



Integrated management of artificially created salt marshes in the Wadden Sea of Schleswig-Holstein, Germany

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Abstract

In the about 10,000 km² large Wadden Sea 353 km² of salt marshes exist. The great majority of these are artificial, i.e. developed through accretion enhancement techniques. Salt marshes in the Wadden Sea have a high coastal defence value as well as ecological significance. High salt marshes in front of sea walls reduce the wave-impact on the dikes and, therewith, the danger of breaching. At the same time, the salt marshes have a high ecological value, e.g., as resting places for migratory birds. In consequence, for coastal defence, salt marshes should be created and/or maintained. For nature protection, natural dynamic processes (incl. erosion) should prevail. To anticipate this possible conflict among coastal defence and environmental administration, in Schleswig-Holstein an interdepartmental working group established a salt marsh management concept. For information of the interested parties and for monitoring of the concept, an integrated salt marsh board was established, consisting of representatives from public administration and local interest groups (NGO's, dike and water boards, municipalities). Five years after implementation of the concept, this board established a first progress report. Although the concept was, in the beginning, met with great scepticism, five years of practical experience demonstrate that it functions well. The salt marshes are stable or growing, i.e. the management measures are successful. As a planning instrument, the concept is unambiguous, i.e. provides clear guidelines on how to manage the salt marshes. Finally, as an instrument of participation, the salt marsh board is valued positively by all members.

Introduction

Salt marshes are intertidal areas of fine sediments stabilised by vegetation, occurring extensively along the seaward edges of low-lying coastal areas (Boorman and Hazelden 1995). Boundary conditions for natural salt marsh development and persistence on tidal flats are an adequate supply of fine sediments, a low-energy environment, regular saltwater conditions, and a moderate sea level rise. As a consequence of thousand years of building sea walls, most of the low-energy environments in the Wadden Sea are, nowadays, cut off from the Wadden Sea. Only a few

regions remain where a natural development of salt marshes may occur.

In the 3,000 km² large Wadden Sea of Schleswig-Holstein about 100 km² of salt marshes exist (Stock et al. 1997). The great majority of these developed through accretion enhancement techniques since about 1850 (Hofstede 1996b). Until the middle of the last century the main purpose of the salt marsh works was to create new land which could be reclaimed and cultivated (Probst 1996). Later, the principle argument became coastal flood defence. A high salt marsh in front of the sea walls causes energy dissipation of storm waves to be transferred from the dike-foot

towards the seaward margin of the salt marshes. This reduces the danger of dike-breaching during storm surges. Accordingly, in the 'Schleswig-Holstein State Water Act', it is regulated that salt marsh works for coastal defence are a public obligation.

During the last decades, a growing environmental concern has led to a new appreciation of the Wadden Sea as one of the last more or less natural ecosystems in North-western Europe. As a framework for environmental management of the Wadden Sea, the Dutch, Danish and German Ministers responsible for nature conservation adopted a Trilateral Wadden Sea Plan. The guiding principle is to achieve, as far as possible, a natural and sustainable ecosystem in which natural processes proceed in an undisturbed way (De Jong et al. 1999). Unreasonable impairments of the interests of the local population (incl. safety against storm floods) and its traditional uses in the Wadden Sea have to be avoided. Apart from this trilateral environmental management plan, major parts of the Wadden Sea have, in the framework of the European habitat directive, been included in the ecological network NATURA 2000. Further, the German and Dutch parts of the Wadden Sea have been designated as Biosphere Reserves under the Man and Biosphere program of UNESCO. Finally, major parts of the Wadden Sea are Ramsar sites.

In Schleswig-Holstein, in the year 1985 the national park 'Wadden Sea of Schleswig-Holstein' was established. As a basis for a masterplan for the national park, a comprehensive ecosystem research program was conducted that concentrated both on fundamental and on applied aspects of the Wadden Sea ecosystem and their interactions with local human activities (Boley 1989; Stock 1996). In 1994 the 'Schleswig-Holstein State Nature Conservation Act' was adopted. According to this law salt marshes have a prominent ecological value. Hence, they are protected and natural processes should prevail. For the salt marshes this implies the abandonment of management techniques.

Being aware of the confusing legislation (pro and contra salt marsh management techniques), the coastal defence and environmental administration initialised in 1994 a working group in order to prepare an integrated salt marsh management concept. August 1995 the working group presented its plan (MELFF 1995; Hofstede 1996a). In order to monitor and, if necessary, adjust the management concept an integrated salt marsh board (ISMB) was established. Its members are representatives of the coastal defence and environmental administration, of regional dike and water boards, of environmental NGO's, and of

local municipalities. After five years with regular meetings the board presented its first progress report for the period 1995 to 2000 (MLR 2001).

After a regional overview the Schleswig-Holstein salt marsh management concept is presented. Further, the experiences after five years of working with the concept as well as some prospects for future integrated management of artificial salt marshes in the Wadden Sea are discussed.

Regional overview

The Wadden Sea is a coastal tidal environment situated between the North Sea and the mainland of Denmark, Germany and The Netherlands. It stretches over a distance of about 450 km from Den Helder in the Netherlands to the peninsula of Skallingen in Denmark. The about 10,000 km² large Wadden Sea is a coastal sediment sink that developed in the course of the Holocene sea level rise. It resulted from a specific combination of sediment availability (mainly from the North Sea) and a hydrological regime of tides and waves Hofstede (in prep). In its present state, the Wadden Sea consists of extensive tidal flats (the Wadden), tidal gullies and inlets, salt marshes, about 24 sandy barriers, and four estuary mouths. As a result of land reclamation during the last Millennium, about one third of the former Wadden Sea (the coastal marshes) is cut off from the sea.

The Schleswig-Holstein sector of the Wadden Sea is about 3,000 km² large (Figure 1). Its coastline (mainland and islands) measures 564 km. In the northern part, barriers shelter the back-barrier bays from the North Sea. Here, the mean tidal range vary among 1.8 and 2.5 m. To the South of Eiderstedt barriers fail, probably as a consequence of the larger tidal ranges of about 3.2 m (Ehlers 1988). An almost 400 km long system of sea walls protect the 3,400 km² large coastal lowlands (former marsh lands) with a population of 252,618 against flooding during storm surges (Hofstede and Hamann 2000).

At present, about 10,000 ha of salt marshes exist in the Wadden Sea of Schleswig-Holstein, of which 5,800 ha are situated within the national park (Stock et al. 1997). Following the classification of Dijkema (1987), three types of salt marshes occur. **Barrier-connected salt marshes** (1,170 ha) appear at the lee side of barriers and in one case (Eiderstedt) on a high and sheltered beach plain. They are characterised by a thin cover of clay-containing layers on a sandy substrate. Most of these salt marshes still show a more or less natural morphology. **Foreland salt marshes**

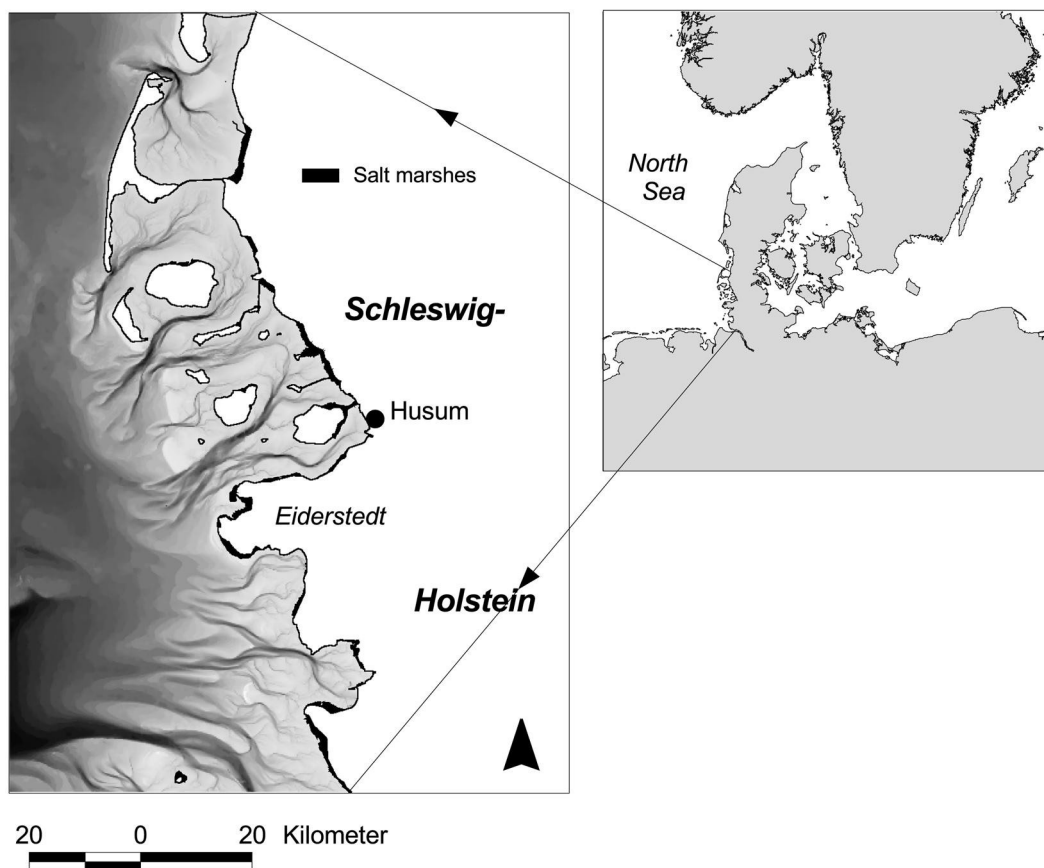


Figure 1. Overview of the Schleswig-Holstein sector of the Wadden Sea.

(6,530 ha) develop in front of an alluvial coastal plain. They are sheltered from the open sea by a chain of barriers or tidal flats. Normally, the sediment layer is more clayish and of greater thickness. Almost all of these salt marshes in Schleswig-Holstein are situated in front of sea walls and are artificial, i.e., developed through salt marsh accretion enhancement techniques (Figure 2). A special type of salt marshes are the 2,300 ha large **Halligen** to the North of Eiderstedt (Figure 3). They are remnants of former coastal swamps that survived destruction as catastrophic storm floods turned the area into tidal flats. Finally, in the Elbe and Eider estuaries some very small fragments of **Estuarine salt marshes** occur. Situated within the upper reaches of the estuary they are highly influenced by fresh water.

Salt marsh management concept

As stated in the introduction, the confusing environmental and water management legislation led to the

initialisation of an interdepartmental working group in Schleswig-Holstein. Their assignment was to establish an integrated concept for the future management of the salt marshes in Schleswig-Holstein (Hofstede 1996a). On the basis of this assignment, the working group performed the following tasks: (1) the establishment of a common principle for salt marsh management, (2) an evaluation of existing techniques, (3) the drawing up of regional salt marsh management plans, and (4) the formulation of a salt marsh monitoring program.

The common principle for salt marsh management

It is clear, that coastal defence and environmental authorities value salt marshes differently. For coastal defence salt marshes in front of sea walls are in the first place a method to transfer the energy-impact of storm waves from the dike towards the edge of the salt marsh (Figure 4). Furthermore, salt marshes may reduce the waves set up at the sea walls and therewith the danger of wave overtopping during storms. After



Figure 2. Salt marshes and salt marsh works in the Husum Bight, Schleswig-Holstein (note the regular and intensive drainage pattern in the salt marshes. View from the North).

dike-breaching, salt marshes prevent the establishment of a scour hole and provides material for reparation of the sea walls. Finally, they prevent damage at the outer dike foot by approaching tidal gullies and

render the building of expensive slope revetments superfluous. The environmental vision on the other hand is a natural salt marsh free of human interference. It possesses a free meandering creek system and



Figure 3. 'Hallig' Süderoog in the Schleswig-Holstein sector of the Wadden Sea (view from the Southwest).

a morphological structure typical for its position. The distribution of plant communities as well as the corresponding fauna is determined by natural dynamics only (Stock et al. 1997).

As a result of the intensive salt marsh works and land reclamation most of the mainland coastline lies in an exposed (high-energy) position. Natural salt marshes, however, can only develop and persist in very low-energy environments (Allen and Pye 1992; Hofstede 1996b; National Rivers Authority 1995). Hence, it is unlikely that the existing salt marshes would have developed here without accretion enhancement techniques. On the contrary, investigations on artificial salt marshes in the Dutch sector of the Wadden Sea suggest that the abandonment of management techniques may result in a strong erosion or even disintegration of existing salt marshes (Dijkema 1997; Esselink 2000; Jansen-Stelder 2000).

These considerations resulted in the establishment of the following common principle for salt marsh management in Schleswig-Holstein: "Common goal of coastal defence and environmental administration is to preserve existing salt marshes. Where no salt marshes exist in front of sea walls they should be created. The techniques used to reach this goal depend upon local circumstances. They must be carried out as ecologically sound as possible. Where local circum-

stances allow these, technical measures are abandoned".

Evaluation of existing techniques

After establishing the common principle, the working group evaluated the main management techniques: (1) drainage furrows, (2) groynes, (3) transport dams, (4) salt marsh turves, and (5) grazing, applied in the salt marshes. They are described and evaluated below.

Drainage furrows

An old technique to enhance salt marsh growth in the Wadden Sea is drainage of the high mud flats in front of salt marshes by digging drainage furrows. The artificial drainage improves the consolidation and aeration of the upper layer of the mud flats and, therewith, the ability for pioneer vegetation (*Salicornia-Spartina* communities) to germinate and grow (Houwink 1999). With this technique, the aerated zone is shifted to a lower level in relation to the mean high water level, resulting in a seaward shift of the salt marsh edge of up to 200 m (Dijkema et al. 1990; Dijkema 1992). In order to function, the furrows need to be cleaned on a regular basis. This is done with spades, milling cutters (Figure 5a) or dredging machines (Figure 5b). The cross sections of the drains

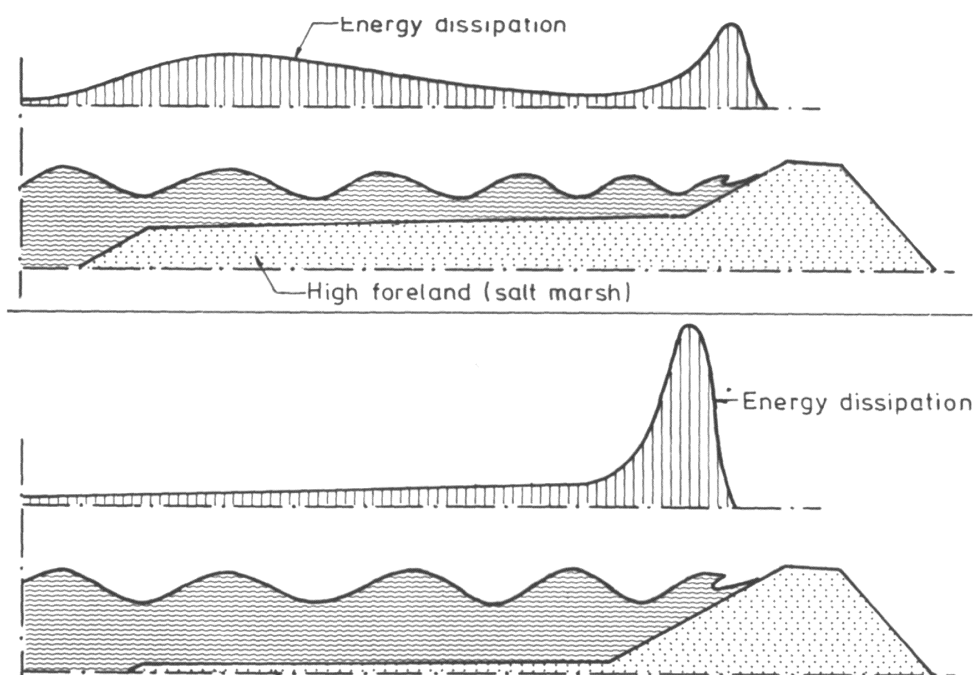


Figure 4. Schematic presentation of energy reduction by high salt marshes in front of a sea wall (source: Führböter 1979).

vary significantly depending upon local circumstances. The main drainage furrows may be as wide as 3.2 m and 0.4 m deep, the smallest ditches are about 0.3 m wide and 0.15 m deep. In the past, most of the larger ditches and furrows were dredged with large machines thereby destroying the whole mud surface (Figure 6). As this technique represents a major interference with nature, digging by hand or with the milling cutter shall prevail in future.

Groynes

Another traditional technique to enhance salt marsh accretion as well as to stabilise existing salt marshes is building groynes at the higher mud flats in front of the salt marshes or sea walls (Figure 7). These groynes function in that they reduce wave energy by up to 55%, and significantly diminish tidal and storm surge current velocities (Hofstede 1998; von Liebermann et al. 1998). In result, an artificial low-energy environment is created landward of the groynes. The sedimentation of fine suspended material is enhanced, and erosion of accumulated sediment is hindered. The positive effect of the brushwood groynes upon salt marsh growth is demonstrated in Figure 8. Only one year after construction of the brushwood groynes, an extra sedimentation of up to 40 cm occurred in the groyne fields (Erchinger et al. 1996). Groynes have been built out of brushwood, stones or plastics. It turned out that plastics are not durable. Furthermore, after destruction plastics were found miles away from the groynes in the sensitive Wadden Sea ecosystem. Hence, the use of plastics for groynes was abandoned. Stone groynes are used in places with high energy-impact where brushwood groynes cannot survive. Normally, the groynes consist of brushwood wedged between wooden poles (Figure 7). The evaluation resulted in the recommendation to maintain present techniques.

Transport dams

About 0.5 m high clay dams cross the salt marshes from the sea walls towards their seaward edges. They function as transport routes for coastal defence and disaster service vehicles. Furthermore, during storm surges they may reduce longshore currents as well as internal wave action on the salt marshes. The distance between the dams is normally about 400 m. As they are not indispensable for coastal defence, and constitute an interference with nature, no new dams will be built in future. Existing dams will be maintained.

Salt marsh turves

The vegetation cover of the lower outer slopes of the sea walls should be halophytic in order to resist saltwater inundation during storms. Turves from the salt marshes possess the best quality for this purpose. Hence, restricted areas (depicted in the regional plans) in the salt marshes are further cultivated as turf-winning areas using existing techniques (incl. grazing, see below).

Grazing

Until recently, grazing at the salt marshes was thought to be an essential management technique in terms of coastal defence. It increases the shear strength of the subsoil and may diminish the amount of organic floating matter along the outer dike slopes after winter storms. However, investigations showed that even without grazing the shear strength of the salt marshes suffices to prevent erosion from the top (Erchinger et al. 1996). On the other hand, sheep grazing constitutes a major interference with nature. As a consequence, sheep grazing is reduced on the salt marshes in the national park 'Wadden Sea of Schleswig-Holstein'. At present, about 62% (3,600 ha) of the salt marsh area in the national park (i.e. 36% of total salt marsh area) is not grazed anymore.

Regional salt marsh management plans

Considering the common principle and the evaluation of the present salt marsh management techniques regionally differentiated plans at a scale of 1:10,000, including 10 reference areas where technical measures are abandoned, were drawn. In principal, the plans have a validity of 10 years. However, a continuous evaluation of their efficiency and environmental tolerance on the basis of the monitoring program is conducted by the Integrated Salt Marsh Board. If necessary, the plans shall be adjusted.

In the regional plans, the salt marshes are divided into developing and existing salt marshes. In the developing salt marshes an echelon system, divided into a salt marsh, an accretion and a turbulence zone is aimed at (Figure 9). Normally, the (artificial) development of a salt marsh occurs in three phases. During the first phase one groyne field of about 200 × 200 m is built in front of the sea wall to reduce turbulence and improve accumulation. When the elevation of this field is high enough (i.e., about 0.5 m below the mean high water level), a system of drainage furrows is established. With this drainage system,



Figure 5. (a; top) Milling cutter in the Dutch sector of the Wadden Sea (note that the material from the ditch is evenly distributed on the flats). (b; bottom) Dredging machine in the Schleswig-Holstein sector of the Wadden Sea (note the huge piles of material left between the ditches).



Figure 6. Drainage ditches in a groyn field in the Schleswig-Holstein sector of the Wadden Sea.

the aeration and consolidation of the soil is improved, and the growth of a pioneer vegetation is initialised (Houwink 1999). Simultaneously, a second groyn field is built seaward of the first that takes over its function (phase 2). If the development remains positive, in the end a salt marsh will emerge. If necessary, this salt marsh zone is protected by a third seaward groyn field (phase 3).

A developing salt marsh turns into an existing when a salt marsh zone with a width of about 200 m is achieved. In the existing salt marshes only those techniques to protect the seaward salt marsh edge, to secure the drainage of the dike foot, and to guarantee the availability of salt marsh turves, are applied.

Based upon the regional plans and the results of the monitoring program (see below), the coastal defence authority that conducts the salt marsh works establishes yearly working schedules. These programs are than co-ordinated with the responsible environmental authority.

Salt marsh monitoring

The monitoring program supplies the necessary data base for a well-founded estimation of the effectiveness of the techniques being applied within the meaning of the above mentioned laws. Simultaneously, the data base allows a thorough checking of the necessity, efficiency, and the environmental impacts of management measures in the area. Finally, the program functions as an early warning system for the consequences of the predicted hydrographic changes, i.e., increase in sea level rise and changes in storminess (Intergovernmental Panel on Climate Change 2001).

For the reference areas and a number of coastal profiles hydrological, morphological and biologic data are gathered (Table 1). For example, every five years a Colour-Infra-Red survey by aircraft is conducted to achieve biological and morphological information. The data are stored and analysed within a Geographic Information System.



Figure 7. Brushwood groins in the Schleswig-Holstein sector of the Wadden Sea (the sea is to the right).

Discussion and prospects

The government of Schleswig-Holstein established an integrated management concept for its salt marshes that aims at a sustainable development both from a

coastal defence and from an environmental point of view. This concept was, initially, met with scepticism by the different local stakeholders. The local population has a strong attitude towards salt marsh works (including grazing) as a part of their cultural identity,

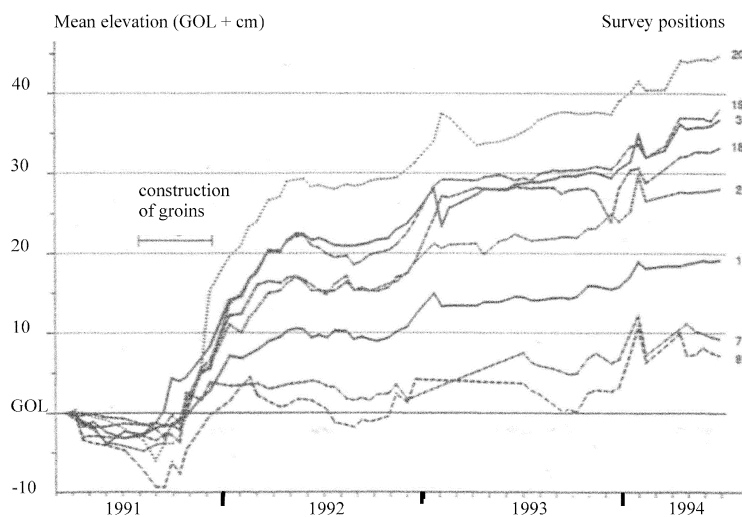


Figure 8. Effects of groin construction on the sedimentation on tidal flats (source: Erchinger et al. 1995).

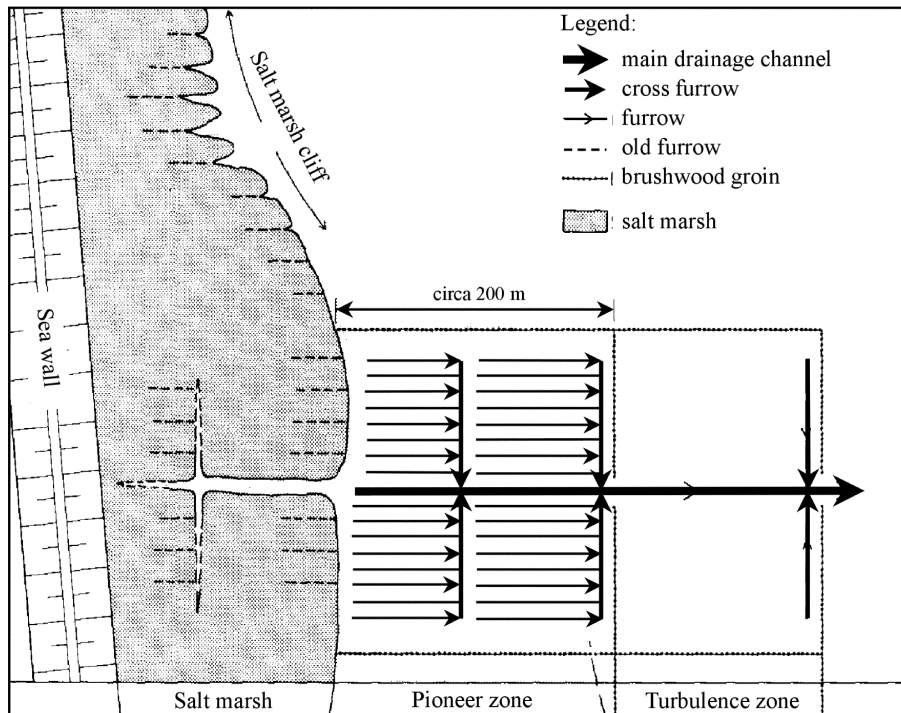


Figure 9. The 'Schleswig-Holstein echelon system' for salt marsh management.

i.e., the continuous struggle against the sea. A possible reduction in the intensity of salt marsh works is seen as a threat to the safety against storm floods, and as a personal defeat. Generations have been working to create salt marshes that are now abandoned and may be lost again. On the other hand, environmental NGO's state that, with the aim of a sustainable development, natural dynamics should prevail in the Wadden Sea. Hence, they react very sceptical upon every technical plan to manage the salt marshes. To address these conflicts and discuss the effects of the management concept, the Integrated Salt Marsh Board (ISMB), consisting of all stakeholders and public administration, was established. During regular meetings the administration informs the (other) stakeholders about the development and dynamics of the salt marshes and the effects of the management concept. After five years, a first progress report was established, in which the results of the monitoring program as well as an evaluation of the functioning of the ISMB are included (MLR 2001). The main outcomes are discussed below.

The monitoring program allows for a detailed analysis of the development of the salt marshes. In general, the salt marshes in the Schleswig-Holstein

sector of the Wadden Sea are stable or growing (horizontally as well as vertically). On a very local scale, the development of salt marshes cliffs was observed and, outside the reference areas, measures to counteract this negative development were applied successfully. Hence, the types and intensity of technical measures as defined in the regional plans were appropriate and should be maintained.

As a planning instrument, all members of the ISBM agree that the concept is straightforward, practically oriented, pertinent and integrative. The regional plans enable the coastal defence and environmental administration to pragmatically (and time-saving) coordinate the necessary measures. Further, the large scale (1:10,000) and flexibility of the regional plans allows for optimal local solutions as well as for necessary adjustments, e.g., the construction of groynes in front of developing cliffs or the ditching of extra furrows to drain the dike-foot.

Finally, the ISMB as an instrument of information, communication, integration and co-ordination is valued positively by all members. For the public administration, the ISMB functions as a platform to inform local stakeholders about the necessity to either continue or to reduce/abandon certain management

Table 1. The monitoring program within the Schleswig-Holstein integrated salt marsh management concept.

| Parameter | Area | Method | Frequency | Responsible authority |
|------------------------------------|-----------|--------|-----------|-----------------------|
| <i>Hydrology</i> | | | | |
| mean tidal high water | Rt and Rf | P | 5 | ALR |
| mean tidal low water | Rt and Rf | P | 5 | ALR |
| mean tidal range | Rt and Rf | P | 5 | ALR |
| flooding frequency | Rt and Rf | P | 5 | ALR |
| <i>Morphology</i> | | | | |
| elevation | Rt/Rf | N | 5 resp. 2 | ALR |
| seaward edge | G | CIR | 5 | NPA/ALR |
| seaward edge | Rf | CIR | 2 | NPA/ALR |
| topographic | G | CIR | 5 | NPA/ALR |
| topographic | Rf | CIR | 2 | NPA/ALR |
| <i>Sedimentology</i> | | | | |
| corn size distribution | Rf | B | 5 | NPA/ALR |
| C/N-ratio | Rf | B | 1 | NPA/ALR |
| organic substances | Rf | B | 1 | NPA/ALR |
| depth of aeration | Rf | B | 1 | NPA/ALR |
| <i>Technical measures and uses</i> | | | | |
| flotsom | Rf | B | 1 | ALR |
| groins | G | K | 1 | ALR |
| main drainage | G | K | 1 | ALR |
| ditches | G | K | 1 | ALR |
| suppletion | G | K | 1 | ALR |
| sod-winning | G | K | 1 | ALR |
| grazing | G | K | 1 | NPA/ALR |
| <i>Biology</i> | | | | |
| vegetation types | G | CIR/K | 5 | NPA |
| vegetation zonation | Rf | K | 5 | NPA |
| vegetation dominance/diversity | Rf | K | 1 | NPA |
| vegetation height | Rf | B | 1 | NPA |
| biomasse | Rf | K | 5 | NPA |
| breeding birds | G | K | 5 | NPA |
| breeding birds | Rf | K | 1 | NPA |
| resting birds | G | K | 5 | NPA |
| resting birds | Rf | K | 1 | NPA |

G – total area, Rf – reference areas, Rt – reference profiles, CIR – color-infrared airborne survey, N – geodetic survey, K – field survey, P – tidal gauge analyses, B – field probes, M – Measurements, 1 – once per year, 5 – once per five years, ALR – Regional coastal defence office, NPA – State authority for the national park.

measures. Local stakeholders have the opportunity to transport their concerns and demands to the administration and to discuss common solutions. On the basis of the common principle it was possible to, sometimes after controversial discussions, achieve a compromise solution for most problems. It should be stressed, however, that a board cannot provide an ultimate solution to every problem. Varying opinions and demands remain as a consequence of different backgrounds of the members. Hence, the ISMB may be seen as a win-win approach, not a win-win solution.

One option to be discussed in the ISMB might be a revision of the present drainage system. In a natural salt marsh meandering, narrow and deeply incised creeks develop that function both as transport routes for sediments towards the salt marshes and as dissipa-

tion zones for tidal energy (Pethick 1992; Allen and Pye 1992). The present artificial drainage system with a straight and evenly distributed channel pattern (Figures 2 and 6) differs strongly from the natural situation. According to Esselink et al. (1998), this may be an explanation for the lower spatial variation of elevation, soil conditions and vegetation in the ‘man-made’ salt marshes. Hence, in order to return to a more natural development of salt marshes, it might be an alternative to reduce drainage intensity, especially in the transition or pioneer zone.

In future, the main challenge for salt marsh management will be the adaptation to increasing energy impact of (storm) waves and currents resulting from climate change (Intergovernmental Panel on Climate Change 2001). Most attention will have to be directed

to the pioneer zone. When the accumulation in this zone remains behind sea level rise, (the intensification of) management techniques that enhance accretion, might be an environmentally more sound solution than the, otherwise necessary, fortification of salt marsh edges and outer dike-slopes (Dijkema 1992).

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