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Thematic Report No. 8

Salt Marshes

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for the management for the entire area (Trilateral Wadden Sea Plan 1997). The aim of the Wadden Sea Plan (WSP) is to maintain, and where possible, to extend the area of salt marshes. In general, it is the aim to reduce human interference with salt marshes and to enhance natural development by reducing the intensity of drainage and grazing in order to gain a high biodiversity in the entire Wadden Sea Area. Coastal protection activities, such as protection of salt-marsh edges or seawall reinforcement, are carried out in coordination with nature protection needs, *e.g.* by applying Best Environmental Practice (see also QSR Chapter 3.1 Coastal Defence).

European Directives

Salt marshes are also protected within the EU Habitats Directive (Annex I habitat types 1310 *Salicornia* and other annuals colonising mud and sand, 1320 *Spartina* swards, 1330 Atlantic salt meadows). The Habitats Directive (HD) provides an European network of special areas of conservation (Natura 2000 (Balzer *et al.* 2002)). The aim of the HD is to achieve a favourable conservation status for habitats and species across Europe, including birds (Birds Directive).

In addition, within the Water Framework Directive (WFD), salt marshes are considered as part of the quality element "angiosperms" which is one element to assess the ecological status of water bodies. The aim of the WFD is to achieve a good ecological status for all water bodies until 2015.

The status assessment and conservation objectives for salt-marsh habitat types are to a large extent comparable among the two above-mentioned EU directives and the WSP. In the framework of the Marine Strategy Framework Directive (MSFD), it has to be discussed at a later stage how salt-marsh habitat types can be incorporated to assess the good environmental status.

1.2 Outcome of the 2004 QSR

The main achievement of the QSR-2004 was the incorporation of the TMAP vegetation typology in order to monitor the status of Wadden Sea salt marshes in a standardized way. With the aid of aerial photography and GIS tools, the area of different vegetation zones has been calculated. The geomorphological classification of salt-marsh types was adapted by subdividing mainland marshes into barrier-connected and foreland marsh (including estuarine marsh) and adding summerpolders and de-embanked summerpolders as new types (for island and mainland marshes). Because of differences in both classification and methodology, a direct comparison with the 1999 QSR was not feasible.

It was decided that grazing terminology should be based on the structure and heterogeneity of the vegetation instead of stocking density. A discussion on naturalness resulted in a distinction between landscape and vegetation level. The result of this hierarchical classification is that changes in land use and management cannot result in a transition from semi-natural to natural marsh (landscape level), but meanwhile the vegetation may develop towards a more natural state.

A new topic in the 2004 QSR was the so-called ageing of the salt marsh, i.e. the extension of late-succession salt-marsh communities, mostly with low species diversity, at the expense of young succession stages. Removal of artificial dune ridges, de-embankment of summerpolders and low-intensity grazing were suggested as management options in order to preserve young succession stages and high species diversity.

The following recommendations were formulated:

- In the Wadden Sea area, the common monitoring programme of the salt marshes according to the TMAP guidelines should be continued with a frequency of once in five years. The TMAP typology is sufficient to fulfil the requirements of the Habitats Directive.
- In addition, long-term annual recording of vegetation, surface elevation change and management at several permanent sites is required to gain insight into different processes and developments.
- Target No. 3 on 'natural vegetation structure' of artificial salt marshes should be specified as follows: "The aim is a vegetation diversity that reflects the geomorphological conditions of the habitat."
- The application of livestock grazing should be determined by the conservation targets per area.
- Future management should aim at:

  a) Preclusion of engineering measures in the geomorphology of both natural salt marshes and of intertidal flats in front of sedimentation fields,

  b) Restoration and increase of the total area of especially mainland salt marshes through de-embankments of summerpolders,

  c) Rejuvenation of salt marshes on barrier islands through removal of artificial dune ridges

d) Increase of the natural morphology and dynamics of artificial salt marshes through cessation of the upkeep of artificial drainage,

e) Enhancement of a natural vegetation structure through cessation and adaptation of grazing and drainage regimes.

1.3 Aim of the 2009 QSR

The aim of the current quality status report is at least twofold:

- The first aim is based on the common monitor programme, and is to give an overview of the present status the Wadden Sea salt marshes. This status review includes aspects of total extent, geomorphology, vegetation characteristics and management.
- The second aim is to highlight actual affairs in salt-marsh management and research. Following the outcome of the 2004 QSR, the following topics will be addressed:

(a) Vegetation succession and ageing of salt marshes;

(b) Success of restoration of salt marshes through de-embankments;

(c) Management of the artificial[1] foreland marshes (i.e. the so-called salt-marsh works);

(d) Influence of artificial dune ridges on back-barrier salt marshes.

[1] The term "artificial salt marsh" is used throughout this report for salt marshes that have been developed within sedimentation fields or by ditching of tidal flats. Their development has thus been enhanced anthropogenically.

2. Methods

In the framework of TMAP, a monitor programme for salt marshes has been developed. On a regular time base, the following salt-marsh parameters are monitored:

- Location and total area
- Vegetation composition on the base of the standardized TMAP vegetation typology (Appendix I)
- Land use and management
- Geomorphology and artificial drainage

A time frequency of once per five year has been recommended. The programme is functioning successfully in both the Netherlands and the various German sectors of the Wadden Sea (Table 1). In Denmark, monitoring of salt marshes is carried out on the basis of EU habitat types. Here, an assessment is performed at the level of the HD habitat types. The TMAP programme requires an aerial survey of the salt marshes, which is followed by the collection of ground truth. The exact procedures differ sector-wise across the Wadden Sea, and are documented in the TMAP salt-marsh monitoring guidelines. The programme forms the basis of much of the data presented in this QSR. Additional information has been provided by special programmes or projects.

In the 2004 QSR, salt-marsh vegetation zones were described for the first time with the standardized TMAP typology. Initially six different zones were distinguished, *viz.*: pioneer vegetation, low marsh, high marsh, green beach, brackish marsh and fresh grassland. In the present QSR, green-beaches have been redefined at the landscape level: green beaches may comprise a mosaic or complex of dune slack, dune and salt-marsh vegetation. From the transition from salt marshes to dunes, two vegetation zones with seawater influence have been added, *viz*: (1) a zone that comprises the zone of embryonic dunes and drift-line vegetation, and (2) a zone that comprises seepage vegetation (Appendix I).

Since the previous QSR of Wadden Sea salt marshes (Bakker *et al.* 2005), nearly all salt marshes in the Netherlands and German sectors have been re-surveyed, and new vegetation maps have become available. Hence, the present report is based on surveys from 2002 – 2007, whereas the 2004 QSR was based on salt-marsh surveys from the period 1995 – 2002 (Table 1).

In the Netherlands, the salt marshes of the Wadden Sea are mapped within the VEGWAD-programme. Since the introduction of the WFD, the programme has a mapping frequency of each area of once per six years. Vegetation maps are produced with a scale of 1:5,000 or 1:10,000. Input is from remote sensing (interpretation of stereo false-colour photographs) and fieldwork. The interpretation is improved by the use of a digital 3D-photogrammetric system. For the classification of the vegetation a detailed standard typology is used (SALT97, de Jong *et al.* 1998). This typology can easily be transformed into the TMAP typology.

In Lower Saxony the entire terrestrial area of the National Park was surveyed in 2004 with the use of the TMAP typology. This survey was carried out by a combination of remote sensing, GIS and extensive field verification (Petersen *et al.* 2008). The accurateness of the new maps in location and vegetation assignment was improved considerably compared to the previous survey. The latter had been based on mapping of biotopes, and was performed by air-picture analyses with limited effort on gathering ground truth. In the evaluation of monitoring results, the change of methodology must be considered.

In Schleswig-Holstein, a new salt-marsh survey was carried out in 2006/2007. The same method was used as in Lower Saxony in 2004. The TMAP-vegetation maps of Lower Saxony and Schleswig-Holstein are freely accessible at the homepages of the national parks.

In Denmark, In the framework of the National NOVANA programme, the EU habitat type 1330 (Atlantic salt meadows; cf. App. I) was surveyed in 2005/2006 within the Natura 2000 area in the Wadden Sea Area; surveys of the habitats H1310 and H1320 are planned for the period

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Country/Sector	Time / Frequency	Level
The Netherlands	Every 5-7 years[1]) since 1980	Vegetation, land use and management
Lower Saxony	1991, 1997, 2002 2003/2004	Biotope and land use Vegetation, land use and management
Hamburg	1995 – Neuwerk 1998 – Neuwerk (east), Scharhörn, Nigehörn 2004	Biotope and land use Vegetation, land use and management
Schleswig-Holstein	1988 [2)], 1996 [2)], 2001/2002, 2006/2007	Vegetation, land use and management
Denmark	2000 [3)], 2005/2006 [4,5)] Annual [5)] Every 6 years [5)]	Area, state indictors, management Monitoring 40–60 permanent plots in H1330 Monitoring 9 permanent plots in H1330

1) Rotating monitoring schedule of sites with a frequency of 5–7 years (since 1980), VEGWAD-programme, Ministry of Transport, Public Works and Water Management. 2) Salt marshes on the Halligen and islands excluded. 3) Inventory of salt marshes: Ribe Amt, 2002: Strandenge i Ribe Amt – Status 2000. 4) Survey of salt marshes inside the Natura2000 site in the Wadden Sea area. 5) In the framework of the Danish NOVANA programme.

5.

3. Status

3.1 Total area of salt-marsh types

Based on the most recent data, salt marshes in the Wadden Sea extend over slightly more than 400 km², summerpolders included (Table 2). The size of the Wadden Sea salt marshes represents about 20% of the total area of coastal salt marshes in Europe (Doody 2008). Although the size of salt marshes in the Wadden Sea is still considerable, it is worth remembering they have been much more extensive than they are today. The major cause for the decline of salt marshes has been land-claim in order to acquire new land for agriculture, and more recently, coastal protection measures. Loss of salt marsh through human intervention continued throughout the 20th century.

From a morphological view, four types of salt marsh may be distinguished in the Wadden Sea, *viz*. (Table 2): (a) back-barrier marshes, (b) green beaches, (c) foreland marshes and (d) Hallig salt marshes. Summerpolders have a risk to be flooded by seawater during extreme storm tides. Because they have a high potential for restoration of salt marshes, their 2,520 ha have been added to Table 2 and Figure 1.

Foreland salt marshes on the mainland make up approximately half of the salt-marsh area in the Wadden Sea. These salt marshes are largely of anthropogenic origin, because their development has been promoted by ditching and the construction of sedimentation fields. Despite their artificial origin, the mainland marshes are appreciated for their value for nature conservation. The most extensive foreland marshes may be found in Schleswig-Holstein with more than 40% of their total area.

Back-barrier marshes and green beaches are in principal natural salt marshes. Back-barrier marshes develop in the lee of a barrier beach, whereas green beaches are generally found more exposed in the foreshore area of the barrier beach. The construction of artificial dune ridges in the past has stimulated the development of back-barrier marshes, such as for instance the Boschplaat salt marsh on the island of Terschelling, Netherlands and the salt marsh of the Skallingen peninsula, Denmark. The presence of artificial dune ridges explain why in the Netherlands Wadden Sea the extent of back-barrier marshes today is much greater than their historic reference values (Dijkema 1987).

The distribution of the salt marshes shows some conspicuous variation across the Wadden Sea (Fig. 1). Back-barrier marshes on the mainland coast, for instance, are restricted to the northern part of the Wadden Sea. Here the principal coastline has a north to south orientation, whereas the western Wadden Sea has a west to east orientation. A hallig is a salt-marsh island, which in the past has been part of the mainland and which is not protected by a seawall. Hallig salt marshes thus accreted on low-lying old land. Hallig salt marshes are found almost only in Schleswig-Holstein, with the Punt van Reide salt marsh, the

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Landform	The Nether-lands	Lower Saxony	Hamburg	Schleswig-Holstein	Denmark [1]	Total
Year of survey	2002-2006	2004	2004	2006/2007	2005	
Islands						
Back-barrier (foreland incl.)	4,280	3,660	260	1,250	2,230	11,770
Green beaches	850	280	4	100	320	1,550
De-embanked (summer)polder	90[2]	150	40			280
Summerpolder	10	60	80			150
Mainland						
Back-barrier				720	1,620	2,340
Foreland-type	3,910	5,460		7,880	2,240	19,490
De-embanked summerpolder	320	240[3]				560
Summerpolder	960	1,400			10	2,370
Hallig						
	50			2,160		2,210
Total	**10,470**	**11,250**	**380**	**12,200**	**6,320**	**40,620**

1) Habitat type 1330 only (cf. Appendix I)
2) Total de-embanked area
3) includes both de-embanked and opened summerpolder

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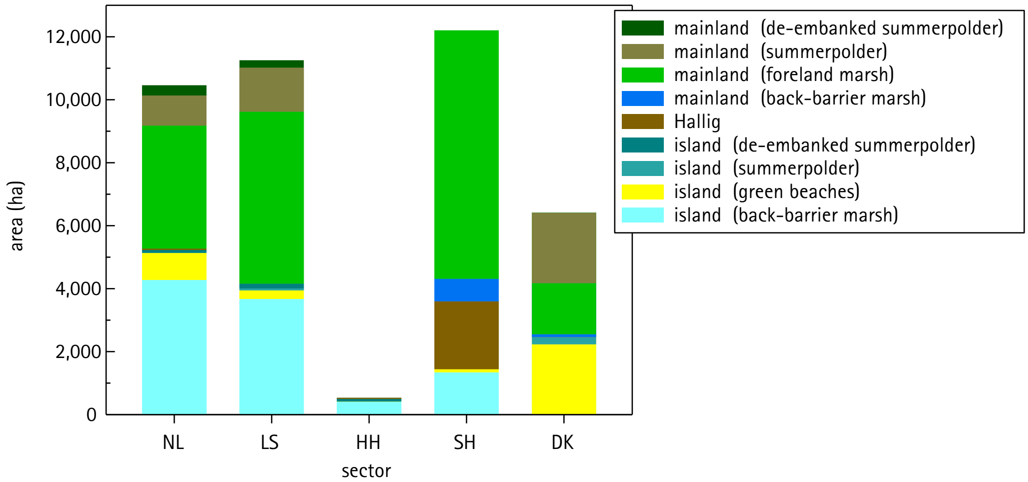

Netherlands, as an exception. Hallig salt marshes are often protected with revetments. They show a greater resemblance with the clayey foreland salt marshes than with the sandy back-barrier marshes.

3.2 Salt-marsh zones and vegetation composition

3.2.1 Current distribution

Between the 1995/2001 and 2002/07 surveys, changes in the total area of salt marshes differed markedly between islands and mainland marshes and among sections (Fig. 2). On the trilateral level, the data show a net loss of 650 ha of salt marsh between the two surveys. This development is largely caused by changes in the Danish Wadden Sea. The Danish salt marshes may well have been overestimated during the first survey, however. Leaving the Danish data aside, the total extent of salt marshes increased by nearly 1,600 ha.

This increase was found predominately on the islands (Fig. 3A). On the Netherlands islands, the area of all salt-marsh zones increased, especially the zone of embryonic dunes and drift-line vegetation. In Lower Saxony and Hamburg, island salt marshes grew with ca. 300 ha, but the high-marsh zone increased by almost 700 ha, and now covers over 50% of the entire salt-marsh area (Fig. 3B). The high marsh is to a limited degree covered with the climax community of *Elytrigia atherica* (Appendix II). In Schleswig-Holstein, the island salt marshes increased by almost 300 ha. The area of both the pioneer and the low-marsh zone remained more or less constant, which resulted in a lower relative weight of these two zones. On the island of Trischen, *Spartina anglica*-dominated vegetation took up a significant proportion (30%) of the entire salt marsh (Appendix II).

The size of the mainland marshes in both the Netherlands and Lower Saxony showed a minor decline, whereas in Schleswig-Holstein mainland marshes increased by 450 ha (Fig. 3C). In all three sectors, the area of the pioneer zone diminished, whereas that of high-marsh zone increased. In Lower Saxony, the high-marsh zone now occupies

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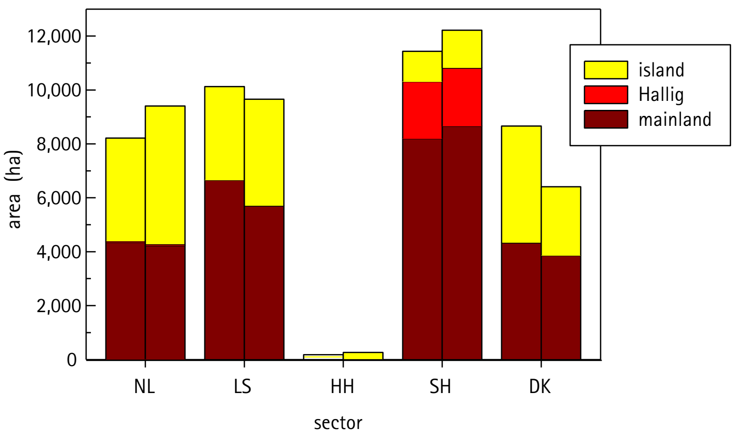

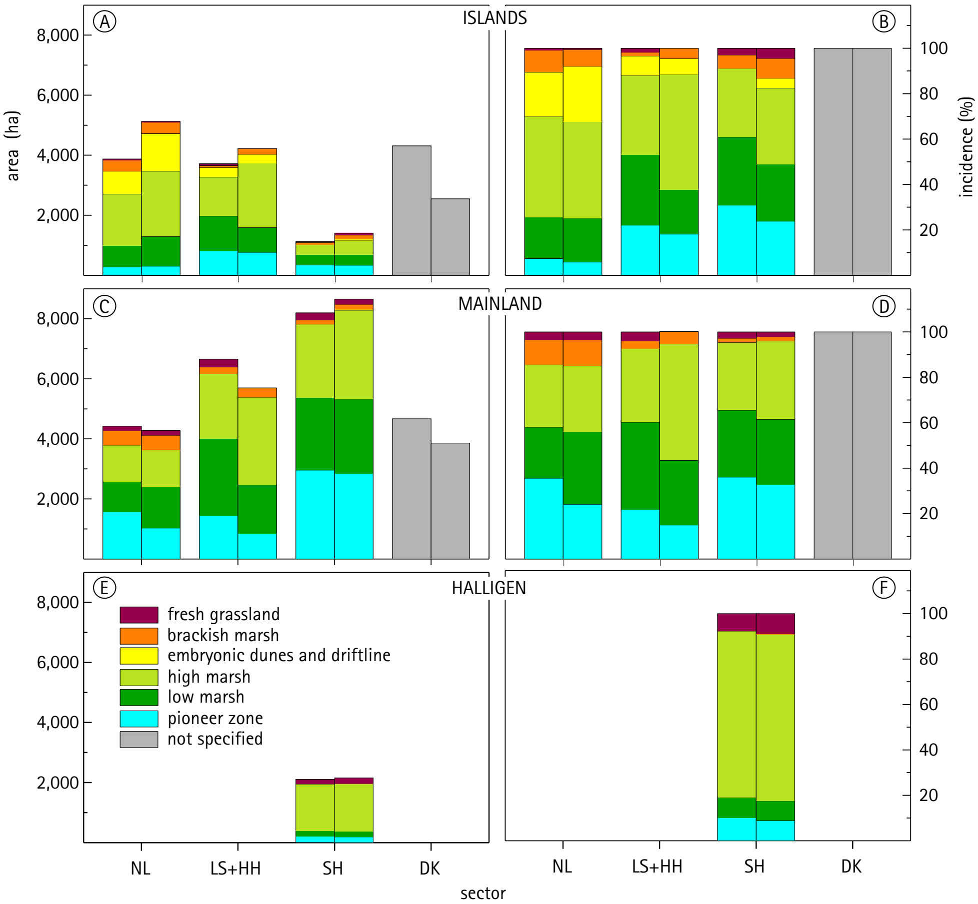

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over 50% of the area (Fig. 3D). In the mainland marshes, vegetation of *Elytrigia atherica* appears to be of greater importance than on the island marshes. During the last survey of several larger salt-marsh complexes (500 ha or more) in Lower Saxony, this vegetation type occupied over 40% of the area (Krummhörn, Ostfriesland, Jade and Budjadingen; Appendix II).

The area of Hallig salt marshes remained more or less constant (Fig. 3E). The Hallig salt marshes are for nearly 75% comprised of high salt marsh, but generally with a low incidence of *Elytrigia atherica* vegetation (Appendix II). The latter does not count for the two smallest Hallig salt marshes (Norderoog and Habel), which were for more than 40% covered by *Elytrigia* vegetation.

3.2.2 Vegetation change

Vegetation change Netherlands sector

On nearly all Netherlands mainland - and barrier-island salt marshes succession and ageing of the vegetation are the dominant processes. The distribution of different salt-marsh vegetation zones in the Dutch Wadden Sea is diverse from the early 1980s to the first years of the new millennium (Fig. 4). The largest area of pioneer vegetation is found in the mainland salt marshes of Groningen and Friesland. This can be explained by extensive engineering measures, the so-called salt-marsh works (Dijkema *et al.* 2001; Bakker *et al.* 2005). The area of pioneer zone shows high year-to-year variation which is not reflected in Figure 4. In most sites, the dominant change during this 25-year period has been a decrease of vegetation diversity because of the increase of a single vegetation type; to a lesser extent the same counts for the brackish salt-marsh zone as well. This loss of biodiversity is mainly caused by the increase of the climax vegetation types of *Elytrigia* spp and *Phragmites australis*. As a consequence, on the islands the other vegetation types of the high marsh decreased, and on the mainland the types of the low marsh decreased.

On the barrier islands, the incidence of the *Elytrigia* climax redoubled in the Schorren marshes at the island of Texel, and in the salt marshes of the islands of Terschelling, Schiermonnikoog and Rottumerplaat. In these marshes the increase was much higher than on the island of Ameland where a high grazing intensity and soil subsidence arrested vegetation succession (Dijkema *et al.* 2007).

The incidence of the *Elytrigia* climax was highest on the Boschplaat salt marsh on Terschelling. This is the first back-barrier salt marsh that became protected by an artificial dune ridge, and where this dune ridge is still intact. In the Dollard, the climax[2] of *Elytrigia repens* decreased, because of the combined effect of grazing and an increased soil waterlogging. The latter was caused area of the *Spartina* pioneer community, on the contrary, has increased from 124 ha in 1991 to 417 ha in 2004. The strongest increase of *Spartina* was observed in the mainland salt marshes. Only did *Spartina* decrease, where erosion of salt-marsh edges had already been registered since the 1960s.

The area of low salt marsh in Lower Saxony is squeezed by two opposite developments: the strongest development was succession to high salt marsh; the area of high salt marsh increased in Lower Saxony from 3790 ha in 1991 to 5050 ha in 2004. Between 1991 and 2004, the low salt marsh decreased from an area of 3640 ha to 1180 ha.

To a minor extent, *Spartina* facies encroached into the low salt marsh. The "Ostplate" on the island of Spiekeroog may illustrate the main development of the salt-marsh vegetation on the East Frisian barrier islands. The Ostplate has developed since the 1960s from a high sand into a dune-salt marsh complex. In 1991 and 1997, a great continuous *Salicornia* pioneer marsh was found on the south side of the island, which until today is extending in southwest direction. Between 1997 and 2004, this pioneer marsh developed to a great extent into a low salt marsh. Former low salt marsh developed into high salt marsh and the incidence of the *Elytrigia atherica* climax community also increased (Appendix III).

The Elisabeth-Außengroden salt marsh may serve as an example of the Lower Saxony mainland salt marshes (Appendix III). The vegetation maps

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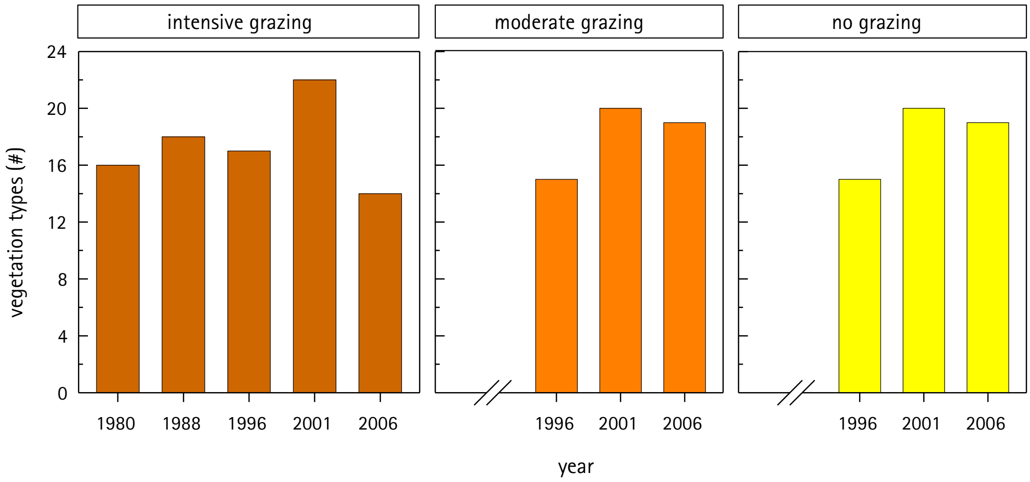

scheme with three levels of grazing: no grazing, moderate grazing, and high-intensity grazing. This scheme is valid until today. Subsequent surveys were carried out in 1996, 2001 and 2006. The last two surveys cover the entire salt marsh area in Schleswig-Holstein.

Except for the 2001 survey, the highest number of vegetation types or plant communities was found in the ungrazed parts of the salt marshes (Fig. 6). This may be explained by the large amount of vegetation complexes in the intermediate successional stage of the vegetation, which appeared in all management regimes.

Marked changes occurred in the intensively grazed parts of the mainland salt marshes (Fig. 7). The incidence of the *P. maritima* community decreased, whereas the incidence of the *Salicornia* community increased. For the 2006 survey, this is partly explained by the fact that *Puccinellia* swards that were codominated by *Salicornia ramosissima* (= *S. europaea*), have been classified according to the TMAP key as *Salicornia* plant community (see App. I).

In the intensively grazed salt marshes, the incidence of the *Spartina anglica* and *Festuca rubra* communities remained more or less constant during the period 1988–2006, whereas the *Juncus gerardi* community increased slightly. In 1980, most of the upper salt marsh has been classified as *Juncus gerardi* community. In the intensively grazed marshes, the *Elytrigia atherica* community increased only slightly over the whole period of

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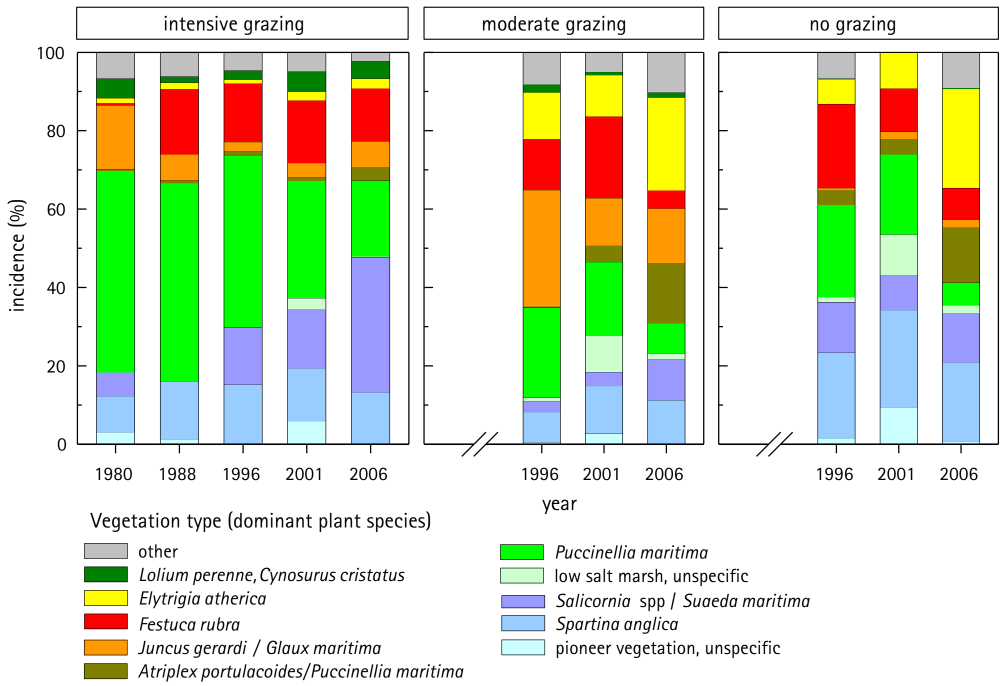


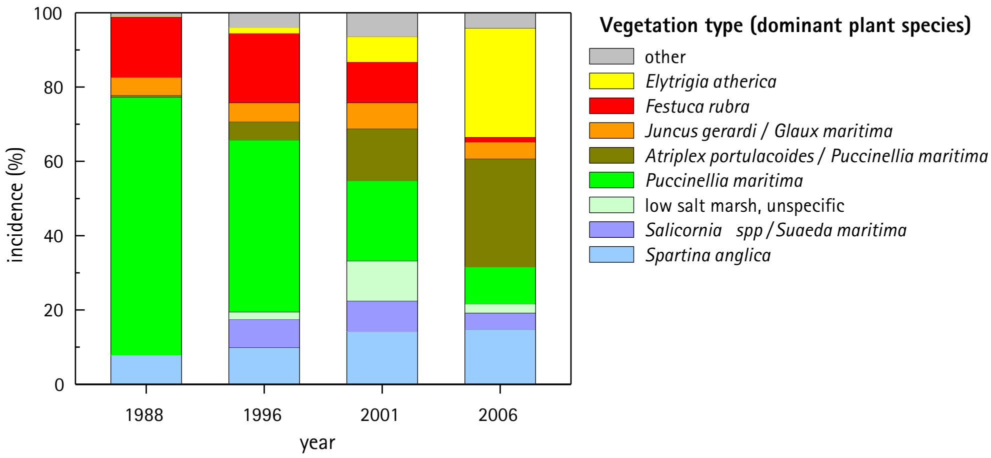


Figure 8: Vegetation development on the Hamburger Hallig from 1988 until 2006 based on vegetation surveys of the total area. Note that the whole area was grazed intensively with sheep until 1991, then three management regimes were introduced in different parts of the area. Vegetation types are according to TMAP typology (Appendix I). For geographical reasons, vegetation types with a limited distribution (incidence < 5% in all years), were merged into one group ('other').

26 years of successive mapping, but did remain below 5 % of the area. *Atriplex portulacoides* and *Artemisia maritima* communities increased slightly only during the last 10 years; their occurrence stayed below 5%.

The overall trends in vegetation changes differed locally in relation to local grazing intensity, elevation and waterlogging of the specific site. The Hamburger Hallig, for example, was intensively grazed until 1990. Since 1991, however, about 53% of the site is ungrazed, 26% moderately and 20% intensively grazed. As a result of this decreased grazing intensity, the *Puccinellia maritima* community decreased steadily from more than 70% to less than 10% (Fig. 8). The *Festuca rubra* community showed the same trend, although its decrease was less pronounced. On the other hand, the incidence of *Atriplex portulacoides* and *Elytrigia atherica* types increased significantly (Seiberling & Stock 2009).

In summary, it may be concluded that the formerly intensively grazed marsh dominated by a short monotonous *Puccinellia* turf, now supports a variety of vegetation types. The spatial pattern of the vegetation is related to variation of abiotic factors (such as elevation, drainage pattern, waterlogging, and nutrient supply) and to biological interactions including successional change.

Vegetation changes in Danish Wadden Sea

The Danish salt-marsh surveys were almost confined to their areal extent with the exclusion of the pioneer zone. Because neither vegetation types nor salt-marsh zones have been distinguished, vegetation changes can not be evaluated on an areal base. Data from the NOVANA monitor programme have not yet been analysed, and it is therefore too early for any conclusion about changes in plant-species composition.

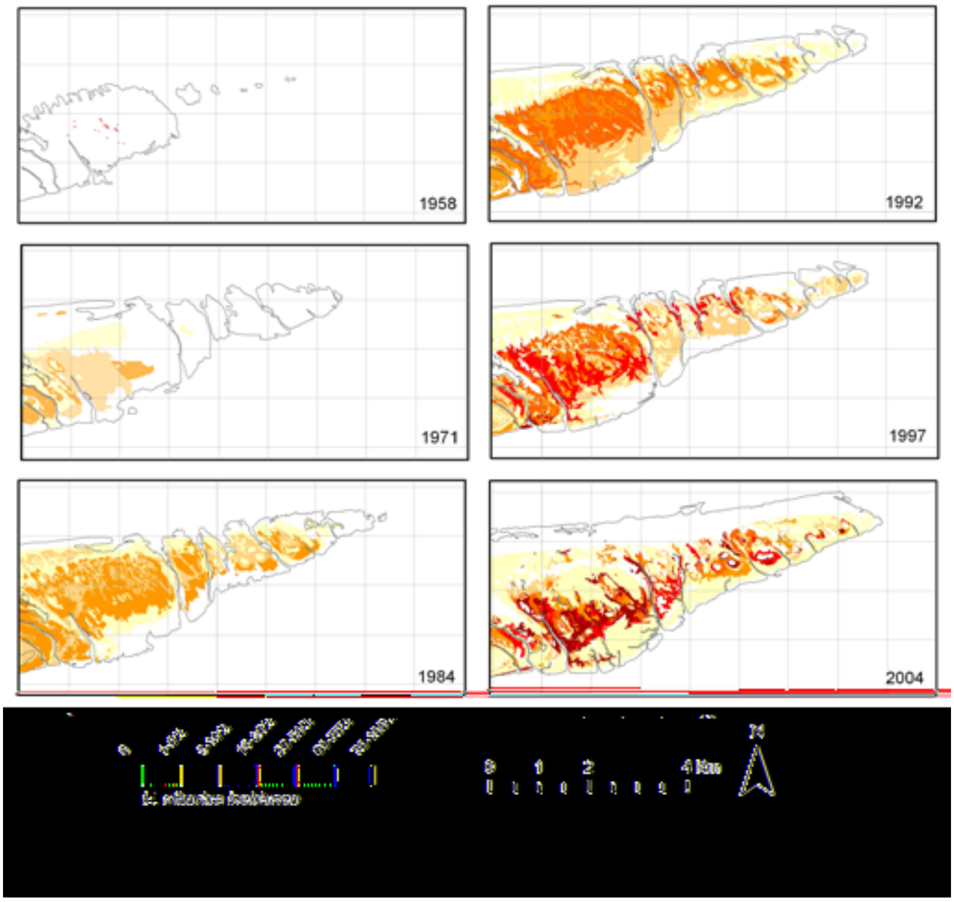
Methods of the two recent Danish surveys (Tables 1, 2) were not consistent, and the results can not be compared. In the recent years there has been an increase in the area of green beach on the islands of Fanø and Rømø, and an increase of salt-marsh vegetation on the high sand south of the island of Fanø (Keldssand).

3.2.3 *Elytrigia atherica* encroachment in back-barrier marshes

On the barrier island of Schiermonnikoog, the species *Elytrigia atherica* is expanding eastwards along with the eastward expansion of the island. At the same time, the species increases in abundance. In 1958, the area of the *E. atherica* community (TMAP vegetation type 3.7: *E. atherica* cover >25% and highest abundance among plant species) was less than 0.01% of the salt marsh (the area of creeks not included). By 1992, the area of the *E. atherica* community had increased to 20% of the salt marsh. In recent years, the expansion of this community levelled off (Fig. 9). Within the *E. atherica* community, however, the abundance of *E. atherica* continued to increase, from >25% to >50% cover. A similar levelling off in expansion, as a result of reaching equilibrium or simply because of limited space, has been found in old and well-established stands of *Phragmites australis* and *Spartina* alterniflora (Rice *et al.* 2000; Civille *et al.* 2005).

Recently, in the oldest part of the salt marsh at a great distance from the intertidal flats, a decrease of the *E. atherica* community has been observed.

The decrease of *E. atherica* community may be related to environmental changes. In the old marsh, soil compaction and a decrease of sediment input may have led to the formation of depressions with standing water. Here, former *E. atherica* stands have been replaced recently by stands of



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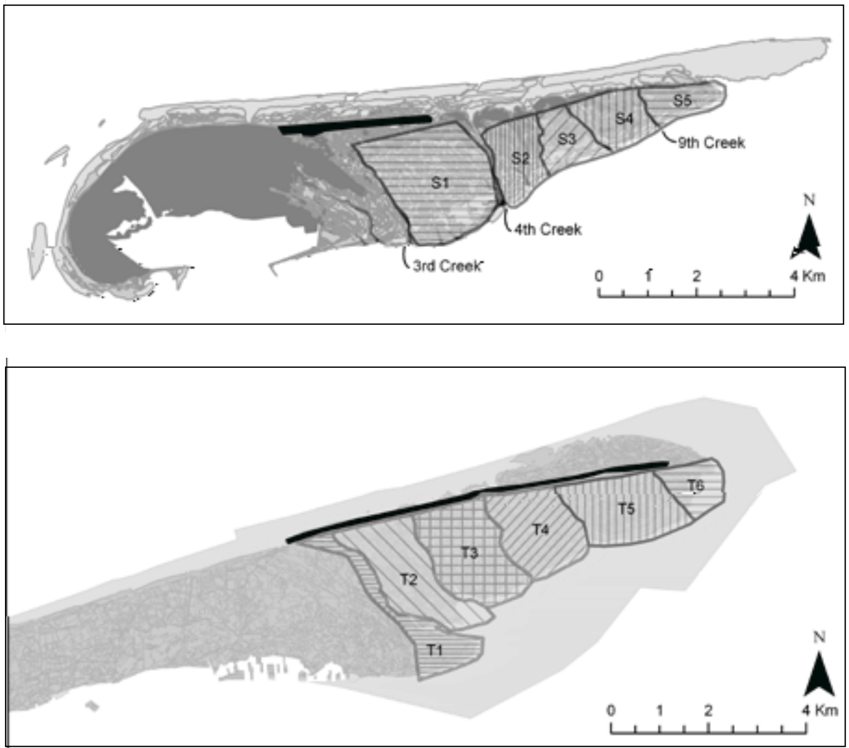

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Phragmites australis and *Juncus gerardi*. Further research on soil conditions is required to support these ideas.

We compared the spread of *Elytrigia atherica* on four back-barrier salt marshes on the island tails of four islands with differences in human influence on the geomorphology of the islands tails, *viz*.

(1) Terschelling: artificial dune ridge along the entire island tail,

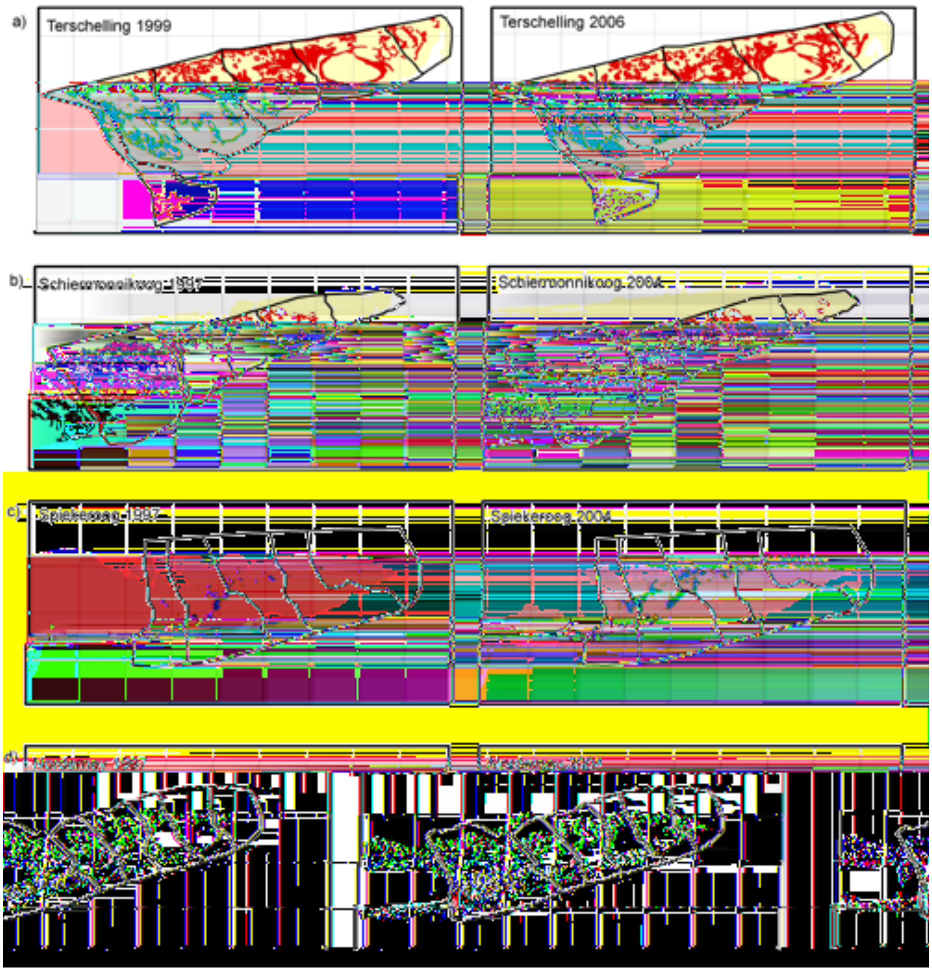
(2) Schiermonnikoog: artificial dune ridge partly present,

(3) Spiekeroog: artificial dune ridge not present,

(4) Norderney artificial dune ridge not present; artificial drainage of salt marsh.

On Schiermonnikoog, an artificial dune ridge was constructed in the late 1950s north of the sections S1–S3 (Fig. 10). This dune ridge breached every winter, however, and became only maintained north of section S1. Since the mid-1960s, the more eastern part of the island (sections S2–S5) has not been protected from the North Sea. The eastward part of the contemporary salt marsh thus developed in the absence of an artificial dune ridge (see Fig. 9). On Terschelling an artificial dune ridge was constructed in the early 1930s north of the sections T1–T6 (Fig. 10). This dune ridge was maintained successfully from the beginning. Hence, the salt marsh started to develop in the shelter of the artificial dune ridge in all sections simultaneously. Comparison of the two most recent vegetation maps revealed that the incidence of the *Elytrigia atherica* community was between 20–25 % of the vegetated salt marsh, and its increase was about 4% per year in all sections T1–T6 (Fig. 11A).

On the island of Schiermonnikoog, a gradient was found of a high incidence of the *Elytrigia atherica* community on the old salt marsh in the west to a low incidence on the youngest salt marsh in the east. The increase of *E. atherica* on the unprotected salt marsh was stronger (sections S2–S5) than at the old marsh (Section S1), protected by the artificial dune ridge (Fig. 11B), possibly because of a change in soil conditions in the old salt marsh (see above).



[illegible] *Elytrigia atherica* [illegible]

Box 1: Towards a New Geomorphological Concept of Wadden Sea Barrier Islands

Figure 12: New geomorphological model of a barrier island with its characteristic main units and sub-units (after Löffler et al. 2008). Values between brackets refer to expected longevity of main units (years; other symbols refer to different sub-units. Salt marshes may be found in sub-units [illegible] and 5a.

Main units

1 Island head (25-50)
2 Closed dune bow complex (50-400)
3 Washover complex (25-100)
4 Island tail (25-40)
5 Beach and foreshore

In response to questions about both climatic change and coastal safety on the one hand, and different scenarios for a nature-conservation strategy on the other hand, a new model on the geomorphological functioning of Wadden Sea barrier islands has been developed (ten Haaf & Buijs 2008; de Leeuw *et al.* 2008; Löffler *et al.* 2008). The model was developed specifically for the Netherlands islands, and hence applies to the west-east orientated barrier islands of the southern Wadden Sea only. The model identifies the most important geomorphic driving forces at different spatial and temporal scales. As a result, a barrier island in the model comprises five geomorphological main units with several sub-units (Fig. 12). Salt marshes may be found in all five main units of a model island. It is unclear yet to what extent these salt marshes differ ecologically.

The model is likely to influence coastal management, and our view on the functioning of island salt marshes. The model is therefore briefly introduced here by a characterization of the five main units of an ideal barrier island (cf. Fig. 12):

(1) Island heads

On the island heads, green beaches may develop in places where the beach plain is partly cut-off from the sea. This situation may be found on the islands of Terschelling, Ameland and Schiermonnikoog. The vegetation of green beaches is characterized by a combination of pioneer species from salt marshes and dune valleys. Salt marshes may also develop on the leeside of embryonic dunes or dune ridges.

(2) Dune-bow complexes

Extensive salt marshes have developed on the south side of dune-bow complexes under the influence of inundation by seawater from the Wadden Sea. These marshes are characterized by different vegetation zones from high to low salt marsh and pioneer vegetation. The low marsh and pioneer zone may be subject to erosion as well as accretion. Large parts of these salt marshes have been turned into agricultural area through embankment.

(3) Washover complexes

Washover complexes that are formed on the North Sea side of the island gradually merge with salt-marsh vegetation on the Wadden Sea side. The washover complex itself can either be bare, covered with algae or with pioneer salt-marsh or dune vegetation comparable to green beaches. A dynamic washover complex is subject to both the deposition and erosion of sand by wind, as well as to frequent inundation by seawater and sedimentation from the water column. These processes affect both succession and rejuvenation processes of the salt marsh that fringes the washover complex to the south.

(4) Island tails

Initially, island tails are bare sand flats that are periodically subject to erosion and accretion. On these sand flats, small embryonic dunes may be formed, which may grow into larger dune complexes that are separated from each other by washovers. On most of the Netherlands islands, these dune complexes have been connected by an artificial dune ridge, especially during the 20th century. On the leeside of these artificial dune ridges extensive salt marshes have developed, such as the Boschplaat on the island of Terschelling. The presence of the artificial dune ridges explains why in a quantitative sense, island tails are the most important units for salt-marsh vegetation, and why the actual extent of islands salt marshes is well above historic reference values (Dijkema 1987). In addition, the almost complete elimination of morphodynamic influences from the North Sea on both sedimentation and erosion explains that young succession stages are almost absent, and old succession stages generally predominate the northern fringe of these marshes.

(5) Beach and foreshore

The beach and foreshore can be found along the entire North Sea side of the barrier island. Periodically, extensive areas of green beach may develop, which may disappear quickly when large-scale dynamic processes are less favourable.

Though on Spiekeroog, the incidence of the *Elytrigia atherica* community was lower than on Schiermonnikoog, the expansion pattern appeared very similar (Fig. 11C). On Norderney, a significant expansion of the *E. atherica* community was only observed in the western part of the salt marsh (Fig. 11D). In this section, remains of artificial drainage furrows are still present, which may have stimulated the expansion of *E. atherica*.

The long time series of Schiermonnikoog, reveals that the increase of *Elytrigia atherica* on salt marshes is strongly related with the age of the vegetated marsh (Fig. 9). The comparison of the development of *E. atherica* on the four back-barrier marshes allows us to evaluate the effect of coastal management on vegetation succession on the back-barrier marshes. The well maintained artificial dune ridge on Terschelling enhanced the succession, and allowed *E. atherica* to develop rapidly to a climax vegetation type. Also the drainage works on Norderney enhanced the increase of *E. atherica* vegetation. On the unmanaged salt marshes, natural dynamics appear to prevent, or at least to hamper the succession to a climax vegetation of monostands of *E. atherica*.

3.3 Management

3.3.1 Salt-marsh works

From the current total of about 400 km^2 of salt marshes in the Wadden Sea, over 50% is formed by foreland-type salt marshes on the mainland (Table 1, Fig. 1). These mainland marshes have to a great extent been developed artificially from sedimentation works. In general, management aims have shifted over the past decades from agricultural exploitation and land claim to nature conservation. Concurrently, on parts of the coast artificial salt marshes have been developed and are managed for coastal protection. In this section, the major developments per sector are reviewed.

Netherlands

Mainland salt marshes in the Netherlands Wadden Sea are almost entirely of anthropogenic origin. Their development has been stimulated by a system of drainage ditches, and since the 1930s especially by a lay-out of sedimentation fields surrounded by brushwood groynes, which improved conditions both for sedimentation and plant establishment. The main aim of this construction was land reclamation for agricultural purposes. The sedimentation fields originally measured 400 m × 400 m and were arranged in three rows from the salt marsh onto the intertidal flat. Accretion works reached their greatest extent in the 1960s, when a turning point was reached. A study from 1965 concluded that developing salt marsh for land reclamation was not an economic enterprise, whereupon it was decided to downgrade the aim of the management of the accretion works to maintaining the status quo.

From about 1975, there has been a growing recognition that the remaining mainland salt marshes have an important value for nature conservation. In the framework of an integrated management plan for the Dutch Wadden Sea, a "no-net-loss" policy was developed during the 1980s for the existing mainland salt marshes. Since accretion works protect the existing salt marshes from erosion, this policy has become the main reason to maintain accretion works in the Netherlands. In order to enhance more natural development, human intervention gradually has been diminished from 1990 onwards by a more judicious maintenance of groynes and a reduction of artificial drainage systems. In summary, since 1990 the following changes in management have been introduced:

- Abandonment of the third, most seaward row of sedimentation fields, which did not contributed to the protection of the salt marsh.
- Cessation of all engineering measures on coastal stretches where either accretion rates were very high or where accretion rates were negligible and elevations stayed too low to allow salt marshes to develop.
- Run-down of all groundwork, i.e. a minimum-intervention management of the drainage system by 2000.
- The construction height of new groynes was restored to the original relative height of 0.30 m above MHT with an extra margin for future sea-level rise (groyne height had not been adapted to local sea-level rise for several decades).
- A flexible protection regime of the zone directly in front of the salt marsh which was realized by a reduction in size of sedimentation fields to 400 m × 200 m or 200 m × 200 m at sites where elevation development of the pioneer zone did not keep pace with the increase of MHT and where low salt marsh deteriorated.
- Constant monitoring and maintenance of a solid connection between brushwood groyne and salt marsh to prevent erosive water currents to occur in between.
- Use of more durable brushwood filling (*Picea abies, Pseudotsuga menziesii, Picea sitchensis*), which allowed a lower filling frequency, and meant a cut in maintenance costs.

As a result of all changes, the area of both the pioneer and other salt-marsh zones started to increase again. The total groyne length along the Frisian and Groningen mainland coast decreased from 220 km to approximately 140 km in most recent years and 2,000 ha of intertidal flats have been returned to the influence of natural dynamics without that the extent of salt marshes was negatively affected.

Lower Saxony

Similar to the situation in the Netherlands, salt marshes on the mainland coast of Lower Saxony are mainly of anthropogenic origin. Land claim and shortening of the coastline for coastal-protection have reduced the formerly extended salt marshes into a narrow band of salt marshes in front of the seawall. The vast majority of the mainland salt marshes developed from accretion works.

The current focus of nature conservation is to improve the habitat quality of the salt marshes. A common concern of coastal defence and nature conservation in Lower Saxony is to preserve the present extent of salt marshes as far as possible. This implies that for areas with strong salt-marsh erosion, nature-conservation agencies support engineering measures to preserve the salt marsh. In concurrence with the establishment of the National Park, the appreciation of salt marshes as habitat for animals and plants improved greatly. The salt marshes in Lower Saxony, comprising a total of 8,600 hectares between the Dollard and Cuxhaven on the mainland and on the East Frisian islands, are located entirely within the national parks of the Lower Saxon Wadden Sea. The approach of the national parks is to preserve or restore the development of salt marshes under natural or nearly natural conditions as far as feasible:

- At present, sedimentation fields are constructed for coastal protection only. In order to create a buffer protection of the seawall against wave-energy, – contrary to the management in the Netherlands, – salt-marsh development is also stimulated on coastal stretches where the foreland is very small or absent.
- The development of salt marsh in front of a seawall by means of sedimentation fields will be implemented in special cases. The intention is to stimulate sedimentation in the sedimentation fields by periodic refurbishment of the ditches until a closed vegetation cover has developed.
- In agreement with the organisations for coastal protection, maintenance of the drainage system on the mainland marshes as well as on the islands has largely been abandoned, especially where agricultural exploitation has stopped. In order to ensure drainage of the foot of the seawall, the upkeep of the drainage system is continued in a restricted part of the marshes only.
- The opening of summer banks, the reactivation of former creek systems, the abandonment of the artificial drainage system and an enhanced salt-water influence have been realized successfully in accordance with coastal protection issues.
- In some areas, particularly in the Jadebusen, strengthening of the seawall is necessary. The required clay is primarily extracted from clay pits inland of the existing seawall or, in exceptional cases, from existing salt marshes. The site selection and design of the clay pits is done in accordance with the authorities for nature-conservation: clay pits are restricted to areas where in the new developed salt marsh in the medium term, an improved habitat structure and diversity is expected.
- The major concern of nature conservation in recent years was a further reduction of the agricultural use of salt marshes, which resulted in the current mosaic of exploited and especially unexploited salt marshes. On state-owned land, agricultural use is of a low intensity in accordance with strict guidelines about grazing intensity, date of mowing, *etc*.

In order to combine the various issues of coastal defence and nature conservation in relation to salt marshes, management plans will be formulated for all foreshore coastal sections separately by institutions that are either responsible for coastal defence or nature conservation.

Hamburg

In the past there were no regularly salt-marsh works on the island of Neuwerk for a long period. In the 1930s groynes were built in front of the eastern part of the island to support the sedimentation and the development of foreland. The experience of the following years indicated, however, that this did not have any effect. Therefore engineering measures were abandoned during the 1950s. The rest of the foreland on Neuwerk consists of natural-developed salt marshes. On the islands of Scharhörn and Nigehörn, the salt marshes have developed completely naturally without any human interference.

Schleswig-Holstein

The great majority of the salt marshes on the mainland coast of Schleswig-Holstein have been developed through accretion-enhancement techniques since about 1850. This has been achieved by the construction of sedimentation fields surrounded by brushwood groynes. Until the 1950s, the main purpose was to reclaim new land for agriculture. Later, the main objective became coastal defence. During the last few decades and with the implementation of the national park in Schleswig-Holstein (1985), a growing environmental concern led to a new appreciation of salt marshes. The guiding principle for salt-marsh management became to achieve a natural and sustainable ecosystem where ideally, natural processes should proceed without human interference. Consequently, a new concept for the management of the salt marshes in Schleswig-Holstein had to be prepared, and the following common principles for salt marsh management were established:

- The common goal of the coastal defence and the environmental administration is to preserve existing salt marshes.
- Salt marshes will only be created in front of the seawall where prevailing sedimentation processes allow it.
- The techniques that are used to reach these goals depend upon local circumstances. They must be carried out in an ecologically sound way as far as possible.
- Where local circumstances allow, technical measures are abandoned.
- A salt-marsh monitoring programme has been established to assess the success of these measures.

As a consequence of these management principles the main management techniques have been evaluated. Artificial drainage has been abandoned in the ungrazed marshes and was reduced in the grazed parts of the marshes. Brushwood groynes enhance salt marsh accretion and stabilise existing salt marsh edges. This traditional technique shall be maintained in most areas. The traditional set-up to create a salt marsh consists of three sedimentations fields in front of the seawall, each 200 m x 200 m large. For the protection of the marsh edge a simple field in front of it is sufficient. In sheltered locations and favourable sedimentation conditions, the maintenance of the groynes has been abandoned. Transport dams, perpendicular to the seawall, are only maintained in the grazed marshes and in the ungrazed where they are essential for coastal defence. Considering the common principles and the evaluation of the present salt-marsh techniques, regionally differentiated plans were developed, including ten reference areas where technical measures are abandoned.

Denmark

Also in Denmark, the foreland-type salt marshes are mainly artificial. They area confined to the mainland coast between Esbjerg and the Danish-German border, where they were developed in connection with 20th-century land claims.

Today, salt marshes in Denmark fall under the Danish Nature Conservation Law (1992) and the Wadden Sea Ministerial Order (1998). This legislation entails limitations to the use and management of the salt marshes. Neither new drainage works nor sedimentation fields with ditches and groynes are maintained any longer. The exception is along the low tide dam to the island of Mandø where these activities are carried out in order to secure the island passage.

In the framework of the elaboration of the Danish Wadden Sea Natura 2000 Management Plan, the following objectives and management measures for the future maintenance have been formulated:

The salt marshes have a favourable conservation status, which implies that:

- The area and the biological condition should be stabilized or being increased;
- The natural drainage and hydrology are secured;
- Optimal (low-intensity) maintenance is secured;
- Their function as breeding- and roosting ground for birdlife is secured.

3.3.2 Drainage

In the framework of the artificial enhancement of salt-marsh development in most of the foreland-type salt marshes of the Wadden Sea, the digging and the upkeep of drainage furrows has traditionally been an important management tool. The function of artificial drainage was to drain seawater after flooding and to improve soil conditions for plant growth. As an effect of drainage measures, the lower fringe of both the pioneer and the low-marsh zone could descend vertically by 0.2 metre (Dijkema *et al.* 1991; Bakker *et al.* 1997). The construction and upkeep of a dense artificial drainage system does generally not have any direct effect on vertical accretion rates (Dijkema *et al.* 1991; Arens & Götting 2008; Michaelis 2008). In traditionally exploited marshes, the upkeep of the artificial drainage was continued in order to enhance the carrying capacity for livestock grazing.

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Parallel with the shift away from agricultural exploitation towards the recognition of conservation values of salt marshes, the view on drainage measures has changed dramatically over the last decades. In order to increase the natural morphology of artificial salt marshes (Wadden Sea Plan Target), the maintenance of artificial drainage systems has ceased completely over extensive marsh areas (Fig. 13). In Germany, this development has been stimulated with the creation of the national parks during the 1980s. A few years earlier, the upkeep of the artificial drainage was stopped already in the larger part of the Netherlands salt marshes in the Dollard (Esselink 2000). Maintenance of the ditches in the salt-marsh works on the north coast of the provinces of Fryslân and Groningen was stopped by 2001 (Dijkema *et al.* 2001). In the Netherlands, ditching is continued locally by farmers in order to facilitate livestock grazing. This small-scale practice contributes to the local diversity of the salt marshes.

In the western part of the Wadden Sea (i.e. Netherlands up to and including Hamburg), islands salt marshes have been disturbed by ditching in the past to a minor extent, whereas in Schleswig-Holstein more than 60 % of islands marshes have been touched (Fig. 13AB). During the past 10 years, however, ditching has virtually not been practiced here anymore. To restore the natural morphology and drainage in a back-barrier marsh that had been disturbed by ditching in the past, a 9-ha pilot project has been carried in 2008 on the island of Norderney (Bunje, unpubl.).

For the Danish salt marshes, recent data on the development of drainage management over time are not available (Fig. 13). Ditching is licence-restricted. During the most recent survey (2008), 43% of the Danish salt marshes were classified as "undrained", 39% as "moderately drained" and 18% as "intensively drained" on the average with only minor differences between island and mainland marshes.

In the artificial foreland salt marshes, it may be virtually impossible to develop a full natural drainage system. Natural creeks develop during a certain time window in the process of salt-marsh initiation. Once the salt marsh has been formed, creeks remain relatively stable. In the artificial salt marshes, the presence of an artificial drainage system precludes the formation of natural creeks and the time window of creek formation has passed (Esselink 2000; Dijkema *et al.* 2007).

Neglect of the artificial drainage system results in silting of most ditches, whereas the remaining ditches will increase in size. Elevated levees may develop along the ditches as long as the latter are functioning as creeks. Behind the levees, depressions develop. In the Dollard salt marshes, the process of silting up of ditches lasted more than 20 years (Esselink 2007). Once ditches were completely silted up in these marshes, elevation differences between depressions and levees faded in time. Also in the Paezemerlannen, a developing pattern of levees and depressions seemed only transitory after this salt marsh became de-embanked 35 years ago (van Duin *et al.* 1997, 2007a). Based on the developments in the Dollard marshes and a comparison with salt marshes elsewhere, it may be assumed that a distinct pattern of levees and depressions will have the longest life expectancy in salt marshes where vertical accretion rates are relatively low, for instance in the back area of broad marshes.

Salt-marsh creeks are, in general, spatially stable. This implies that a straight ditch will not change easily in a meandering creek. Such creeks are more likely to develop in artificial salt marshes by headward erosion of creeks. This is normally a very long-lasting process.

Opposite to ditching, neglect of the artificial drainage will cause increased soil waterlogging or rewetting of the salt marsh. This may partially reset or at least retard vegetation succession.

3.3.3 Livestock grazing

The main land use of salt marshes is either agricultural use or nature conservation. Similar to the 2004-QSR data, the respective areas have still not been quantified. In principal, within each land-use type, management practices such as livestock grazing, mowing, and abandonment are distinguished and these have been quantified in the TMAP surveys.

Agricultural exploitation of salt marshes is not a modern phenomenon. Already during the mid Holocene, salt marshes in western Europe were used for livestock grazing, especially where the vicinity of higher grounds or peat domes permitted permanent dwelling (Allen 2000). In the Netherlands, the oldest archaeological evidence for salt-marsh exploitation, leaving hunting aside, originated from cattle grazing during the Late-Neolithic (about 2,600 B.C.; Bakels & Zeiler 2005). After the construction of seawalls during the Middle Ages, grazing soon became mentioned in local regulations on management of the foreland for coastal defence (*e.g.* for the Netherlands: Rustinger Law first half of 12th century (Acker Stratingh 1886, cited by Oost 1995)). Firstly, grazing should provide the possibility to cut salt-marsh sods for seawall repair. Secondly, grazing was thought to have a positive effect on the shear strength of the marsh bed, thus to prevent erosion, and hence to contribute to the stability of salt marshes. Because salt marshes have a positive effect on the safety of seawalls, grazing became advocated, at least regionally, for reasons of coastal defence. This has proven to be a fallacy. Leaving out the pioneer zone, there is ample evidence meanwhile that surface erosion from a vegetated salt marsh can be ignored (Erchinger *et al.* 1996; Zhang & Horn 1996).

Among the three Wadden Sea countries, the starting point of the management for nature conservation differs. In the German national parks, the undisturbed course of natural processes is by law the declared prime objective. This implies a ban on livestock grazing in a considerable part of the salt marshes. In the Netherlands and Denmark, objectives of management for nature conservation are more centred on the preservation of biodiversity. In order to halt vegetation succession, livestock grazing is advocated in these countries, especially in the semi-natural foreland salt marshes.

Between the 1995/2001 and 2002/2007 surveys, the status of livestock grazing, including mowing over limited areas, has approximately been stable in the Netherlands and German sectors over the last ten years (Fig. 14). In Denmark, survey methods evolved from livestock counting from the air to assessment of the grazing status during fieldwork for the EU habitat survey more recently (see Table 1). Data may therefore not be fully comparable. In the Danish sector, the area of minimum-intervention management seemed to have more than doubled on both island and mainland marshes.

During the surveys, grazing has been subdivided in two classes of intensity which have been defined on the basis of appearance of the vegetation:

- 'intensive grazing' is indicated by a uniform short sward,
- 'moderate grazing' is indicated by a heterogeneous sward of with short and tall canopies.

Mainland salt marshes were more frequently grazed than island marshes, especially in the western Wadden Sea (i.e. west of the Elbe estuary). North of the Elbe, island salt marshes seem more frequently and more intensively grazed than in the western Wadden Sea. The foundation of National Parks in the German Wadden Sea in the 1980s signified cessation of the agricultural use of extensive areas of salt marsh. Before these

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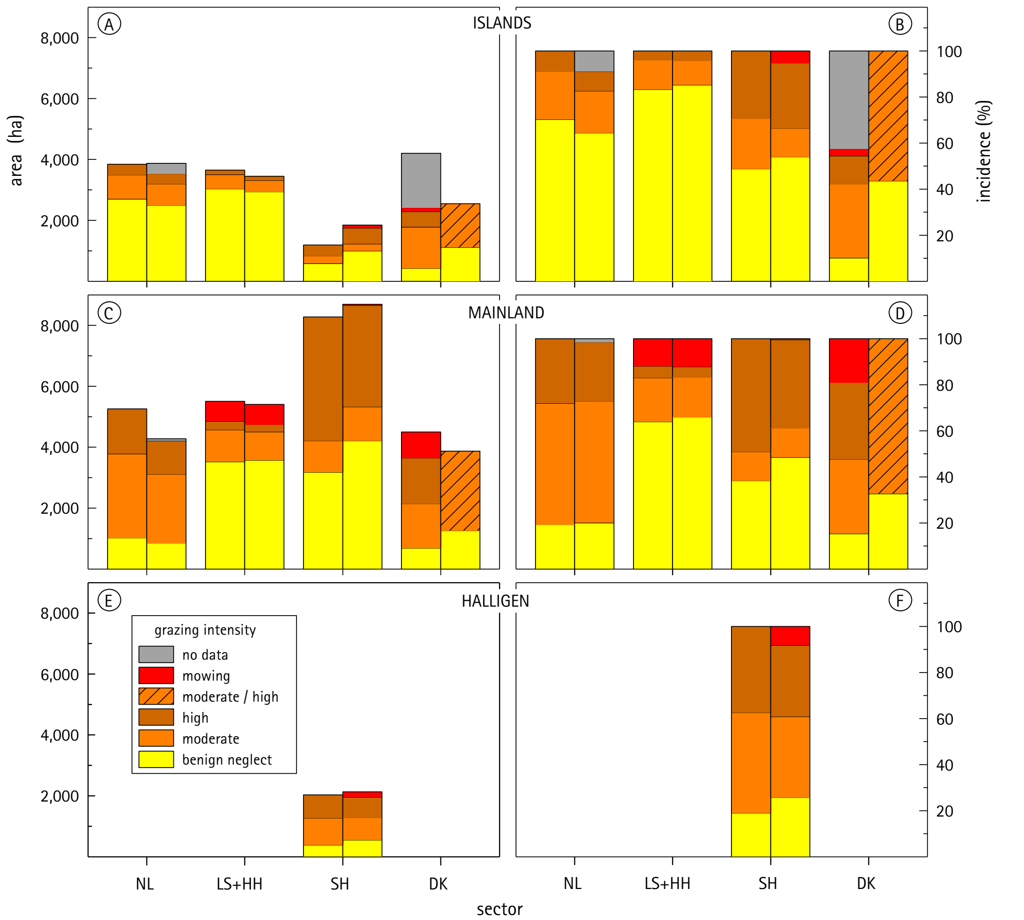

national parks affected the use of the salt marshes, the situation on the mainland marshes in Lower Saxony differed from that Schleswig Holstein, however: in 1986, 42% of the mainland marshes of Lower Saxony were managed already with a policy of minimum intervention in comparison with only 3% in Schleswig Holstein.

- The major changes in livestock grazing of the salt marshes over the 20-year period that is covered by Figure 15, may be summarized as follows:
- Island salt marshes Schleswig-Holstein: an increase in the incidence of the area that was managed with minimum intervention from 30% to 54% at the expense of the area with a high grazing intensity.
- Island salt marshes Denmark: a sharp increase in the incidence of minimum-intervention management from 5% to over 40%.
- Mainland marshes Netherlands: redoubling in the incidence of moderate grazing from nearly 25% to just over 50% of the marsh area.
- Mainland salt marshes Lower Saxony: if mowing is ignored, a cut in the incidence of intensive use from over 25% to less than 5%, followed by an increase of minimum-intervention management.
- Mainland salt marshes Schleswig-Holstein: A sharp drop of intensive sheep grazing from almost 90% of the area in 1986 to 38% by 2008 with a similar increase in the incidence of minimum-intervention management (Stock *et al.* 2005). In order to guarantee the possibility for sod cutting for seawall repair, intensive grazing is continued in a restricted area that fringes the seawall.
- Mainland salt marshes Denmark: A fourfold increase from 8% to 33% in the incidence of ungrazed marshes.

Data presented by Kempf *et al.* (1987) on the management of the Hallig salt marshes cannot be compared with the two TMAP surveys: data of Kempf *et al.* concern only the foreland marshes of the Halligen, whereas the data of the TMAP surveys refer the Halligen proper. The comparison with the data of Kempf *et al.* can only be performed on a percentage base because of data incompatibility. Small changes in grazing management on a percentage base, for instance of the islands marshes in the western Wadden Sea may be the result of changes in the total marsh area.

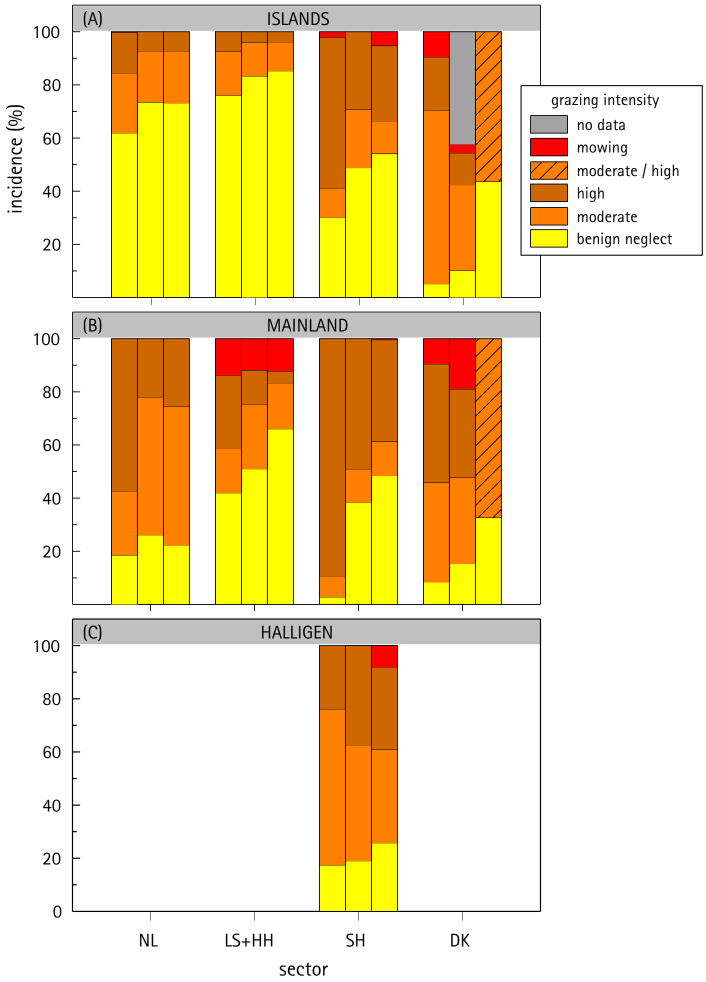

Figure 15: Development of livestock grazing, mowing and minimum-intervention management in the Wadden Sea salt marshes from 1986/1987 (left bars) to 2002/2008 (right bars). The centre bars present the results of the 1997/2001 survey (Fig. 14; Bakker *et al.* 2005). Data of the 1980s have been modified after Kempf *et al.* (1987). Data of the three surveys can be compared on a relative scale only. See Figure 14 and text for further explanation.

3.4 Vertical accretion and vegetation succession in broad marshes: the Hamburger Hallig case

Most of the Wadden Sea salt marshes in Schleswig-Holstein have been grazed intensively by sheep for centuries. Because nothing was known about natural succession of the vegetation in the area, an enclosure of 0.8 ha was established in the central part of the Hamburger Hallig in 1978. In one half of this enclosure, different management regimes (grazing, mowing) were applied for three years. The other half of the enclosure was managed with non-intervention. This management was extended to the entire enclosure when the management experiment stopped after 1980. Artificial drainage of the area was also abandoned.

Detailed elevation data of the enclosure are available from 1979. Elevation measurements have been repeated yearly from 2001 onwards. These data show an average accretion rate of 3.9 mm/yr for the last seven years. Over the entire time span since 1979, the net accretion rate was not more than 1.5 mm/yr.

A detailed vegetation map from 1980 is missing, but according to a vegetation map of the entire area in 1980, the vegetation was dominated by *Juncus gerardi*. 15 Years after the cessation of grazing in the enclosure, a first vegetation map was drawn in 1995 (Fig 16). Mapping was repeated in 2007 with the same methodology. Over the last 27 years, the vegetation developed from a J. gerardi-dominated sward in 1980 into ungrazed, species-rich *Festuca rubra*-dominated vegetation. In 1995, large parts of the enclosure were also covered by *Aster tripolium* and to a lesser extent by *Artemisia maritima*. *Aster tripolium* decreased again afterwards. The high incidence of this grazing-sensitive species in 1995 can be seen as an effect of the cessation of grazing 15 years before. Following the neglect of the drainage

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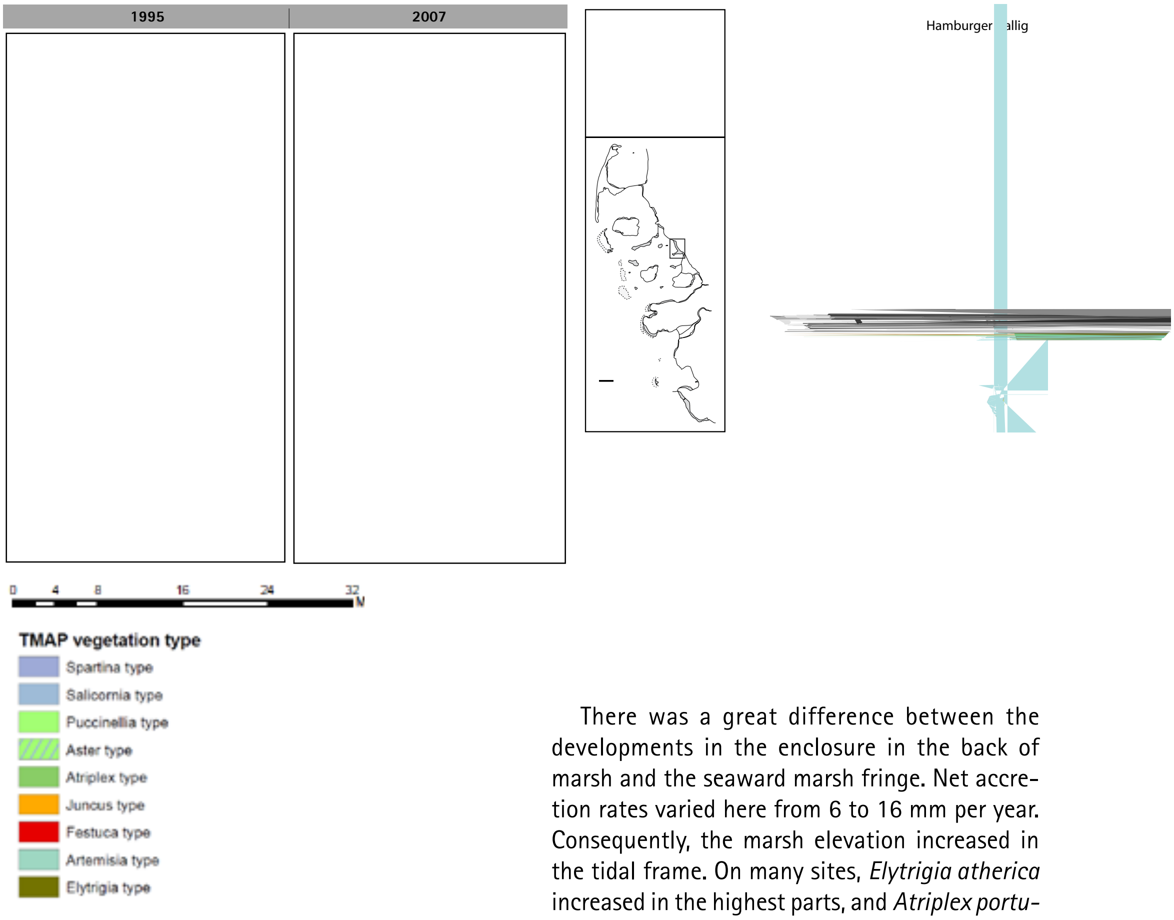

system, *Spartina anglica* is now found in former ditches. *Atriplex portulacoides* has increased from 5% in 1995 to 12% in 2007. The latter species was growing on lower and well aerated parts of the salt marsh. *Elytrigia atherica* had already established between 1978 and 1980. In 1995, it covered 3 % of the vegetation. In 2007, 27 years after the abandonment, it covered 17 % of the enclosure, but was limited to the highest parts (Fig. 16).

Within the last 27 years, the elevation of the enclosure in relation to mean high tide has not increased. On the contrary, because the rise of the mean high tide level exceeded the average net accretion rates, the elevation of the plot in the tidal frame is even slightly lower today than it was in 1978 (Table 3). Thus, soil waterlogging of the site has been constant or slightly increased. We conclude that these circumstances form an important factor that may control both the rate and the direction of vegetation succession in an ungrazed situation (Schröder *et al.* 2002). Until today, the vegetation is dominated by a species-rich *Festuca* community and a dominance of *E. atherica* did not develop.

There was a great difference between the developments in the enclosure in the back of marsh and the seaward marsh fringe. Net accretion rates varied here from 6 to 16 mm per year. Consequently, the marsh elevation increased in the tidal frame. On many sites, *Elytrigia atherica* increased in the highest parts, and *Atriplex portulacoides* on the less elevated parts, irrespective of whether these parts of the marsh were moderately grazed or ungrazed.

3.5 Restoration

Salt-marsh restoration has received increasing attention during the last two decades. Since 1973 some 16 restoration projects have been implemented in the Wadden Sea Region or are planned for the near future, including 567 ha for the Netherlands, 385 ha for Lower Saxony and 40 ha for Hamburg (Table 4; Textboxes 2 – 4).

Key factor in these projects is the re-introduction of tidal influence to areas that have been embanked for decades to centuries. These areas are mainly summerpolders which have been reclaimed from artificial salt marshes, but also include beach plains and former dune slacks. Tidal influence is completely restored by bank removal from the marsh bed, or partly by the installation of sluices, culverts or dams. The success rate varies from low to high with different salt-marsh plant species establishing, but with ageing, low tidal amplitude and silting up of the sublittoral zone as limiting factors for species diversity. Es-

Elevation above NN	Year	MHT	Elevation above MHT	Reference
(m)		(m)	(m)	
1.92	1979	1.48	0.44	Hansen (1982)
1.90 – 1.95	1995	1.55	0.35 – 0.40	Heinze (1997)
1.96	2007	1.55	0.41	Stock unpubl.

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pecially sites with regulated tidal access (Polder Breebaart and Lütetsburger Sommerpolder) have a low success rate. In case, the aim of restoration is to develop a characteristic salt-marsh vegetation with different vegetation zones, ageing appears to be a constraint mainly in sites with a laissez faire policy, whereas the implementation of unrestricted tidal access and a moderate grazing regime are the best ingredients for success.

It is important that restoration sites are monitored annually from one year prior to at least 10 years after de-embankment, with sedimentation rate, vegetation development and elevation change as the most important variables. This will increase our understanding of the processes involved in salt-marsh establishment and allows adaptation of management regimes (grazing, drainage) or engineering (removal of sediment blockades, changing tidal inlet). It is also important to state clear and objective targets that can be easily measured in the field. Not only is the setting of targets indispensable for the assessment of restoration success, it is also of crucial importance in the process of gaining and retaining the necessary support from policy makers and society.

Location	Site	Year of de-embank-ment	Polder period (yr)	Total area (ha)	Tidal ex-change	Nature manage-ment	Restora-tion suc-cess	Ref.
Netherlands								
mainland Friesland	Paezemerlannen	1973	40	100	U	LF	moderate	1,2,6
mainland Friesland	Holwert West	<1990	NA	51	U	G	good	10
mainland Friesland	Holwerder zomerpolder	1989/1995	33	37	R	LF	good	2,3,5
mainland Friesland	Noarderleech	2001	91	123	U	G	good	5,7
mainland Friesland	Biltpollen	2009	NA	70	NA	G	NA	
mainland Groningen	Polder Breebaart	2001	22	63	Rg	G	low	8
Island of Vlieland	Kroon's Polders	1996	76	85	R	M	good	2,3,5
I. of Terschelling	Groene Strand	1996	NA	23	T	G	low	2,3,5
Island of Texel	De Slufter	2002	NA	15	T	?	?	4
Lower Saxony*)								
Leybucht	Hauener Hooge	1994	50	80	U	LF	moderate	11,12
Norderland	Lütetsburger Sommer-polder, embanked part	1986	?	c. 15	U	LF	moderate	11
Norderland	Lütetsburger Sommer-polder	2007	25	50	Rg	G	low	11
Island of Langeoog	Sommerpolder Langeoog	2003	70	150	U	LF/G	good	9,11
Wurster Küste	North of Cappel Neufeld	2008	> 100	47	U	LF/G	NA	11
Wurster Küste	North of Dorum Neufeld	2008	> 100	43	U	LF/G	NA	11
Hamburg								
Neuwerk	Ostvorland	2004	79	40	U	LF	good	12

*) The project in the summerpolder "Spieka-Neufelder Sommergroden" has been omitted. The decision-making process allowed only a regulated saltwater exchange via the construction of a small sluice. Because of the restricted saltwater influence, no salt marsh did develop in the summerpolder as result of the project (Kinder *et al.* 2003).

References: 1) van Duin *et al.* 1997, 2) www.zoetzout.nl; 3) Esselink *et al.* 2003; 4) de Leeuw & Meijer 2004; 5) Wolters *et al.* 2005; 6) van Duin *et al.* 2007a; 7) van Duin *et al.* 2007b; 8) Esselink & Berg 2007; 9) Barkowski *et al.* 2009; 10) Esselink pers. obs. 11) Bunje, pers. obs; 12) this report.

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Box 2: From summerpolder to salt marsh: salt-marsh restoration in Noarderleech, Netherlands

An extensive 970-ha complex of summerpolders is located on the mainland coast of the Province of Fryslân, Netherlands. These summerpolders were developed from artificial salt marshes, but have a high potential for salt-marsh restoration. In 1996 an ambitious restoration project, financially supported by the EU-life programme, was launched to create one of the largest continuous salt-marsh areas in Europe. In 2001, a pilot project was carried out by de-embankment of a 123-ha summerpolder.

Restoration included the construction of three 30 to 40-metre wide breaches in the summer bank, digging of three artificial creeks in the summerpolder, and continuation of livestock grazing. The pilot included a 5-year monitor programme and evaluation (van Duin *et al.* 2007b).

In the third year after de-embankment up to 100% of the target species were recorded in 100-m wide permanent transects (Fig. 17). It should be noted that 80 % of the target species were already present before de-embankment as a result of import of seeds by seawater, either via intrusion through culverts or by overtopping of the summer bank and inundation of the area during severe storms. Nevertheless, breaching the summer bank caused a rapid spread of salt-marsh species in the area within the first year. *Puccinellia maritima*, for example, occurred with at least 10 % coverage in almost the entire Transect 2 in the first year after de-embankment (Fig. 18).

Elevation of the restoration site in relation to the tidal frame, an unrestrained tidal exchange, drainage, the presence of a fronting salt marsh as source area for target species, and the grazing management were all considered to be important factors for the rapid development of a halophytic vegetation and the success of the restoration efforts.

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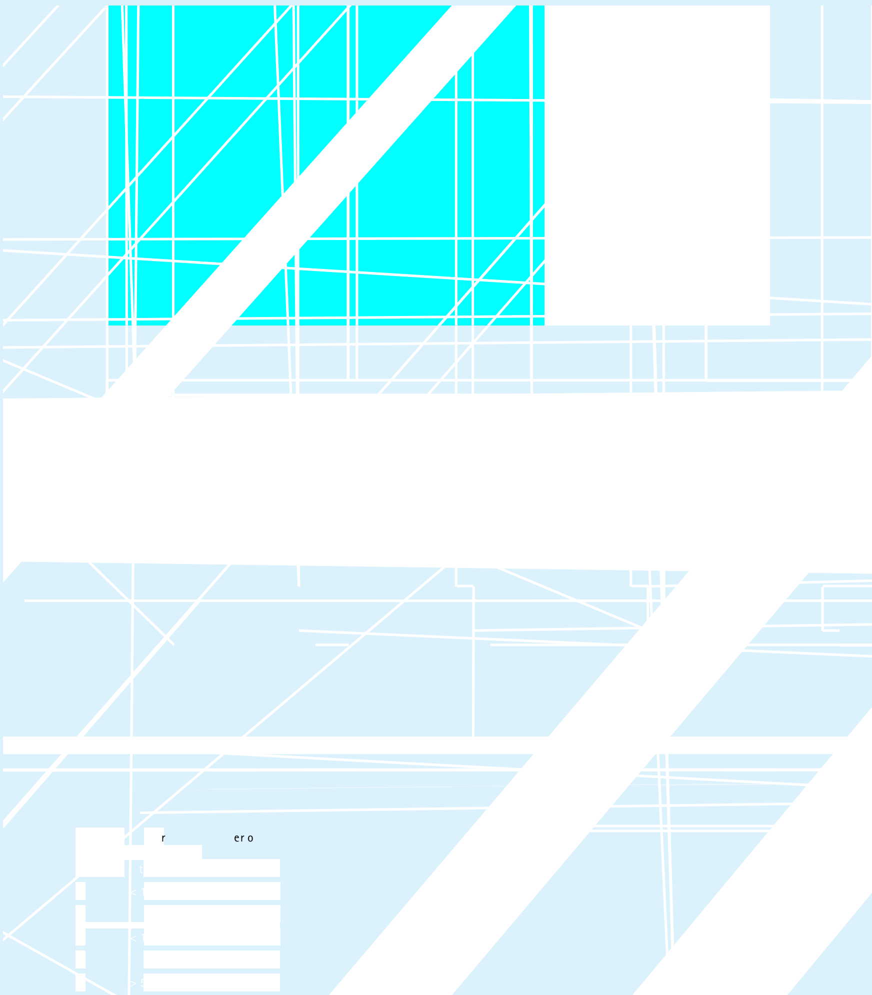


Box: 3 Vegetation change in a restored salt marsh in the Leybucht

In 1994 a summerbank was breached to allow free entrance of seawater to the summerpolder of the Hauener Hooge in the Leybucht. Over a period of 12 years the vegetation development has been monitored by successive mapping of the area and by permanent-plot recording (Arens 2005, 2007).

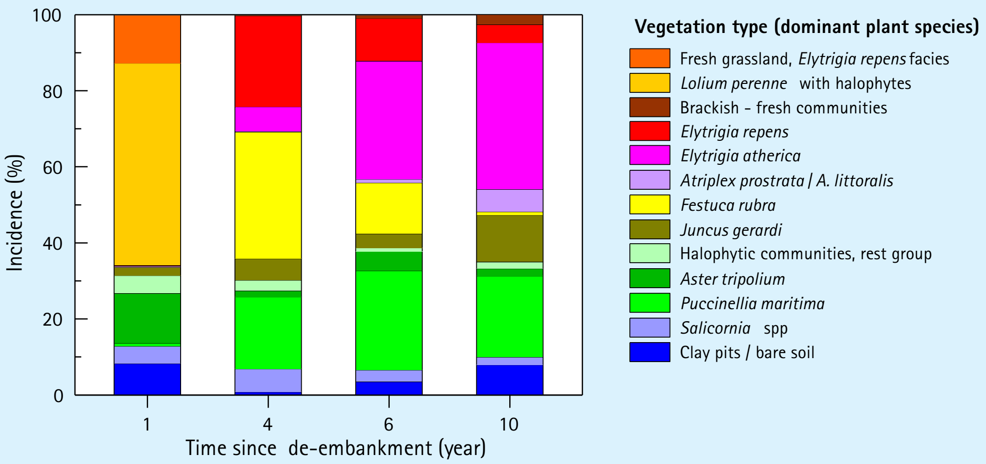
Before the breach was created, the area was predominantly covered by a Lolium perenne community. In the year after the opening, this community was invaded by halophytes, but still covered more than 50% of the area (Fig. 19). A fresh *Elytrigia repens*-dominated community covered 13% of the area, whereas other parts were covered by halophytic vegetation, especially by communities of *Aster tripolium* (13%), of Salicornia spp (5%) and of *Puccinellia distans - Spergularia salina* (5%). Areas without vegetation comprised shallow depressions and dug clay pits (8% in total).

Ten years after the breach, the incidence of the *Elytrigia atherica* community augmented nearly 40%. The *Festuca rubra* community had almost disappeared. The clay pits and the eastern part of the Hauener Hooge were dominated by the *Puccinellia maritima* type. In the northern part, bare depressions developed.

In 10 years time, all glycophytic and brackish plant species had disappeared from the permanent plots, and as a result, the total number of species diminished (Tables 5, 6). The current number of plant species is comparable to other salt marshes in the Leybucht that are not grazed (Arens 2007).

The investigations at the former Hauener Hooge summer polder have shown that in most of the areas salt-marsh vegetation could develop within a few years after breaching the summer bank. Because of the increasing salt-water influence, a rapid decrease of most fresh-grassland species was observed during the first years. At the same time different salt-marsh species increased or invaded the area.

The investigations at the former Hauener Hooge summerpolder have shown that the opening of summerbanks is a successful measure in order to restore salt-marsh habitat. Therefore the opening of summerbanks should be integrated in future management plans of the Wadden Sea Area.



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Salt indicator value*	Plant species	Presence (%)								
	Time after breach (yr)	1	2	3	4	5	6	8	10	13
	Pioneer zone									
8-9	*Salicornia spp*	8	8			17	8	8	50	58
8	*Spartina anglica*								8	25
8	*Suaeda maritima*	58	8	100	8	25	17	33	42	75
	Salt marsh									
8	*Aster tripolium*	100	100	100	75	100	67	92	50	100
8	*Spergularia media*	8		8	8	8	8	8		
8	*Cochlearia anglica*		8							
8	*Triglochin maritima*					8	8			17
8	*Puccinellia maritima*	8	17	8	8	17	17	25	25	42
8	*Atriplex portulacoides*								8	17
7	*Atriplex littoralis*								42	8
7	*Atriplex prostrata*	92	100	100	92	100	100	100	92	83
7	*Plantago maritima*	25	50	50	33	42	17	8	8	8
7	*Glaux maritima*	33	75	67	75	75	75	58	67	42
7	*Festuca rubra*	100	100	100	100	100	100	92	92	42
7	*Juncus gerardi*	17	17	17	8			17	17	17
6	*Agrostis stolonifera*	100	83	83	92	75	75	58	42	
6	*Elytrigia atherica*	42	42	100	92	92	100	92	92	92
5	*Artemisia maritima*	17	25	25	25	33	58	25	25	25
5	*Elytrigia repens*	50	58	50	58	67	58	83	58	17
5	*Parapholis strigosa*								8	
5	*Potentilla anserina*	83	67	50	58	42	42	25		
4	*Hordeum secalinum*	92	75	42	33	17	8	8		
4	*Trifolium fragiferum*	17								
	Grassland/brackish marsh									
3	*Cirsium arvense*	100	83	50	25	17	17	8		
3	*Leontodon autumnalis*	100	67	17						
3	*Taraxacum officinale*	50	50	17						
3	*Lolium perenne*	25		8				8		
3	*Sonchus arvensis*		17							
3	*Triglochin palustre*		8							
2	*Plantago major*	100	67	50						
1	*Trifolium repens*	50	8							
1	*Poa trivialis*							8		
1	*Ranunculus repens*		8							

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Time after breach (year)	Species richness (no. of plant species / plot)		
	Total	Salt-marsh species	Fresh / brackish species
1	12.8	8.5	4.3
2	11.4	8.3	3.1
3	10.4	9.0	1.4
4	7.9	7.7	0.3
5	8.3	8.2	0.2
6	7.8	7.6	0.2
8	7.6	7.3	0.3
10	7.3	7.3	0.0
13	6.7	6.7	0.0

Box 4: Salt-marsh restoration on the island of Neuwerk

This salt-marsh restoration project was a great success within a couple of years after tidal influence had been re-introduced after almost 80 years in a 40-ha summerpolder. After the sluice of the summerpolder was set out of function in September 2004, vegetation development led to the whole range of the vegetation types that were expected to develop. The opening width of the sluice was sufficient to allow almost natural tidal dynamics in the whole restoration site. Within the few years, fresh and brackish vegetation were replaced by more salt-tolerant salt-marsh communities, Vegetation change was most rapid at lower elevations, i.e. in the lower salt marsh and pioneer zone. Also morphological changes of the natural tidal creeks started again. Birdlife responded positively on the restoration: breeding birds (especially Redshank) increased, whereas the area was also more frequently used as feeding ground.

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4.1 Vegetation development

4.1.1 Vegetation development and ageing

The main result that follows from the comparison of vegetation changes in the present QSR is a decrease of the pioneer zone and an extension of late successional and climax stages in many poorly drained sites, succession may be impeded by a low nutrient availability. This may be illustrated by the occurrence of the *Limonium vulgare/Juncus gerardi* community in the inner parts of the Boschplaat salt marsh on the island of Terschelling (de Leeuw *et al.* 2008; App. III). Environmental variation provided by a pristine natural drainage of a barrier marsh may preclude a total dominance of late-succession plant communities.

4.1.2 Spatial fixation and ageing

A lack of natural spatial dynamics may form an second important factor for the observed overall trend of ageing. Salt marshes normally are spatial dynamic: they either protrude or erode. The contemporary Wadden Sea salt marshes have to a large extent been fixated by anthropogenic influences. On the mainland, the landward boundary is fixed by the seawall, whereas on many coastal stretches the seaward boundary is fixed by sedimentation works. In the sedimentation fields, the sheltered environment enhances the expansion of pioneer salt marsh, and the succession of the pioneer salt marsh to low salt marsh. Within the sedimentation fields space is limited, however. Inevitably, in many locations the extension of the pioneer salt marsh will eventually be squeezed between the protruding low salt marsh and the fixed seaward boundary of the sedimentation fields. There are areas, however, that form an exception. For instance, in the southern parts of the west-coast of Schleswig-Holstein, an increase of pioneer salt marsh may be found seaward far outside the sedimentation fields. In the Netherlands, currently there seems ample space for growth of pioneer salt marsh within the sedimentation fields. In the long run, primary pioneer salt marsh might be preserved if spatial dynamics become integrated in the management of the sedimentation fields (Esselink 2000). Whether this is a realistic option has been questioned, however, by van Duin *et al.* (2007c).

A secondary pioneer community may be preserved in poorly drained depressions. This community is generally dominated by *Salicornia europaea* and *Suaeda maritima* in contrast with the primary pioneer community in front of a salt marsh which is dominated by *Salicornia procumbens*. It follows that these two pioneer communities are not equivalent ecologically. Because of the ecological differences, the mergence of both communities into one TMAP-type may be reconsidered.

The construction of artificial dune ridges on some islands limited erosion processes but enhanced the sedimentation of clayey material from the Wadden Sea and thereby enhanced both the extension and ageing of the affected back-barrier marshes. A second effect was that in the lee of the dune ridge, vegetation succession was more or less synchronized, which has further decreased the spatial variation in these marshes.

4.2 Management

4.2.1 Artificial dune ridges and salt marshes

The presence of the artificial dune ridges restricts to a great extent the natural geomorphological processes of island salt marshes, especially in the washover complexes and island tails (Box 1; see above). Artificial dune ridges have been constructed especially on the islands in the Netherlands and on the Skallingen peninsula in Denmark. In order to bend ageing, and to restore spatial diverse salt marshes, the removal, at least partially, of these dune ridges seems a prerequisite. Although the artificial dune ridges have been constructed for in the framework of coastal defence, coastal safety is generally not at risk, because the removal has been proposed for uninhabited parts of the islands only.

On coastal stretches where the barrier system does not hold any direct human or economic interest in the Netherlands, the regular upkeep of the artificial dune ridges has been abandoned recently (Lammerts & Petersen 2009). This can be seen as a first step to achieve greater dynamics. De Leeuw *et al.* (2008) go one step further and review the potential ecological outcome of different scenarios for the partial active removal of the artificial dune ridge. The latter authors argue that restoration of a washover should preferably be located on the divide between the catchment areas of two salt-marsh creeks. A washover channel which is directly connected to an existing salt-marsh creek might result in enhancement of the ageing of the salt marsh by an improved drainage. In order to fill up gaps in the existing knowledge, any restoration effort should be accompanied with research.

4.2.2 Future of salt-marsh works

The majority of mainland marshes originated as a result of salt-marsh works. From a geological perspective thereby are man-made or artificially. From an ecological point of view, however, because the vegetation carpet was self-established, the salt marshes may be considered as semi-natural, and are of high conservation value. The construction of sedimentation fields would change highly valued habitats – the intertidal flats or Zostera beds – into another one. Therefore, the restoration of a continuous band of salt marshes along the entire Wadden Sea mainland coast is not demanded. The exception might be for future coastal defence, i.e. the development of artificial marshes in order to protect the seawall under the condition of an increased sea-level rise.

The extension of the artificial salt marshes by the establishment of new sedimentation fields has ensured the presence of an extensive pioneer zone. The pioneer zone itself protects the salt marsh higher up. The construction of brushwood groynes is enough to fulfil the requirements of protection. Additional engineering (*e.g.* drainage and groundwork) in the pioneer zone and the growing marsh is neither recommended nor required.

The edge of naturally-growing salt marshes should not be disturbed. Sedimentation fields should therefore not be planned in front of natural salt marshes or where natural salt-marsh growth is expected.

Cliff erosion is a natural process, in both natural and artificial salt marshes. Cliff erosion therefore should not be automatically interrupted by counter measures. In an extended salt marsh, natural processes should be given space, and one should refrain from the construction of sedimentation fields. In case, cliff erosion has to be stopped, the counter measure should be adapted to the local circumstances (Adnitt *et al.* 2007). The least negative solution is the construction of new sedimentation field in front of the cliff. Sedimentation fields do not function everywhere, however, they fail for instance where high stream velocities prevail. In such circumstances, a gradual transition between salt marsh and intertidal flats may successfully be preserved by the construction of offshore breakwaters (Storm 1999). Stone revetments should only be considered under very stressful conditions, as for instance around the Halligen.

Sediment recharge is a relative new technique for salt-marsh creation or as protection measure for in front of salt marshes. The authors consider this technique as too conflicting with the Guiding Principle and strongly advice not to apply this technique in the Wadden Sea.

4.2.3 Drainage

Barrier-connected salt marshes

The natural drainage system in these marshes may be restored successfully after disturbance by ditching. The aim of restoration is to increase both the natural dynamics and the abiotic diversity of the salt marsh, and to retard ageing by the rewetting process. A pilot project has been conducted on the island of Norderney recently (section 3.3.2).

Mainland salt marshes

In comparison with natural salt marshes, drainage systems of artificial salt marshes are generally oversized (Reents *et al.* 1999). In order to increase the naturalness of existing mainland salt marshes, it is necessary to rewet the salt marsh by a reduction of the artificial drainage. Aim is an increase of the abiotic variation and a retardation of the ageing process. The effect of rewetting can be reinforced by moderate grazing with cattle that is adapted to wet circumstances. Ditching of salt marshes should be restricted to the purpose of draining the seawall.

Neglect of the artificial drainage increases the naturalness of the salt marsh and its creek system, but does not result in the development of a fully natural creek system. Ditching during the (pre)pioneer phase of salt-marsh formation precludes the development of a natural drainage system (Section 3.3.2). It is sometimes believed that ditching enhances the vertical growth of a salt marsh (*e.g.* Nottage & Robertson 2005). This is probably a wrong-footed assumption. In several field studies, not any positive effect of ditching on vertical accretion was found (section 3.2.2; Dijkema *et al.* 1991, Arens & Götting 2008, Michaelis 2008). It follows that it is recommended to refrain from any groundwork both in natural extending salt marshes, and in sedimentation fields that are maintained to create new salt marshes for coastal defence. One exception might be stretches of the coastline where without ditching a salt marsh would not develop.

4.2.4 Salt-marsh restoration

In the 2004 QSR, an increase of the area of semi-natural and natural salt marshes was assessed as management target. In order to achieve this target, de-embankment of summerpolders was considered as an appropriate measure. This policy has been quite successful and over 800 ha of salt marsh has been restored so far. In addition to the total area, de-embankment of summerpolders may improve the quality of the salt marshes, because de-embankment creates the possibility to restore wide salt marshes with a more complete hydrodynamic gradient than most of the existing salt marshes.

Salt-marsh restoration by de-embankment should be preceded by the assessment of clear restoration targets (section 3.5), and be accompanied with an integrated package of restoration measures. In order to increase the naturalness and abiotic variety of the de-embanked area, former creeks and depressions may be restored, and ditches may be filled up. In order to prevent the dominance of one vegetation type, moderate grazing may be considered.

Through de-embankment, sedimentation gives the area the possibility to adapt to the expected sea level rise and climate change.

5. Target evaluation

In the 2004 QSR four different targets were assessed four salt marshes (Essink *et al.* 2005). These targets were related to:

1) Total area
2) Geomorphology
3) Vegetation structure
4) Provision of favourable habitat for migrating and breeding birds

Similar to the 2004 QSR, the fourth target will not be discussed in this report, but will be addressed in the thematic report on birds [ref].

5.1 Total area of salt marshes

Natural salt marshes by definition have not been affected by anthropogenic influences (Bakker *et al.* 2005). This means that the geomorphology has not been influenced by any engineering practices: neither by erosion-protection measures, nor accretion enhancement and not by ditching. Natural processes are here still in place. In the Wadden Sea, natural salt marshes occur mainly as barrier-connected marshes, whereas most of the mainland salt marshes are artificial because their geomorphology is strongly affected by anthropogenic influences.

In comparison with the data presented in the 2004 QSR, the total extent of salt marshes in the Netherlands and German sector of the Wadden Sea increased by nearly 1,600 ha (= 5%). This increase occurred predominantly on both the islands and the mainland coast of Schleswig-Holstein. The new marshes will comprise mainly young natural salt marsh including embryonic dunes and driftline vegetation (Section 3.2.1). The Danish salt-marsh data have been left aside, because the consecutive surveys were not comparable. Natural and semi-natural salt marshes in the Wadden Sea cannot be fully discriminated in the data-analysis, because geomorphology and vegetation have not yet been integrated in a common GIS database. A further point that is not cleared is whether salt marshes which developed in the lee of artificial dune ridges should be classified either as natural or semi-natural.

In the Netherlands sector, today the total size of island salt marshes is well above any historic reference value. This is mainly due to the presence of artificial dune ridges (Box 1; Section 3.2.3; Dijkema 1987; Dijkema *et al.* 2005). Efforts that aim to restore geomorphological processes on the islands at a greater scale including the restoration of washover complexes may yield in a more diverse salt marsh with greater spatial dynamics, and counterbalance ageing, but will probably be accompanied with a diminished size of island salt marshes. For the Netherlands islands, this would imply that the target has been reached.

In the mean time on the mainland of the Netherlands, the size of clayey foreland marshes has diminished to an historic minimum due to the long history of land claims, whereas the development of new salt marsh and the preservation of existing salt marsh largely depend on engineering measures (Dijkema 1987). This situation differs greatly from that in Schleswig-Holstein, where naturally developing foreland salt marsh may be found at several sites.

An increase in the area of salt marshes may be achieved by de-embankment of summerpolders. Currently, a total of nearly 1,000 ha have been de-embanked compared to 780 ha by 2004 (Table 4; Section 3.5). These values include also restoration sites with regulated tidal regime.

Natural salt marshes that have been disturbed by ditching may be restored by the filling of ditching and restoration of the former creeks (Section 4.2.4).

Target

- An increased area of natural salt marshes

Target evaluation

In comparison with the 2004 QSR, the total extent of natural plus semi-natural salt marshes in the Netherlands and German sector increased by 1,600 ha (5%). For the Danish sector, a sound comparison is not available, because of shortcomings in the figures from the 2004 QSR. An evaluation of the target in quantitative terms is, however, currently not feasible, because geomorphology and vegetation have not yet been distinguished.

Conclusions

- Natural salt marshes in the Wadden Sea are mainly found as sandy barrier-connected island marshes. At least in some sectors, the size of these marshes is much greater today than ever before due to the presence of artificial dune ridges. There is currently greater concern about the quality than the areal extent of these salt marshes.
- The construction of artificial dune ridges on some islands and on the Skallingen Peninsula in the north did not only facilitate the extension of barrier-connected salt marshes, but also resulted in spatial fixation and ageing of these marshes.
- Re-introduction or restoration of geomorphological processes, including the restoration of washover complexes may yield in a more diverse salt marsh with greater spatial dynamics, and counterbalance ageing, but will

probably be accompanied with a diminished size of island salt marshes.

- On the mainland coast, the size of clayey foreland salt marshes is below historic reference values. The fast majority of these marshes are named artificial salt marsh, since they developed from salt-marsh works (see above); natural foreland salt marshes are relatively rare. Artificial salt marshes can be regarded as semi-natural, which cannot be restored to natural salt marsh. There is concern on both the extent and the quality of the mainland salt marshes.
- Barrier-connected salt marshes that have been disturbed by ditching can successfully be restored to natural salt marsh by filling up the ditches and excavating former creeks and depressions.
- The size of mainland salt marshes can be increased by de-embankment of summerpolders in the Netherlands and Lower Saxony. If restoration is aimed at the development of a characteristic salt-marsh with different vegetation types, the implementation of unrestricted tidal access and moderate grazing may be the best ingredients for success.

5.2 Increased natural morphology and dynamics of artificial salt marshes

For historic reasons, artificial salt marshes represent approximately 50% of the total salt-marsh area in the Wadden Sea (Fig. 1; Section 3.1). Typical aspects of the artificial marshes were an evenly distributed dense drainage network and a very flat topography. With some exceptions, the mainland marshes form a narrow band between fixed borders: the seawall and the groyne system of the sedimentation fields which have to protect the salt marsh from erosion. Traditionally, the artificial drainage system was refurbished very regular in order to (1) enhance vegetation establishment high on the intertidal flats, (2) increase the carrying capacity for livestock grazing and (3) prevent the formation of depressions.

In order to enhance a more natural morphology of the mainland salt marshes, maintenance of artificial drainage systems has ceased over extensive areas (Fig. 13CD; Section 3.3.2): in the Netherlands-German sectors the area where the drainage system had not been refurbished in the foregoing 10 years increased from nearly 7,400 ha (39%) during the surveys for the 2004 QSR to almost 13,000 ha (71%) for this QSR. In the two sectors, the drainage system in an area of 3,300 ha (18%) had been refurbished within a ten-year period prior to the most recent survey. There is probably also an increase neglect of the artificial drainage in the Danish sector, but the drainage data from this sector do not allow a comparison in time (Section 3.3.2).

Neglect of the artificial drainage system results in silting up of part of the ditches and an increased variation of the topography due to the formation of depressions and the building up of levees along ditches that remain open. It further leads to rewetting of the salt marsh, which may result in retardation of the succession and an increase of the vegetation diversity (Section 4.2.3).

Abandonment of the artificial drainage thus increases the naturalness of the salt marsh and its creek system, but the development a fully natural creek system may not be expected in the foreseeable future (Sections 3.3.2; 4.2.3). Once a salt marsh has been formed, the phase for creek formation has passed, and creeks stay relatively stable.

The morphology of mainland salt marshes may further be improved when wide marshes can be restored by de-embankment of summerpolders. Wide salt marshes have a more complete hydrodynamic gradient than most of the existing salt marshes (Sections 3.4; 4.2.4).

Whereas natural salt marshes are generally spatial dynamic, artificial salt marshes are relatively fixed. Cliff erosion is a natural process, in both natural and artificial salt marshes. It follows that cliff erosion should not automatically be interrupted by counter measures, but natural processes should be given space, especially in extended marshes (Section 4.2.2). If cliff erosion has to stopped, any counter measure should be adapted to the local circumstances.

Target

- An increased natural morphology and dynamics, including natural drainage patterns, of artificial salt marshes, under the condition that their present size is not reduced.

Target evaluation

- In order to create a more natural morphology and to increase natural dynamics in the artificial salt marshes, the area where the maintenance of the artificial drainage has ceased in the Netherlands-German sector, has risen further from 7,400 ha during the surveys for the 2004 QSR to almost 13,000 ha (71%) for this QSR. Cessation of artificial drainage results in increased naturalness of the marshes, which includes both their morphology and vegetation dynamics. The remaining ditches that do not silt up, will not easily develop into natural-like creeks.

Conclusions

- In the Netherlands and German sector, the area where the artificial drainage is now neglected, has increased significantly recently, and includes now over 70% of the mainland salt marshes.
- Neglect of the artificial drainage leads a more diverse topography in the artificial salt marshes, which include the formation of levees along the remaining ditches and the development of depressions.
- Neglect of the artificial drainage also leads rewetting of the salt marsh, which will retard ageing, and enhance vegetation diversity.
- Natural creeks normally develop in a very early stage of salt-marsh formation. Cessation of ditching in an existing salt marsh therefore does not automatically lead to the development of a natural creek system.
- The morphology of a salt marsh also includes size. In comparison with narrow salt marshes, wide marshes have a greater, more complete internal hydrodynamic gradient which enhances internal variation in both vertical accretion rates and vegetation development.
- The anthropogenic impact on the coastal landscape explains why wide salt marshes have become an exception.
- In comparison with natural salt marshes, artificial salt marshes lack spatial dynamics.

5.3 Improved natural vegetation structure, including the pioneer zone, of artificial salt marshes

In the 2004 QSR it was concluded that Target 3 requires specification. Bakker *et al.* (2005) therefore reformulated the target as follows:

- The aim is a salt-marsh vegetation diversity reflecting the geomorphological conditions of the habitat

An important question that has not been addressed on the trilateral level, however, is how the target should be evaluated. For the German sector, an evaluation has been formulated in the framework of the HD. From a geomorphological perspective, most artificial salt marshes are relatively uniform, also after rewetting. If these marshes are not grazed, they may be very susceptible to ageing, which will result in a dominance of *Elytrigia atherica* vegetation over extensive areas. This is for instance, currently the case in some large salt marshes in Lower Saxony (Section 3.2.1). The development towards a dominance of *E. atherica* may be retarded or even prevented in salt marshes where the target of an increased natural morphology of artificial salt marshes has been fulfilled.

Management objectives are diverging among the three countries and areas. In the German national parks, minimization of anthropogenic influences has been formulated as guiding principle of salt-marsh management. The objective is a vegetation development in relation to the geomorphological conditions. A definite aim for a certain composition of flora or fauna has not been formulated. Outside the national parks, management objectives may be more distinct, for instance favourable conditions for migrating and breeding birds. In order to realize such goals, livestock grazing may be used here as management instrument.

In the Netherlands, the main aim of nature conservation of the mainland salt marshes is the preservation and enhancement of the current biodiversity. Livestock grazing is considered an indispensable tool for nature management to prevent dominance of a few late-successional stages. This implies that a vegetation diversity is aimed at which is the outcome of the interaction between geomorphological conditions and livestock grazing. Also in Denmark, livestock grazing is seen as indispensable management tool to prevent dominance of late successional vegetation stages.

In conclusion, in order to do justice to both approaches in the management of the artificial salt marshes, Target 3 may require revision. Secondly, evaluation tools based on vegetation parameters should be developed on a trilateral level.

From the evaluation of Target 2 (Section 5.2), it follows that an increased natural morphology is a pre-requisite in order to achieve improved vegetation diversity. For instance at low elevations, i.e. in sedimentation fields around MHT, improved vegetation diversity may be reached by cessation of artificial drainage. On existing salt marshes in the absence of grazing, high sedimentation rates will result in monotonous climax vegetation due to ageing. Differences in geomorphology will be masked by such homogeneous vegetation. In such marshes moderate grazing may result in high vegetation diversity. In wide salt marshes with low sedimentation rates (1–3 mm/year) in the inner parts, high vegetation diversity may develop autonomously (Section 3.4).

Artificial salt marshes often have two fixed boundaries: the seawall at the landward side and a groyne system at the seaward side. Where this situation prevails, the position of primary pioneer vegetation will ultimately become delicate after the available space has been consumed by salt-marsh development (Section 4.1.2). Since livestock grazing does not affect the fate of the pioneer zone, primary pioneer salt marsh may only be preserved if spatial dynamics become integrated in the management of sedimentation fields.

Long-term studies had already indicated that Wadden Sea salt-marsh vegetation may succeed relatively quickly towards species-poor late-successional communities. This so-called ageing was a new topic in the 2004 QSR. Except for wide salt marshes, where inner parts of the marsh may be characterized as low-sedimentation areas, the majority of the artificial salt marshes may be susceptible to ageing, due to their low geomorphological variation and high sedimentation rates. This is sustained by the results presented in this QSR. In the Netherlands-German sector, out of the 34 TMAP types, the climax community of *Elytrigia atherica* was the most common community with an almost 20% incidence (App. II). The community was clearly more common in the clayey mainland salt marshes than in the barrier-connected salt marshes (Section 3.2.2). The increase of *E. atherica* community was clearly related with cessation of livestock grazing (Figs 5, 7). In ungrazed mainland salt marshes of Lower Saxony, the incidence of the *E. atherica* community reached values of over 40% without an indication that the community has reached its maximum extent.

Target

- An improved natural vegetation structure, including the pioneer zone, of artificial salt marshes.

or (2004 QSR)

- The aim is a salt marsh vegetation diversity reflecting the geomorphological conditions of the habitat

Target evaluation

- In some artificial marshes, increased vegetation diversity has been observed as a result of management changes and an increased natural morphology.
- Ageing is a common process in most artificial salt marshes, especially in the absence of grazing. In salt marshes with improved morphology (Target 2), the ageing process may be retarded or stopped.
- For the evaluation and assessment of vegetation diversity data from longer time periods are required. Therefore an evaluation of the target can not be given yet. On the trilateral level, an evaluation method has still to be developed.

Conclusions

- On the trilateral level, management objectives of the artificial salt marshes are diverging. One approach is to aim at a vegetation development in relation to the geomorphological conditions with a minimum of anthropogenic influences. In the second approach, the aim is to prevent dominance by species-poor climax vegetation, and to preserve and enhance vegetation diversity in a semi-natural landscape with livestock grazing as indispensable tool for nature management. In this approach vegetation diversity is thus the outcome of the interaction between geomorphological conditions and grazing.
- In order to integrate the two management approaches, the target may require revision.

6. Recommendations

6.1 Recommendations for monitoring and research

a) The monitoring according to the TMAP guidelines should be fully implemented.

In order to assess the "favourable conservation status" of the HD and the "good ecological status" of the WFD on the trilateral level, the TMAP Salt-Marsh Working Group (SMWG) concluded that the TMAP monitoring according to TMAP guidelines is a pre-requisite (Bakker *et al.* 2005). Therefore, in order to allow of a trilateral assessment, implementation of the TMAP salt-marsh monitoring programme by Denmark is awaited.

b) Distinction of secondary pioneer vegetation in the TMAP typology.

The primary pioneer zone and the secondary pioneer plant community in the inner salt marsh are not equivalent ecologically. In order to assess both communities separately, it is advised to consider a subdivision of the TMAP type vegetation of *Salicornia* spp / *Suaeda maritima* (type S.1.2; App. I).

c) The monitoring according to the TMAP guidelines should be extended with monitoring of marsh elevation.

Elevation is a basic measure for all salt marshes. Changes of elevation are an essential parameter for the evaluation of salt-marsh development. Monitoring of elevation on selected permanent transects or monitor stations is therefore recommended.

d) The monitoring according to the TMAP guidelines should be extended by monitoring plant species of the TMAP vegetation types.

At present, the TMAP monitor programme does not provide monitor data at the level of plant species, but on the level of plant communities only. Data on the level of individual plant species, however, are required by the WFD. In order to assess processes of salt-marsh change, Bakker *et al.* (2005) recommended the annual monitoring of vegetation types at selected permanent sites on in relation with elevation changes and management data. It follows that this recommendation can be specified as the monitoring of plant species in permanent plots, ideally in relation with marsh elevation and management.

e) Addition of geomorphological layers.

In order to analyse vegetation maps or vegetation changes, data on substrate or salt-marsh type may be very relevant. So far such information is not available at the trilateral level. Additionally, the WFD requires data on geomorphological elements. There are also some gaps in the habitat typology data (*e.g.* lagoons). The SMWG therefore recommends the addition of standardized geomorphological map layers to the TMAP vegetation maps.

f) Harmonisation with data of other TMAP monitoring programmes.

In the framework of the Trilateral Monitoring and Assessment Programme, spatial data are al so being assessed by other working groups (*e.g.* dunes, birds). Harmonisation of the different datasets would allow of studying interrelationships among different ecosystem compartments.

g) Every 6 yrs TMAP shall be used.

The HB and WFD both prescribe an evaluation cycle with a time interval of 6 years. The SMWG advises to harmonize the mapping frequency with this evaluation cycle, and to adapt to a 6-year time interval for the next vegetation mappings. This is currently being incorporated in the TMAP guidelines.

h) Integration of additional relevant available data in relation to salt marshes, especially legal protection status, ownership and land use.

Land use of Wadden Sea salt marshes can be subdivided into agricultural exploitation and nature conservation. These two land-use types cannot be separated and quantified with the available data. In order to separate, for instance, agricultural exploitation by livestock grazing, grazing as management tool in nature management, the land-use types should be available in a harmonized GIS-dataset. The SMWG recommends therefore the addition of a harmonized dataset on legal protection status, ownership and land use.

- Study of the possible interrelationship between ageing towards climax vegetation, rate of sedimentation and cessation of grazing;
- Continuation of long-term study sites and incorporation of these sites into the International Long-Term Ecological Research sites (ILTER).
- Study the significance of the new geomorphological concept of the W-E orientated barrier islands for the S-N orientated barrier islands in the northern part of the Wadden Sea.

6.2 Recommendations for management

- The development of naturally protruding salt marshes is best guaranteed by leaving the geomorphology of both the growing marsh and the adjacent intertidal mudflats undisturbed.
- In order to allow natural creek systems to develop in sedimentation fields which are

maintained to create new salt marsh for coastal defence, it is advised to refrain from any groundwork in these sites.

- The size of mainland salt marshes can be restored by de-embankment of summer-polders.
- Wide salt marshes have a higher conservation value than narrow marshes (Section 4.1.1). A priority should be given to the preservation and restoration of wide salt marshes wherever this is attainable.
- A further diminishment of ditching in the artificial marshes is recommended.
- In order to prevent waterlogging at the foot of the seawall, ditching of salt marshes should be confined to this purpose only.
- Cliff erosion should be considered as a natural process in both natural and artificial salt marshes. It follows that cliff erosion should not automatically be interrupted by counter measures, but natural processes should be given space, especially in extended marshes.

Future management should aim at:

- Rejuvenation of salt marshes and restoration of washover complexes on barrier islands through removal of artificial dune ridges.

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