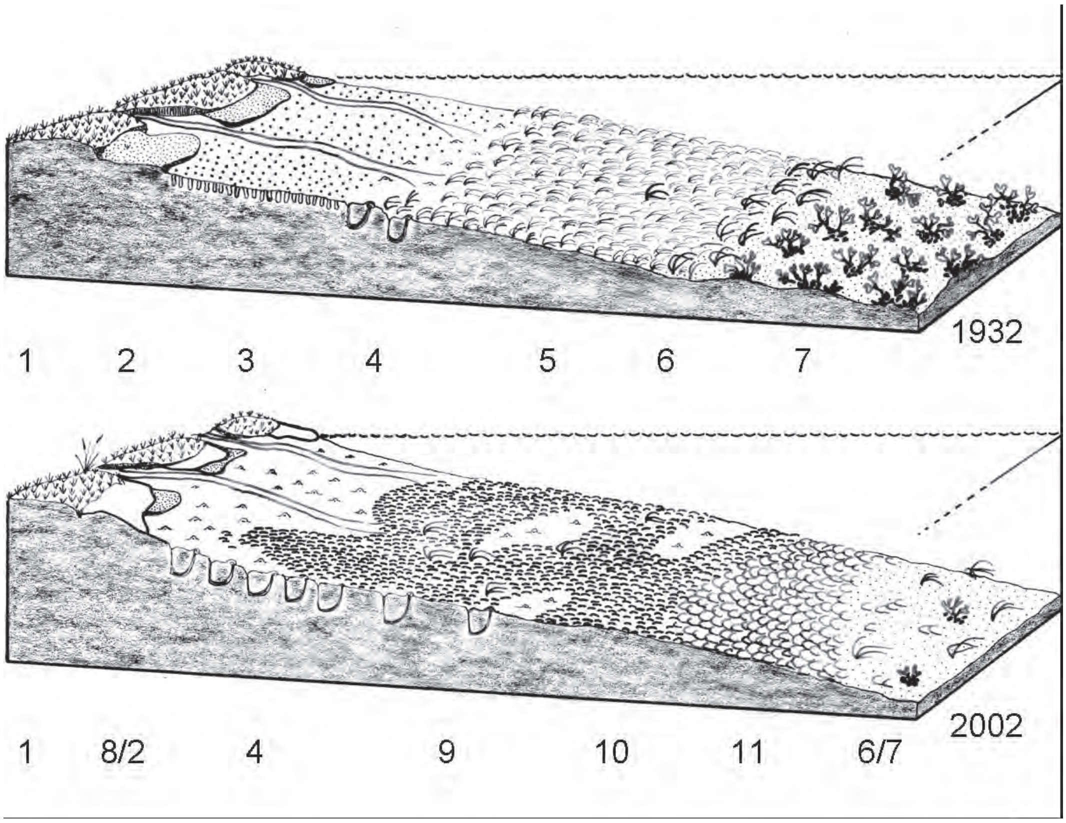

Figure 7: Macrobenthic zonation in Gröning-Watt (Königshafen Sylt) from a salt marsh down to low tide level in 1932 and seven decades later following a rise in high tide level of 25 cm and a period of elevated nitrate concentration in the tidal water. 1 salt marsh, 2 Cynaobacteria-mats, 3 *Corophium volutator* – belt, 4 *Arenicola marina*, 5 *Zostera noltii*, 6 *Zostera marina*, 7 *Fucus vesiculosus* anchored by mussels, 8 sandy beach, 9 filiform green algal mats of *Enteromorpha* spp., 10 *Chaetomorpha sutoria* – mats, 11 lettuce-like green algal mats of *Ulva* spp. (from Reise *et al.*, 2008).

adapted genotypes which may be present in the southern ranges of these species. Massa *et al.* (2009) determined experimentally the sub-lethal temperature limit at 38°C for *Z. noltii* in Portugal. This is beyond what is likely to occur in the Wadden Sea, but genotypes north of Portugal may have lower limits of tolerance.

3.1.6 Sea level rise and storm surges

The sea level is expected to rise by 0.5 to 1.4 m until the end of this century in response to global warming (Rahmstorf, 2007). It is not clear to what extent natural sediment accretion could compensate for such an increase in water levels especially in the face of the fixed coastline, but it is assumed that at least in the larger tidal basins the sediment supply may lag behind and consequently the duration of tidal submergence will increase (CPSL, 2005). With higher water levels above seagrass beds, storm surges will have stronger effects on sediment stability. This could affect the seagrass directly (see above). Extrapolating winter storm surge levels observed at tide gauges over the last four decades (Weisse and Plüß, 2006) into the next 40 years, water levels would rise by about half a meter, irrespective of any acceleration in global sea level rise.

3.1.7 Interactive effects

Attempts to understand observed changes in seagrass performance and to project its prospects in a future Wadden Sea should combine the various relevant factors rather than treating them separately. This is a highly complex endeavor and opens a new field of research in seagrass ecology. It is necessary to undertake this challenge because we find within the Wadden Sea the largest intertidal seagrass beds in Europe. At first sight it seems simple: nutrient loads have declined and seagrass area has increased over the last decade. If this would be the sole causal relation relevant to long-term seagrass development in the Wadden Sea, one would expect seagrass bed area to follow inversely the nutrient loads of the main rivers discharging into the southern North Sea. However, caution is advised. As pointed out by Reise and Kohlus (2008), the conspicuous increase of seagrass area in the North Frisian Wadden Sea (Figure 4) may also correlate with a relaxation in storm frequency since the second half of the 1990s. At least the spatial pattern of seagrass beds suggests in part the importance of shelter against storm surges from the south-westerly direction. Field experiments combining transplantations and fertilizer additions into locations of low and high exposure to hydrodynamics could help to partition effects of eutrophication, hydrodynamics and their interaction terms.

Particularly at sheltered locations, smothering by green algal mats could harm the seagrasses while, at more exposed locations, epiphytes may become problematic because there grazing on fouling microalgae by snails is depressed (Schanz *et al.,* 2002). Both factors, cover by opportunistic macroalgae and fouling by microalgae, are part of the eutrophication process but have reverse relations to hydrodynamics. A decline in phytoplankton due to a combination of decreased nutrient availability and increasing temperature during summer months (Philippart *et al.,* 2005; van Beusekom *et al.,* 2009) could improve transparency during tidal submergence of seagrass beds. For a more detailed discussion see Reise and van Beusekom (2008).

In considering the prospects of seagrass in the Wadden Sea, we also need to take into account the influx of alien species (see QSR 2009, Thematic Report 7). Beds and reefs of Pacific oysters have been proliferating in recent years. These spread mainly along the low tide line and may eventually provide more shelter to seagrass beds than blue mussel beds ever did. Transplantation experiments with seagrass indicated that such a shelter could be essential (Bos and van Katwijk, 2005 and 2007). In addition to Pacific oysters, the invasions of Pacific macroalgae like *Sargassum muticum* and *Gracilaria vermiculophylla* could also be relevant to seagrass performance in subtidal and intertidal areas, respectively.

In conclusion, it is rather unlikely that seagrass long-term development will be a straightforward function of nutrient supply in the Wadden Sea. Interactions with a wide spectrum of other factors may mask such a relationship and they also require the attention of environmental management.

3.2 Reintroduction of *Zostera marina*

The project "Reintroduction of eelgrass (*Zostera marina*) in the western Wadden Sea" was carried out from 2002 to 2005 (Bos and van Katwijk, 2005). During this 4-year period, approximately 5,900 *Zostera marina* seedlings were transplanted from the donor population in the Ems estuary (eastern Dutch Wadden Sea) to several carefully selected locations at the tidal flats of Balgzand (mainland of North-Holland Province) and Mokbaai (Texel Island). The transplantation locations varied in height, hydrodynamic conditions and presence of mussel beds. Furthermore, *Z. marina* seedlings were planted in different densities and numbers per transplantation unit. By doing so, the transplantation techniques were optimized and the risk of losing plants by local disturbances was reduced. Transplantations were carried out in June and plant survival and plant development were monitored during the growing seasons. Each year in August, plant cover, leaf development and seed production were monitored. Moreover, biotic and abiotic parameters, such as epiphyte cover, macro-algal abundance, invertebrate densities, pore water quality and sediment quality were intensively studied.

Only two transplantation locations were successful. At one location *Z. marina* has asserted itself since 1998, but does not flourish due to regularly being covered by dense mats of macroalgae. The other location shows high survival of transplanted *Z. marina* seedlings, but poor seed survival and germination due to intermediate hydrodynamic conditions and slightly lower salinity. This contradiction describes the situation of *Z. marina* populations in the entire Dutch Wadden Sea. *Z. marina* prefers locations with little hydrodynamic disturbances, but such locations also tend to accumulate macroalgae that smother the *Zostera* plants (Bos and van Katwijk, 2007; van Katwijk *et al.*, 2009). Nevertheless, in the northern Wadden Sea, local sub-populations of *Z. marina* manage to thrive under such conditions (Reise *et al.,* 2008)

In 2005, a small population of *Z. marina* was present at the tidal flats of the Balgzand area, as a result of the aforementioned transplantation activities. Next to it, a number of *Z. noltii* plots were present, the result of an earlier small-scale transplantation experiment. The *Z. noltii* plots gradually increased in size and cover. The *Z. marina* transplants gradually disappeared. Larger scale transplantations could increase the chances of *Z. marina* survival, but their outcome is generally unknown (van Katwijk *et al.,* 2009). Therefore it is recommended not to continue with expensive large-scale transplantations of seedlings. The cheaper alternative of deposition of seed bearing reproductive shoots is suggested instead. This method has been tested on a small scale in The Netherlands (Bos and van Katwijk, 2005).

3.3 Possibilities for re-establishment of seagrass in the Wadden Sea

In The Netherlands, the large area of submerged seagrass beds that was present in the south-western part in the past was formed by Z. marina growing around and below the low water mark. Due to the construction of the 'Afsluitdijk' this submerged Z. marina could not recover from its collapse in the 1930s. Van der Heide et al. (2007) investigated the possibilities for this submerged Z. marina re-establishing itself in this area. In this study, the current conditions in the Dutch Wadden Sea regarding tidal exposure, turbidity, salinity and nutrient availability, were compared with the conditions at the time that Z. marina was still abundant in the Dutch Wadden Sea or with conditions in neighbouring areas where Z. marina still occurs. It was concluded that especially light availability and the large fluctuations in salinity limit the possibilities for re-establishment of submerged Z. marina in the south western Wadden Sea.

Ever since the start of the mapping (from 1950 onwards) the distribution and area of intertidal seagrass beds in the western Wadden Sea has shown little change. However, in the 1950s the distribution between the two species was somewhat more even. This limited distribution of intertidal seagrasses can be ascribed to the exposed situation for prevailing storms.

For the Netherlands, the current surface area of intertidal seagrass beds is regarded as more or less the maximum that can be expected in the intertidal area. Only by intensive effort might an increase in area be possible. The seagrass opportunities map (de Jong *et al.*, 2005) estimates that there is potentially 180 ha very suitable for *Z. noltii* or *Z marina* and 1,750 ha suitable. Even though this is more than the current seagrass area, it is far below the 30,000 ha from before the 1930s.

In a report by Wanink and van der Graaf (2008), research on the subject of seagrass in the Dutch Wadden Sea was summarised with the following conclusions:

1. There are no chances in the Dutch Wadden Sea for natural restoration of *Z. marina*, due to salinity fluctuations, nutrient-supply and turbidity (see also Van der Heide *et al.*, 2007). It would be better to focus the attention on re-introduction towards other Dutch locations, such as brackish lakes in the southwest part of the country.
2. The chances for expansion of intertidal *Z. noltii* are very restricted. The best results are probably to be obtained within and in front of the artificial saltmarshes.
3. The seagrass beds on "De Paap" are possibly somehow connected to the old artificial gas-island on the northern part of this natural island. This might reduce the wave energy. The present reduction in seagrass area might be due to the increased turbidity in the location.

One of the reasons for the postulated low chance of re-establishment may be that the Dutch part of the Wadden Sea is very exposed to wave energy; along the coast of Friesland and Groningen to winds from the N-NW-W-directions, and near the island to winds from SW-W-directions. These are the main storm directions. Only in very sheltered areas like in the reclamation works or in the shelter of (artificial) islands are there some chances. Probably, further expansion of seagrass can only be achieved by creating more of these sheltered areas, but this is against the general policy against human interference with natural proceses.

In 2008, the total area of Lower Saxonian intertidal seagrass beds reaches approx. 50% of the bed area in the 1950s/70s and can be regarded as clearly below the potential area which may be estimated to at least 35 km^2. In Schleswig-Holstein, the maximum surface area of seagrass beds which seems possible (no more land claim and other mechanical disturbances, continued decrease of nutrient input) would be about 5-10% areal share in the Dithmarschen intertidal area (today 0.3%) and about 15-30% in the North Frisian Wadden Sea (today 10% of the intertidal zone) assuming a more or less continuous belt of seagrass along the mainland coast where it is scarce today. In the North Frisian Wadden Sea seagrass beds with >20% coverage were at least once recorded in the interval from 1994 to 2006 on an area of 187 km^2 or about 20% of the entire tidal area (Figure 2), adding to this a continuous belt with seagrass of about 2 km in width fringing the mainland shore, brings the areal share to 30%. The only reliable map of seagrass area from the time prior to significant eutrophication is available for 1924 from Königshafen on the island of Sylt, indicating an areal share of about 60% (see Nienburg 1927). In conclusion, the potential area for seagrass beds amounting to an areal share of 15-30% in the North Frisian Wadden Sea constitutes a conservative assumption.

The considerations above on the potential seagrass area can be regionally summarized as follows:

- The Netherlands: the current seagrass area is below the potential area; potentially the area could increase up to about 180 ha.
- Niedersachsen: current areal share of seagrass beds is approx. 50% below the potential area.
- In Schleswig Holstein: seagrass is far below the potential area in the Dithmarschen intertidal area, and at about half to one third of the potential area in the North Frisian Wadden Sea.
- Denmark: there is not sufficient information about the areal share of intertidal seagrass beds in the past, therefore it can not be estimated to which extent the current share meets the potential area.

4. Conclusions

- Most of the seagrass in the Wadden Sea occurs in the northern part. Beds are mainly positioned on the leeside of islands or in the shelter of high sand bars. Few, and generally smaller, beds are found in the Central and Southern Wadden Sea. A larger stock is present in the Jadebusen, mainly consisting of *Z. noltii*. The large *Z. marina* bed in the Ems estuary had almost vanished in 2008, whereas large *Z. marina* beds had developed on the coast between Weser and Elbe (Wurster Küste). Furthermore, some remaining *Z. noltii* beds of a former more or less closed belt of beds occur along the mainland shore. Almost no seagrass is found in the westerly part of the Dutch Wadden Sea.
- In the Southern and Central Wadden Sea, the cover of seagrass has been declining since the 1960s. However, in 2008 a considerable recovery (mainly of *Z. noltii*, only locally of *Z. marina*) is notable. In the Northern Wadden Sea no decline could be ascertained. Here seagrass bed area has doubled since 2001 (mainly *Z. noltii*).
- The reason for the recent increase in seagrass bed area in many parts of the Wadden Sea could be a relaxation from eutrophication stress, improved light conditions or from intermittent decrease in storminess. More research is needed into these and possible other conditions and the interaction between them to determine conditions factors are most important for the establishment of seagrass.
- Sediment stability is an important condition for the growth of seagrass. It does not grow in areas with high sediment turnover, erosion or deposition. High sediment turnover can be caused by strong currents, storm surges, dredging and dumping of sediments, deepening of gullies and rivers as shipping lanes and by land claim operations in the nearshore zone.
- In addition to an excess of nutrients (including smothering by macroalgae), high sediment turnover and turbidity are considered as the main threats to seagrass in the Wadden Sea.
- In the wake of global warming, sea level rise with an associated increase in hydrodynamics would diminish seagrass beds in the long term.
- In The Netherlands, reintroduction experiments with intertidal *Zostera marina* have been carried out with limited success. It is concluded that there are no chances for re-establishment of subtidal *Z. marina* in the Dutch Wadden Sea. *Z. noltii* was successfully reintroduced in the western Wadden Sea (Balgzand), but has disappeared again recently (since 2008).
- Seagrass bed area in the Wadden Sea is assumed to be below the potential seagrass area but estimates differ substantially between sub-regions, indicating a need for research and better definition on this subject. In all areas the coverage of *Zostera* beds is below the estimated potential area. In The Netherlands coverage was much higher in the past. Under the current conditions, however, there seem to be few chances of development of new or larger subridal seagrass beds in the Dutch part of the Wadden Sea.

5. Target evaluation and recommnedations

5.1 Target evaluation

The target of an increased area of *Zostera* fields has not been met in all sub-regions of the Wadden Sea.

5.2. Recommendations

Research

- Studies on interactive effects of eutrophication, climate change, storm surges and land claim activities on seagrass performance;
- Measurements on the strength of hydrodynamics at sites where seagrass is well established, sites where seagrass is colonizing and sites where seagrass has disappeared, throughout the entire Wadden Sea;
- Studies on the effects of salinity fluctuations and changes in salinity on seagrass performance (van der Heide *et al.* 2007), in relation to changes in freshwater inlets all over the Wadden Sea area;
- Studies on the general effects of dredging and especially dumping of sediments on turbidity and subsequent growth of seagrass;

Monitoring and assessment

- Joint efforts to further harmonize assessment methods in the trilateral Wadden Sea.

Management

- Continue to reduce nutrient loads to improve seagrass performance; further reductions of nutrient loads may lead to reduction of epiphyte growth and of green macroalgae on beds of *Zostera* spp.
- If dredging and dumping of sediments proves to have an effect on the growth of seagrass (see the recommendation for research), there is a need to change dredging techniques in the estuaries to lower turbidity during the growth season of seagrass.

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