Flora and vegetation of the Wadden Sea islands and coastal areas

Report 9

Final report of the section 'Flora and vegetation of the islands' of the Wadden Sea Working Group

edited by

K.S.Dijkema

W.J.Wolff

Cover photograph: salt-marsh vegetation - Jan van de Kam, Griendtsveen
Drawings: M.A. Binsbergen, Texel; R.C. Nichols, Texel
Cartography: R.C. Nichols, Texel
Typing: Riny Wielinga, Texel; Jeannette Baken, Anna Paulowna

Report 9 of the Wadden Sea Working Group, ISBN 90 6191 059 5
Clothbound edition of all eleven reports, ISBN 90 6191 062 5

Printed in the Netherlands

TABLE OF CONTENTS

steep) slopes of dunes bordered by salt marsh, frequently reached by the tides, but with intervals too long for the establishment of halophytes, where no vegetation is present. Here water erosion often causes small cliffs, which may be a starting point for the occurrence of small or large blowouts.

In all these and similar cases, the exact topographic positions of the communities is fluctuating, and succession in a definite direction does not take place. If the situation changes fundamentally, most of the communities mentioned will disappear.

References

Dieren, J.W. van, 1934. Organogene Dünenbildung. Thesis., Amsterdam: 304 pp.

Doing, H., 1974. Landschapsoecologie van de duinstreek tussen Wassenaar en IJmuiden. Med. Landbouwhogeschool Wageningen 74-12: 111 pp.

Doing, H. & C.J. Doing - Huis in 't Veld, 1971. History of landscape and vegetation of coastal dune areas in the province of North-Holland. Acta Bot. Neerl. 20: p. 183-190.

Hartog, C. den, 1951. De plantensociologische structuur van de Binnen-Geul. Ned. Kruidk. Arch. 58: p. 141-175.

Ketner, P., 1972. Primary production of saltmarsh communities on the island of Terschelling in the Netherlands. RIN verhandeling 5: 184 pp.

Schroevers, P.J., 1951. De structuur van het plantendek der Buiten-Geulvallei. Ned. Kruidk. Arch. 58: p. 176-192.

Tüxen, R., 1952. Hecken und Gebüsche. Mitt. Geogr. Ges. Hamburg 50: p. 85-117.

Vries, V. de, 1961. Vegetatiestudie op de westpunt van Vlieland. Thesis., Amsterdam: 187 pp.

Westhoff, V., 1947. The vegetation of dunes and salt marshes of the Dutch islands of Terschelling, Vlieland and Texel. Thesis., Utrecht: 132 pp.

Westhoff, V., 1959. The vegetation of Scottish pine woodlands and Dutch artificial coastal pine forests. Acta Bot. Neerl. 8: p. 422-448.

Westhoff, V. & A.J. den Held, 1969. Plantengemeenschappen in Nederland. Thieme, Zutphen: 324 pp.

6.3 THE SALT-MARSH VEGETATION OF THE MAINLAND COAST, ESTUARIES AND HALLIGEN

K.S. Dijkema

6.3.1 Introduction

In a special study the vegetation and management of the salt marshes along the mainland, in estuaries and on the Halligen (salt-marsh islands accreted on the remainings of flooded former polders) were investigated. Investigations were also made on some sand-dune islands (Fanø, Amrum, Spiekeroog, Norderney, Texel) and comparable sandy areas along the mainland (Skallingen, Eiderstedt). So the classification and description given here is not especially intended for use along the mainland coast and on the "Halligen", but can also be used on the islands, except for the transition zones to beach plains, dune slacks and dry dunes (types To and Tu on the 1:100,000 map).

As is shown by Dijkema in chapter 5.1.3 of this report there are local vegetation-descriptions available throughout the entire Wadden Sea area. A complete list of references is given in that chapter. Some of them contain detailed phytosociological information which procure insight into larger areas, e.g. Warming (1906), Mikkelsen (1949), Iversen (1953) and Beeftink (1959) on the Danish part, Klement (1953), Tüxen (1956, 1957), Wiemann & Domke (1959) and Schwabe (1972) on some German islands, Westhoff (1947) on the western Dutch islands and De Vries (1940), Den Hartog (1958), Menke (1969), Heykena (1970) and Dijkema (1975) on mainland salt marshes. Tüxen (1937, 1955), Runge (1973) and Westhoff & Den Held (1969) give outlines for the German and Dutch vegetation types and Beeftink (1965, 1968, 1977a) gives an overall description of the North-West European salt-marsh communities, all of them according to the floristic-sociological or Braun-Blanquet approach.

Beeftink's thesis (1965) is very complete in its description of environment and vegetation, it gives a detailed syntaxonomic classification and contains synoptic tables. In this paper some smaller changes of this classification are proposed.

This study was to give information about:

a. the complex pattern, which may exist within the units of the small-scale landscape and vegetation map;

b. the geographical variation in the halosere of the Wadden Sea area;

c. the impact of several methods of management on the vegetation (e.g. doing nothing, draining, sedimentation fields, revetments, grazing).

For a more detailed description of the geomorphology and soil of salt marshes readers are referred to chapter 3.3 by Verhoeven.

6.3.2 Methods

With the help of the landscape and vegetation map scale 1:100,000 (chapter 5), aerial photographs and knowledge of the field-situation, several salt marshes situated throughout the entire Wadden Sea area were selected for comparative investigations (fig. 37). From 16 sites the vegetation has been described by vegetation maps and relevés, in other places the zonation in the halosere was recorded in a series of relevés. The relevés from Nordstrandischmoor, Langeness and a few from Gröde were made available by courtesy of Dr. Bracker at Bredsted (Bracker, 1978); the relevés made in 1974 along the northern coast of Groningen were taken from Dijkema (1975). Moreover, in several sites in the entire area field visits were made for confirmation of the

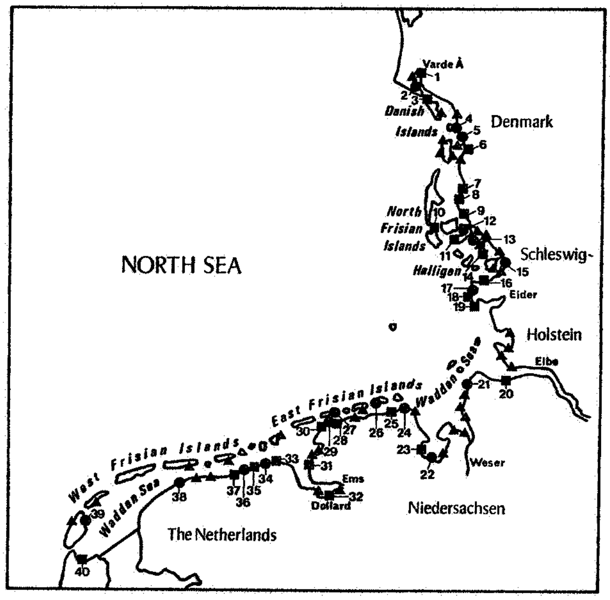

Fig. 37. Investigated areas. ● = vegetation map and relevés; ■ = relevés; ▲ = field visits. 1. Varde Å 1977; 2. Skallingen 1977; 3. Fanø 1976; 4. Rejsby 1977; 5. Astrup 1977; 6. Ballum Sluse 1975; 7. Højer Sluse 1977; 8. Frederikskog 1976; 9. Süderdeich 1977; 10. Amrum 1975; 11. Langeness 1963 (Bracker); 12. Oland 1977; 13. Gröde-Appelland 1975, 1977; 14. Nordstrandischmoor 1963 (Bracker); 15. Schobüll 1977; 16. Norderheverkoog 1977; 17. Nackhörn 1975, 1977; 18. St. Peter-Ording, Böhl 1977; 19. Ehst 1977; 20. Otterndorf 1977; 21. Arensch 1977; 22. Dangast 1977; 23. Idagroden 1975; 24. Elisabethgroden-East 1977; 25. Elisabethgroden-West 1977; 26. Spiekeroog-Neuland 1977; 27. Norderney-Ostheller 1977; 28. Nessmersiel 1977; 29. Hilgenriedersiel 1977; 30. Finkenheller 1977; 31. Pilsen 1977; 32. Dollard 1975, 1978, 1979; 33. Emmapolder 1974; 34. Lauwerpolder, Noordpolder 1974, 1977; 35. Linthorst Homanpolder, Negenboerenpolder 1974; 36. Julianapolder 1974, 1977; 37. Westpolder 1974; 38. Ferwerderadeelsbuitendijkspolder 1977; 39. Texel-Schorren 1977; 40. Balgzand-Schorren 1977.

interpretations of the aerial photographs for the 1:100,000 map.

The method of analysing the vegetation is described by Ellenberg (1956) and Westhoff & Van der Maarel (1973). The maps were prepared with the aid of stereoscopic interpretation of normal black and white vertical aerial photographs (photo-guided field survey according to Zonneveld et al., 1979). The data on management of the salt marshes were obtained from observations in the field, correspondence and conversations with local managers, aerial photographs and from literature. The data on the ranges in level with respect to mean high water level (MHW) of the vegetation types were summarized from literature (König, 1948; Jakobsen & Jensen, 1956; Lafrenz, 1957; König, 1960; Kamps, 1962; Heykena, 1970; Meesenburg, 1971; Forschungsstelle, 1973;

Dijkema, 1975). The data on soil composition were taken from soil maps.

Nomenclature of taxa follows chapter 4.1, only for *Salicornia* species König (1960) is followed. For floristic analysis the combined estimation (cover-abundance) scale of Braun-Blanquet has been used in a slightly modified way (r = one or few individuals; + = occasional and less than 5% cover; 1 = abundant and with very low cover, or less abundant and with higher but less than 5% cover; 2A = very abundant and less than 5% cover; 2B, 3, 4 and 5 = 5-25%, 25-50%, 50-75% and 75-100% cover respectively, irrespective of number of individuals).

6.3.3 Initial growth of salt marshes

Salt marsh development in the Wadden Sea starts on tidal flats, where conditions are favourable for the growth of halophytic terrestrial plants. Accretion to a level of about 40 cm below mean high water (MHW) and a situation not too much exposed to wave-action and currents are necessary conditions.

The most favourable circumstances for sedimentation of fine-grained material are found along the coastline of the islands and the mainland. As a result of decreasing tidal currents and water depths an accumulation of suspended matter takes place along the coastline and towards the watersheds (Postma, 1954; Van Straaten & Kuenen, 1957). However, in many places the coastline is too much exposed or by continuous embankments too low situated to allow a natural accretion to salt marsh. Man has intervened in this situation with land reclamation techniques (chapter 6.3.5) and has thus inverted abrasion into an artificial accretion. In addition, the west-exposed situation along the Danish mainland coast causes another process. During storm tides high situated sand bars are formed by the wave action. They are shaped parallel to the coast and are separated from it by an off-shore channel (landpriel). On top and especially on the lee side of the bars initial growth of salt marsh vegetation takes place (Jakobsen, 1954, 1964).

On the tidal flats microscopic small diatoms, blue-green and green algae protect the settled clayish layers against erosion by formation of mucus. Moreover, they are able to move to the surface through the sediment that has just been settled (De Vries, 1940; Wohlenberg, 1953; Den Hartog, 1958). The role of algae and also of the seagrasses *Zostera marina* and *Z. noltii* is discussed in more detail in Report 3 (Van den Hoek et al., 1979).

As stated above, only in very favourable circumstances the accretion is sufficient to make it possible for halophytic terrestrial plants to establish themselves. In that case two pioneer species can settle and survive within the uppermost part of the daily reach of the tides: *Salicornia stricta* and *Spartina anglica.*

Salicornia stricta is a succulent annual species growing on mud and sand flats, preferably well drained ones. *Spartina anglica* was introduced in the entire Wadden Sea area in the twenties and thirties. It is a tall growing perennial grass, which may supersede *Salicornia* by competition for light (König, 1948, 1960). Both have an optimal growth on sheltered places rich in clay from about 40 cm below MHW onwards (Wohlenberg, 1938; König, 1948, 1960). However, *Salicornia* maintains its position on firm soils and *Spartina anglica* mainly wins the competition on less drained, more water-logged sediments.

Salicornia stricta and *Spartina anglica* may start the initial salt marsh development in different ways.

a. Initial salt-marsh development with *Salicornia stricta* - Around the level of a few decimeters below MHW *Salicornia stricta* may form a vegetation up to 50% coverage. As it is an annual its share in salt-marsh development is small. In summer this vegetation stimulates sedimentation, but the algae are more important in stabilization of the sediment (Wohlenberg, 1953; Den Hartog, 1958). Kamps (1962) showed another, more important role of *Salicornia* in salt-marsh development. He found that *Puccinellia maritima* is spread mainly by vegetative parts. These parts remain hooked on the living or dead *Salicornia* bushes and then they can root.

Puccinellia tillers rapidly, especially in the zone from one dm below to one dm above MHW. It forms tussocks and soon large areas may be covered by this perennial grass. Only now the salt-marsh development is really successfull. Because *Puccinellia* has a great capacity in fixing the sediment, sand as well as clay (Wohlenberg, 1953; Kamps, 1962), the salt marsh is heightened. Under natural conditions *Puccinellia* may contribute to the formation of a pattern of elevations and developing gullies. The draining and drying up that is caused favours plant growth and stabilisation of the sediment.

Table 15 shows an example of the vegetation development in the process mentioned here. Due to the introduction and successful spreading of *Spartina anglica* an example like this, which extends over a large area, is hard to find.

Table 15. Succession from tidal flat to salt marsh in the eastern part of the Jadebusen near Idagroden. No grazing; small drainage furrows at distances of about 25 m at right angles to the coastline; soil consisting of sandy clay. Date 19 August 1977.

number of relevé	P6	P7	P8
coverage in %	30	30	90
height in cm	35	30	20-90
Salicornia stricta	3	3	
Puccinellia maritima		+	5
Aster tripolium (flowering)			2B
Triglochin maritima			1
Limonium vulgare			r
Suaeda maritima			r

b. Initial salt marsh development with *Salicornia stricta* and *Spartina anglica* (Møller, 1963) - At most sites in the Wadden Sea area *Spartina anglica*, occurring at the northern limit of its area, invaded more modestly as in much of the Southwestern Netherlands and Southern England. *Spartina* settles seawards or within the *Salicornia* zone in scattered tussocks or grows solitary mixed with *Salicornia*. In the tussocks sedimentation may take place, so that they rise above the surrounding flat.

In a vegetation dominated by *Salicornia* succession to *Puccinellia* occurs as described above. The scattered growth of *Spartina* does not prevent *Puccinellia* from invading, which is the case in a dense *Spartina* vegetation. *Puccinellia* is also able to invade into the *Spartina* tussocks from a level of about 5 cm below mean high water onwards (Møller, 1963; Meesenburg, 1971). Heykena (1970) observed a degeneration of *Spartina* on the elevated tussocks, while they continued to colonize the flat in a ring-shaped manner. *Salicornia* established on the bare elevations and from a level of 5 cm below MWH onwards *Puccinellia* did the same.

The result is that *Puccinellia maritima* is also able to take up its important part in salt-marsh development. Table 16 and fig. 38 show some examples of this type of succession.

c. Initial salt-marsh development in *Spartina anglica*-swamps (Møller, 1963) - If conditions are more favourable for *Spartina anglica*, namely a sheltered position and a poorly drained, soft (clayish) soil, the above mentioned tussocks may grow together and form a dense swamp. Mostly the soil is not soft enough: too sandy on the islands and too

Table 16. Succession from tidal falt to salt-marsh near Rejsby and near Hilgenriedersiel. Both with little or no grazing; at Hilgenriedersiel (the soil consists of clayish sand) the highest part (relevè IV 29) has drainage furrows at intervals of 8 m. Dates 14 and 30 August 1977.

	Rejsby				Hilgenriedersiel		
number of relevé	127	128	127˙	128˙	IV27	IV28	IV29
coverage in %	1	5	40	70	5	10	40
height in cm	15	15	50	45	20-40	50	10-40
Zostera noltii					+		
Salicornia stricta	+	2A	1		2A	2A	
Spartina anglica	r	1	3	3	1	2B	+
Puccinellia maritima			2A	3		2B	3
Salicornia brachystachya				2A			2A
Suaeda maritima				+			+
Halimione portulacoides							+
Spergularia media							1
Aster tripolium							+
Limonium vulgare							+
	flat		tussocks		flat	tussocks	

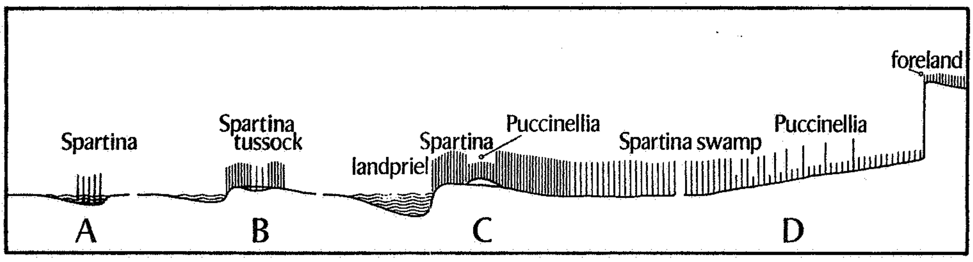

Fig. 38. The different phases of Spartina anglica in the Danish Wadden Sea. A: a puddle wadden with a small open vegetation of Spartina anglica. B: a circular, ringshaped tussock of Spartina anglica. C: a small ridge, densily grown with Spartina anglica; in the central part a smaller tussock grown with Puccinellia maritima. D: a slope, earlier eroded by waves, now grown with Spartina anglica and Puccinellia maritima. After Møller (1963).

much drained along the mainland. König (1948) accentuates absence of exposition as the most important factor, which, as he stated, is also responsible for the more successful spreading of *Spartina anglica* in Southern England and the Southwestern Netherlands. The salt marshes in the Wadden Sea area generally are too much exposed to wave action to enable *Spartina anglica* to form such an extensive dense vegetation. Though ice may destroy *Spartina* tussocks, König observed no damage in dense *Spartina*-swamps.

In the entire area these swamps may develop in sheltered places, in enclosed basins or back swamps, in sedimentation fields (Kamps, 1962) and in clay pits. Then they may even replace the *Puccinellia* zone, e.g. on Trischen (König, 1948; Dircksen, 1968; Schwabe, 1972). It is only on the creek bank levees that *Spartina* does not dominate, as is also shown by Table 17. The *Spartina*-swamps have a soft waterlogged soil. Most authors mention little or no heigtening in dense *Spartina*-swamps due to this unstable soil (König, 1948; Møller, 1963; Forschungsstelle, 1973), but under the influence of land reclamation techniques (digging of drainage furrows) and grazing with young cattle a succession to *Puccinellia* grassland seems possible (Van Eerde, 1942; Møller, 1963; Dijkema, 1975; De Glopper, pers. comm.).

Table 17. Zonation in a Spartina-swamp near Rejsby. Little grazed by cattle; both relevés at about the same level, relevé 136 is situated near the "landpriel".

number of relevé	135	136
coverage in %	70	80
height in cm	60	30
Spartina anglica	4	2B
Puccinellia maritima	2A	4
Salicornia brachystachya	2A	1
Suaeda maritima	+	2A
Aster tripolium	r	+

6.3.4 Further salt-marsh development

In natural salt-marsh development two further developments are possible: the first with the formation of an intricate pattern of creek levees and basins and the second with a sequence of terraces and back swamps parallel to the coastline. The underlying process for both morphological patterns involves the transport of sediment by tidal currents and the trapping of it by vegetation. Terraces are formed when wave action takes a more active part in salt-marsh development. The process of terrace formation determines the geomorphological pattern of most mainland salt-marshes in the Wadden Sea area. This is favoured by artificial drainage too. Within this pattern natural water-courses with creek levees and basins may be formed on a smaller scale (e.g. on the "Halligen"). On more sheltered salt marshes without artificial drainage, especially on the islands (see chapter 3.1), the latter development may play a more dominant part.

a. Formation of creek bank levees and basins - As the *Puccinellia* tussocks expand, the movement of tidal water becomes more and more restricted to gullies, which form the beginning of a creek system. Better drainage causes a lower water content and a better aeration of the soil. This favours plant growth (and species richness), which is able to trap a lot of sediment now. At this stage the sedimentation process is differentiated: water flowing sidewards over the creek banks first deposits the coarser grained sandy sediment; in the basins finer graned clayish material is supplied by the further ramifications of the creeks (Beeftink, 1965, 1966).

The sandy creek banks heighten faster and become better drained and aerated than the clayish basins, which first may remain waterlogged. Moreover shrinkage is later on more prominent in the basins. This results in a fine-grained pattern of creek levees and basins, which is also expressed in the corresponding vegetation patterns (fig. 43, 53 and 60). In general the bigger the part of sand in the sediment is, the more pronounced the differences in level between creek levees and basins will be (Beeftink, 1965, 1966).

b. Formation of terraces - On coasts more exposed to wave action the differentiation in the sedimentation process leads to a pattern parallel to the coastline. In the seawards part of recently overgrown areas the overflowing water will lose especially the coarser grained fraction of the sediment (Jakobsen, 1954, 1964). During storms great quantities of sand are transported just above the bottom in a landwards direction and they are also trapped by the vegetation in this outer zone (Jakobsen, 1954, 1964; Kamps, 1962; De Glopper, 1967). Further inland - along the Danish coast into the direction of the "landpriel" - the finer grained material is deposited (Jakobsen, 1954, 1964; Kamps, 1962; De Glopper, 1967), a process similar to that in the basins mentioned above. This results in a sequence of high loamy to sandy terraces in the seawards part of the salt marsh and a lower more clayish back swamp inland; on broad salt marshes the pattern may include two or more of these elements (figs. 15 and 39-42). The environ-

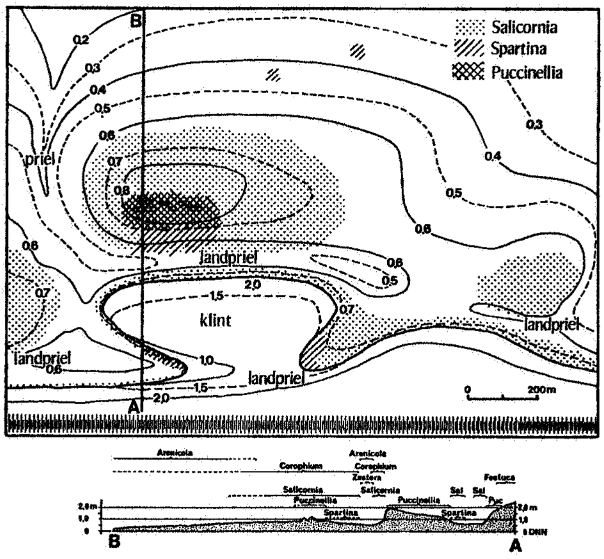

Fig. 39. Map and profile of a typical Danish terraced salt marsh. The heights are indicated in metres above DNN. The MHW level is about 0.85 m above DNN. 1 = Arenicola, 2 = Corophium, 3 = Salicornia, 4 = Puccinellia, 5 = Spartina, 6 = Zostera and 7 = Festuca. After Jacobsen & Jensen (1956).

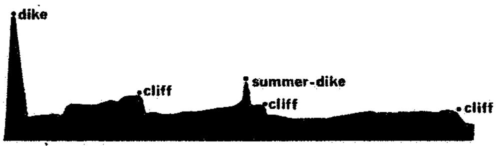

Fig. 40. Profile of successive terraces on the former salt marshes of the now embanked Linthorst Homanpolder, the Netherlands. After De Vries (1940).

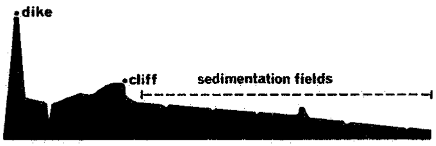

Fig. 41. Profile of an old terraced salt marsh with sedimentation fields in front of it along the Noorpolder, the Netherlands. After Dijkema (1975).

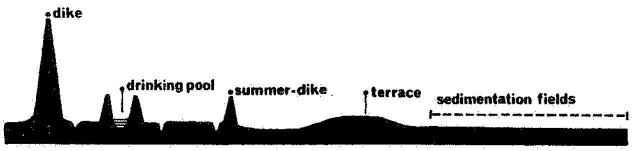

Fig. 42. Profile of the summer-polder and artificial salt marsh with terrace near Ferwerd, the Netherlands. After Anonymus (1975).

mental characteristics of the terraces and back swamps agree with respectively the creek levees and basins in the process mentioned under a (see Beeftink, 1965; Verhoeven & Akkerman, 1967).

The outer part of the terrace is often eroded and then a cliff up to one meter in height is formed. Along the Danish coast a new "landpriel" is formed outside this cliff. On the sand bars in front of it new salt marsh development may take place (Jakobsen, 1954, 1964). Terraces which have a cliff may grow in height up to 1.5 m above MHW level (Ho Bugt, Arensch, Noordpolder-Groningen).

6.3.5 Land reclamation techniques

Techniques for promoting accretion play an important part in salt marsh development in the Wadden Sea area. Especially along the mainland coasts they dominate the landscape. That is why the underlying principles will be discussed here as an artificial process in relation to the natural processes mentioned above. In chapter 8.4 the land reclamation techniques and their application will be discussed in more detail.

a. Improvement of drainage - The process of natural salt-marsh development is accelerated a good deal when the expanding vegetation creates a beginning creek system. The drainage favours plant growth and stabilization of the sediment. An artificial drainage system aims at this effect and is a simple way of land reclamation on highly situated flats. Mostly a system of parallel drainage furrows is cut from a level just below the beginning vegetation upwards. Sometimes this is done in an existing salt marsh (fig. 71).

In this way the drainage is transferred artificially to a more advanced phase and is intensified in density. This intervention has little effect on the development of terraces and the coastal-parallel pattern belonging to it (fig. 46, Rejsby). But small-scaled differentiation in both geomorphological and vegetation patterns is lost:

1. Due to the low level on which draining starts the pattern of elevated *Puccinellia* tussocks and developing gullies (6.3.3. a) does not occur, on the contrary, *Puccinellia* expands regularly over the fields (cf. Wohlenberg, 1938; Lafrenz, 1957). *Spartina anglica* mainly remains limited to the drainage furrows (cf. Forschungsstelle, 1973; Dijkema, 1975).
2. Due to the density of the artificial drainage system a pattern of creek levees and basins does not occur. Because of the well drained and aerated soil the vegetation agrees with that of creek levees. Communities with *Halimione portulacoides* or *Artemisia maritima* therefore have a better chance than communities with *Spartina anglica* or *Limonium vulgare*.
3. If an artificial drainage system is constructed in an existing natural salt marsh the creek system will cease to function and the basins will fill up (Beeftink, 1975, 1977b; fig. 54, Ostheller on Norderney).
4. Maintenance of digging drains in the *Puccinellia* zone in another way than by means of fraising (by this method the warp is spread regularly over the fields) causes regression towards an annual vegetation with *Salicornia europaea* and *Suaeda maritima* (fig. 43; Dijkema, 1975).

b. Groynes and sedimentation fields - A main condition for salt-marsh development is a position not too much exposed to wave-action. Such a position favours the sedimentation and the settlement of vegetation. As stated by Olsen (1959) erosion caused by wave action takes place especially on the level at which the settlement of vegetation occurs.

Groynes (mostly made of brushwood) and sedimentation fields (an area surrounded by groynes) will improve both sedimentation and settlement of vegetation since they create a more sheltered position. Therefore land reclamation by means of this method may start on a much lower level of the tidal flats than reclamation by means of the draining method only. Within the sedimentation fields cutting of drainage furrows is mostly applied (fig. 7 and 72). In addition to the levelling effects due to draining, which are the same as mentioned under a, the construction of sedimentation fields has some other levelling effects:

1. Because sedimentation fields decrease the influence of wave-action there is no formation of terraces and back swamps. On the contrary the level increase gradually from the tidal flat towards the sea-dike (fig. 41 and 57, Noordpolder). In the lower sedimentation fields the sedimentation pattern differentiates perpendicular to the coastline, determined by and parallel to the groynes and main ditches; the material richest in clay is found along the groynes (Kamps, 1962; De Glopper, 1967; Verhoeven & Akkerman, 1967). On a higher level (in the overgrown salt marsh) the groynes lose their sheltering influence and terraces may be formed even yet (fig. 56, Hilgenriedersiel). As a rule there will be no cliff because of further accretion in front of the terraces.
2. The sheltered conditions within the sedimentation fields may favour the development of *Spartina anglica*-swamps (6.3.3.c; fig. 47, Astrup). This effect does not extend over large areas, which is due to the regular unkeep of drainage furrows and to grazing that takes place in most reclamation areas.

6.3.6 Zonation and succession

From the mud flats to the highest salt marshes series of plant communities can be identified, which are determined more or less by three types of factors:

a. Factors related to the stage in salt-marsh formation:
- duration and frequency of tidal inundation (dependent on the level of the marsh);
- drainage and aeration;
- soil characteristics (on a local scale).

b. Factors related to the geographic-ecological position of the marsh:
- salinity of the submerging water;
- fresh water seeping from adjacent dune or geest areas;
- soil characteristics;
- tidal range (determines the vertical scale in zonation);
- transport of organic material by water and wind;
- differences in climate (hardly play a part within the Wadden Sea area).

c. Factors related to human impact:
- artificial drainage;
- construction of groynes, sedimentation fields and revetments;
- grazing, mowing and fertilizing.

The salinity of the soil moisture is a key-factor for salt marsh vegetation. The soil salinity depends on climatic conditions (evaporation and precipitation), tidal inundation, soil texture, drainage (relief and water content) and on aeration. These processes give rise to two gradients perpendicular to each other:
1. With increasing height above MHW the duration and frequency of tidal inundations decrease and the soil salinity adapts itself to a lower average. This enables more plant species to establish.
2. In a landinwards direction in estuaries the average salinity of the submerging water decreases and so does the soil salinity. However, the fluctuations in soil salinity do increase and occur on a lower level relative to MHW (Beeftink, 1965, 1966).

Another process influencing soil salinity is fresh water seeping from adjacent dune or geest areas.

Table 18 shows an outline of the communities (syntaxa) occurring on the Wadden Sea salt marshes. The changing factors during salt-marsh development (type a) cause succession series from plant communities of mud flats to communities of the highest salt marshes. On the 1:100,000 map these series go via Ss, Sp and Sf to Tl or To. On the list of communities it can be seen that within these simple units a complex differentiation may occur. On the one hand this is caused by the differentiation into terraces or creek levees and basins or back swamps (factors of type a). On the other hand human impact (type c) such as land reclamation techniques and grazing play an important part.

In addition, the spatial distribution of the communities is influenced - on a larger scale - by geographically determined factors (type b). E.g. river upwards in estuaries the mud flats are characterized by reed communities (Wp on the 1:100,000 map), or the *Aster*-sociation (St, in the Dollard). Fresh water supply from adjacent dune or geest areas may also cause development of reed communities (with *Juncus maritimus*, *Phragmites australis* or *Scirpus maritimus*). Finally the differences in soil characteristics have their influence. On the 1:100,000 map this is illustrated most clearly on the highest marshes: unit Tl on clayish marshes along the mainland and in estuaries and To on sandy marshes on dune islands and along the coast of SW-Eiderstedt. Some of the differiation within the units Ss, Sp and Sf is also due to these geographical determined soil characteristics.

The dynamics in salt-marsh development causes the succeeding plant communities to present themselves in a zonation pattern. But, to draw conclusions from the succession by studying the sequence of zonation should be done very carefully, as stages of different succession series may be situated close to one another, e.g. as a result of differentiation into creek levees and basins (Beeftink, 1965), fresh water supply, artificial drainage or grazing. With this restriction in mind a succession scheme for salt marshes in the euhaline and polyhaline zones of the Wadden Sea area has been drawn up (fig. 43).

Table 18. Outline of communities occurring on the Danish, German and Dutch Wadden Sea salt marshes.

	code synoptic Tables 19-22	legend units 1:100,000 map
Communities of tidal mud- and sand flats		
Alliance Spartinion Conard 1952		
Spartinetum townsendii Corillion 1953	S	
Alliance Thero-Salicornion Br.-Bl. 1933 em. R.Tx. 1950		Ss
Salicornietum strictae Christiansen 1955	Q	
Communities of low salt marshes		
Alliance Puccinellion maritimae Christiansen 1927 em. R.Tx. 1937		
Puccinellietum maritimae typicum Westhoff 1947		
- initial phase with Spartina anglica nom. nov.	Ps	
- initial phase with Puccinellia maritima Westhoff 1947	P	
- variant with Halimione portulacoides Beeftink 1962 pro phase	Ph	
- variant with Limonium vulgare Beeftink 1962	Pl	
- variant with Aster tripolium Beeftink 1965	Pas	Sp
- facies of Puccinellia maritima Beeftink 1962	Pp	
Halimonetum portulacoides Kuhnholtz-Lordat 1927	H	
- terminal phase with Artemisia maritima Beeftink 1959	Hf	
Communities of high salt marshes		
Alliance Armerion maritimae Br.-Bl. et De Leeuw 1936		
Artemisietum maritimae typicum Beeftink 1962	F	
- facies of Artemisia maritima Beeftink 1965 pro phase	Ft	
- facies of Agropyron pungens Feekes 1950	Fe	
Artemisietum maritimae armerietosum Beeftink 1962	Fa	
Juncetum gerardii inops nom. nov.		
- variant with Juncus gerardii Beeftink 1962	Jj	
- variant with Agrostis stolonifera and Festuca rubra nom. nov.	Jg	Sf
Juncetum gerardii armerietosum nom. nov.		
- variant with Juncus gerardii Beeftink 1962	Aj	
- variant with Agrostis stolonifera and Festuca rubra nom. nov.	Ag	
Juncetum gerardii variant with Limonium vulgare and Plantago maritma Beeftink 1962	Al	
Junco-Caricetum extensae Br.-Bl. et De Leeuw 1936	-	
Communities of highest salt marshes and summer-polders		
Alliance Agropyro-Rumicion crispi Nordh. 1940 em. R.Tx. 1950		
Agropyretum repentis maritimum Nordh. 1940	Re	
Poo-Lolietum D.M. de Vries et Westhoff n.n. apud A. Bakker 1965	Ru	Tl
Potentillo-Festucetum arundinaceae Nordh. 1940	Rr	
Communities of salt marsh and beach plain to sand dune transitions		
Alliance Agropyro-Rumicion crispi Nordh. 1940 em. R.Tx. 1950		
Ononido-Caricetum distantis R.Tx. 1955 n.n.	Ro	
Community of Agrostis stolonifera subvar. salina and Trifolium fragiferum Westhoff 1947	-	
Alliance Armerion maritimae Br.-Bl. et De Leeuw 1936		To
Juncus maritmus-Oenanthe lachenalii association R.Tx. 1937	Bm	
Scirpetum rufi (G.E. et G. Du Rietz 1925) Gillner 1960	-	
Communities of brackish habitats		
Order Glauco-Puccinellietalia Beeftink et Westhoff 1962		
Aster tripolium-sociation Beeftink 1965	Bas	St
Halo-Scirpetum maritmi (Van Langendonck 1931) Dahl et Hadac 1941	Bi	Wp
Phragmites australis-consociation Beeftink 1962	B	
Agrostis stolonifera salina-sociation Beeftink 1962	Bg	Sf
Communities of habitats instable in salt- and water content		
Glaux maritima-sociation	-	
Alliance Puccinellion maritimae Christiansen 1927 em. R.Tx. 1937		
Puccinellietum maritimae pharapholietosum Westhoff 1947	-	
Alliance Puccinellio-Spergularion salinae Beeftink 1965		Tu
Puccinellietum distantis Feekes (1934) 1943	-	
Puccinellietum retroflexae (Almquist 1929) Beeftink 1965	-	
Alliance Saginion maritimae Westhoff, Van Leeuwen et Adriani 1962		
Sagino maritmae-Cochlearietum danicae (R.Tx. 1937) R.Tx. et Gillner 1957	-	
Alliance Nanocyperion flavescentis W. Koch 1926		
Cicendietum filiformis Allorge 1922	-	
Centaurio-Saginetum moniliformis Diemont, Siss. et Westhoff 1940	-	
Communities of tide marks		
Suaedetum maritimae (Conard 1935) Pignatti 1953	-	
Atriplicetum littoralis (Warming 1906) Westhoff et Beeftink 1950	-	

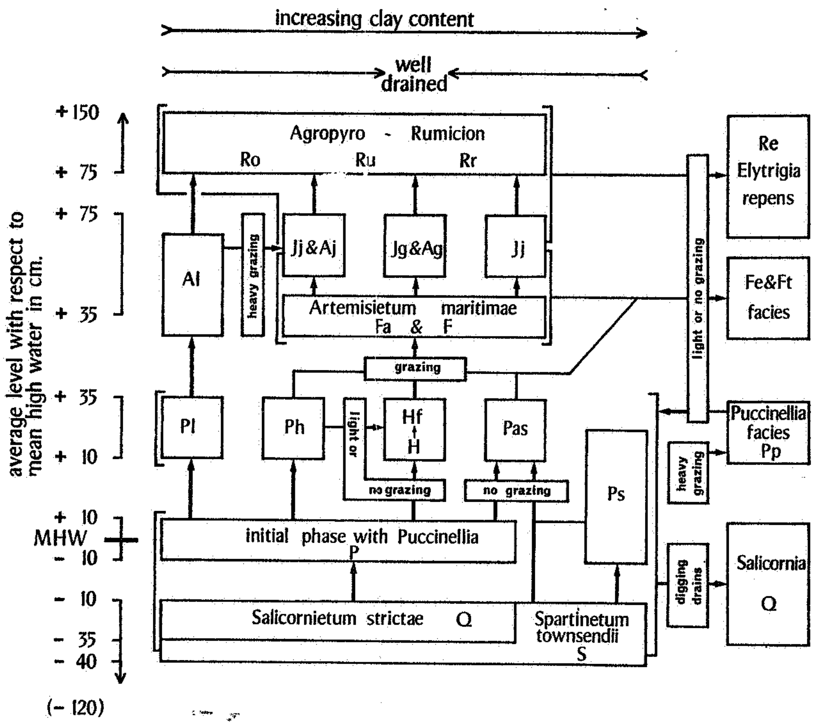

Fig. 43. Principal succession series on the salt marshes of the euhaline and polyhaline zones of the Danish, German and Dutch Wadden Sea. Figures for level are given for tidal ranges between c. 230 and 300 cm.

6.3.7 Outline of communities

6.3.7.1 Introduction

The essentials of the floristic-sociological or Braun-Blanquet approach are (Westhoff & Van der Maarel, 1973):

a. classification and interpretation of communities should be based on their full floristic composition;

b. some species are largely restricted to certain communities and are emphasized as diagnostic species; they characterize the communities and indicate their environments;

c. the diagnostic species may be used to organize the communities into a hierarchical classification.

In the synoptic Tables 19, 20, 21 and 22 the plant communities of mainland salt marshes and Halligen are characterized floristically. Some environmental characteristics are also summarized. The species numbers should be considered in relation to the number of relevés. For a detailed description of most of the syntaxa the reader is referred

Table 19. Floristic-sociological classification of mud flats and low salt marshes on the mainland coast and Halligen of the Danish, German and Dutch Wadden Sea (including relevés on some dune islands).

Classes Orders Alliances	Spartinetea Spartinetalia Spartinon	Thero-Salicornietea Thero-Salicornietalia Thero-Salicornion	Asteretea tripolii Glauco-Puccinellietalia Puccinellion maritimae							
Associations	Spartinetum townsendii	Salicornietum strictae	Puccinellietum maritimae						Halimionetum portulacoidis	
Lower syntaxa			initial phase with Spartina anglica	initial phase with Puccinellia maritima	variant with Halimione portulacoides	variant with Limonium vulgare	variant with Aster tripolium	facies of Puccinellia maritima	typical form	terminal phase with Artemisia maritima
code	S[3]	Q	Ps	P	Ph	Pl	Pas	Pp	H	Hf
number of relevés	39	39	15	42	9	15	16	77	25	10
geomorphology (ratio nat./dr./set.) [1]	4/-/6	3/1/6	2/1/7	3/1/6	2/1/7	8/1/1	2/1/7	1/4/5	5/-/5	7/-/3
% of relevés with artificial drainage	46	64	67	67	67	20	69	79	52	30
grazing (ratio -/±/+) [2]	8/2/-	9/-/1	3/4/3	7/1/2	2/8/-	6/3/1	9/1/-	1/1/8	6/4/-	7/3/-
number of species	10	8	9	13	14	17	15	18	12	12
character-taxa associations										
Spartina anglica	100(+-4)	41(+-1)	100(2-3)	52(+-1)	33(+)	13(+1)	50(+-2)	13(+-1)	20(+-2)	-
Salicornia stricta	54(+-3)	100(+-3)	7(3)	38(+-3)	-	13(+-2)	7(2)	-	-	-
Puccinellia maritima	67(+-3)	15(+-1)	100(2-5)	100(+-5)	100(2-4)	93(+-3)	100(2-4)	100(3-5)	76(1-4)	50(1-2)
Halimione portulacoides	15(+-2)	-	27(+-2)	21(+-2)	100(2)	47(+-2)	63(+-2)	16(+-1)	100(3-5)	100(3-5)
character-taxa Thero-Salicornion and Suaedetum maritimae										
Salicornia brachystachya	44(+-2)	23(+-1)	87(1-3)	86(+-4)	55(+-2)	87(+-3)	13(1-2)	64(+-3)	48(+-2)	-
Suaeda maritima	44(+-2)	21(+-2)	67(+-2)	74(+-3)	100(+-3)	87(+-3)	100(+-3)	69(+-3)	76(+-3)	60(+-1)
character-taxa Asteretea tripolii and Glauca-Puccinellietalia										
Aster tripolium	31(+-2)	3(+)	87(+-2)	43(+-2)	89(+-2)	40(+-2)	100(2-3)	49(+-2)	36(+-2)	50(+-1)
Spergularia media	3(+)	-	7(+)	10(1-2)	33(+-1)	67(+-1)	31(+-1)	65(+-2)	16(+-1)	20(+)
Triglochin maritima	-	-	-	-	11(1)	80(+-3)	-	21(+-2)	12(+-1)	20(1-2)
Limonium vulgare	8(+-1)	3(+)	7(1)	10(+-1)	22(1)	100(2-4)	13(+-2)	10(+-2)	28(+-2)	40(+-2)
Plantago maritima	-	-	-	2(+)	11(+)	47(+-2)	25(+-2)	22(+-2)	8(+-2)	30(+-1)
taxa Armerion maritimae										
Artemisia maritima	-	-	-	2(+)	22(+-1)	20(+-2)	13(1-2)	5(+-1)	-	90(2-3)
Festuca rubra	-	-	-	2(+)	33(+-2)	-	19(1-3)	17(+-2)	4(+)	90(+-2)
Glaux maritima	-	-	-	-	-	7(2)	13(1-3)	21(+-2)	-	20(+)
Juncus gerardii	-	-	-	-	-	13(+-2)	-	3(1-2)	-	-
halo-nitrophilous taxa										
Atriplex hastata	3(3)	-	-	5(+)	11(+)	7(2)	19(+-2)	21(+-2)	-	-
Cochlearia anglica	-	-	-	-	11(1)	-	19(+-1)	5(+-3)	8(+)	10(+)

Addenda Q: Zostera noltii 3(+); Pl: Spergularia marina 7(2), Elymus pycnanthus (= Agropyron pungens) 7(2); Pp: Armeria maritima 1(+), Scirpus maritimus 1(+)

1) nat.: naturally formed salt marsh
dr.: salt marsh formation was stimulated by improving the drainage by means of drainage furrows (farmers' method)
set.: artificially formed salt marsh (with sedimentation fields and often intensive draining; Schleswig-Holstein method)
2) -: light grazing or ungrazed
±: moderate grazing
+: heavy grazing
3) S: swamps; St: scattered tussocks

Table 20. Floristic-sociological classification of high salt marshes on the mainland coasts and Halligen of the Danish, German and Dutch Wadden Sea (including relevés on some dune islands).

Class Order Alliance	Asteretea tripolii Glauco-Puccinellietalia Armerion maritimae								
Associations	Artemisietum maritimae				Juncetum gerardii				
Subassociations	Artemisietum maritimae typicum			Artemisietum maritimae armerietosum	Juncetum gerardii inops		Juncetum gerardii armerietosum		
Lower syntaxa	typical form	facies of Artemisia maritima	facies of Elytrigia pungens		variant with Juncus gerardii	variant with Agrostis stolonifera and Festuca rubra	variant with Juncus gerardii	variant with Agrostis stolonifera and Festuca rubra	variant with Limonium vulgare and Plantago maritimae
code	F	Ft	Fe	Fa	Jj	Jg	Aj	Ag	Al
number of relevés	22	14	19	14	47	46	30	16	18
geomorphology (ratio nat./dr./set.) 1)	3/3/4	5/1/4	4/3/3	5/2/1 2)	5/4/1	2/6/2	7/3/-	1/5/1 3)	10/-/-
soil (sandy/clayey)	3/7	2/8	5/5	7/3	6/4	3/7	7/3	4/6	6/4
% of relevés with artificial drainage	64	42	42	36	51	63	34	56	22
grazing (ratio -/±/+) 1)	3/3/4	5/4/1	5/3/2	4/4/2	2/3/5	1/1/8	2/2/6	3/3/4	3/2/5
number of species	22	26	20	23	37	28	35	22	17
character-taxa associations									
Artemisia maritima	55(+-2)	100(3-5)	47(+-3)	86(+-2)	2(+)	24(+-2)	19(+-2)	38(+-2)	61(+-2)
Armeria maritima	-	7(1)	21(+-1)	86(+-2)	-	-	100(+-3)	100(+-2)	67(+-2)
character-combination Armerion maritimae									
Juncus gerardii	-	14(+-1)	11(1-2)	43(+-2)	100(1-4)	9(+)	100(+-4)	13(+)	72(+-4)
Festuca rubra	95(3-5)	79(2-4)	68(+-4)	100(2-5)	91(1-5)	100(2-5)	87(+-4)	100(3-5)	94(1-4)
Agrostis stolonifera	5(+)	29(+-3)	16(+-2)	29(+-2)	74(1-4)	100(+-4)	52(+-4)	100(1-3)	17(+-1)
Glaux maritima	59(+-2)	-	11(+-1)	43(+-2)	76(+-3)	50(+-2)	71(1-2)	69(1-2)	78(+-2)
character-taxa Asteretea tripolii and Glauco-Puccinellietalia									
Aster tripolium	55(+-2)	57(+-3)	16(+)	43(+-2)	34(+-1)	28(+-2)	26(+-2)	31(+-1)	39(+-2)
Spergularia media	59(+-1)	36(+-1)	-	71(+-1)	49(+-2)	43(+-1)	45(+-2)	63(+-2)	44(+-1)
Triglochin maritima	14(+-2)	7(1)	-	50(+-3)	30(+-2)	7(+-2)	42(+-3)	31(+-2)	27(+-2)
Limonium vulgare	18(+-2)	36(+-3)	16(+-2)	50(+-2)	6(+-1)	9(+-1)	29(+-1)	-	100(2-3)
Plantago maritima	64(+-2)	43(+-2)	11(+)	93(+-3)	66(+-2)	48(+-3)	80(+-3)	81(+-2)	100(+-3)
character-taxa Puccinellion maritimae, Thero-Salicornion and Suaedetum maritimae									
Puccinellia maritima	36(+-3)	36(+-2)	-	14(1-2)	21(+-3)	22(+-3)	19(+-2)	6(1)	27(+-2)
Halimione portulacoides	23(+-2)	43(+-2)	26(+-2)	14(+-2)	2(2)	4(+)	-	6(+)	33(+-2)
Salicornia brachystachya	9(1-2)	14(+-1)	-	7(+)	13(+-2)	7(+-2)	10(+-2)	-	33(+-2)
Suaeda maritima	41(+-1)	14(1-2)	-	14(+-2)	2(+)	7(+-1)	-	6(+)	22(+-2)
halo-nitrophilous taxa									
Atriplex hastata	32(+-2)	14(+-2)	26(+-2)	14(+-1)	28(+-2)	35(+-2)	3(+)	6(+)	-
Cochlearia anglica	23(+-1)	36(+-3)	11(+-2)	43(+-2)	2(+)	11(+-1)	3(1)	25(+)	-
Elymus pycnanthus (= Agropyron pungens)	18(+-2)	29(1-2)	100(3-5)	14(+-1)	6(1)	4(1)	3(2)	31(1-2)	-
Atriplex littoralis	-	14(+)	-	-	-	-	3(+)	-	-
Cakile maritima	-	-	-	-	-	2(+)	3(1)	-	-
other taxa									
Elymus repens (= Agropyron repens)	9(1-2)	7(+)	-	-	11(1-2)	24(+-2)	7(+-2)	-	-
Lolium perenne	5(+)	7(+)	-	-	19(+-2)	24(+-2)	13(+-1)	25(1)	-
Leontodon autumnalis	5(+)	7(+)	11(+-2)	7(+)	17(+-2)	9(+-2)	13(+-1)	-	-
Potentilla anserina	-	7(+)	11(+)	-	19(+-2)	16(+-2)	13(+-2)	25(1-2)	-
Trifolium repens	-	7(+)	16(+-1)	7(1)	30(+-2)	11(+-1)	23(+-2)	31(+-2)	11(+)
Trifolium fragiferum	-	-	-	-	4(1-2)	2(+)	-	-	-
Odontites verna subsp. serotina	5(+)	-	5(+)	-	2(+)	4(+-1)	17(+-2)	-	11(+-2)
Centaurium pulchellum	-	-	-	-	4(+-1)	-	10(+-1)	-	-
Carex distans	-	-	-	-	-	-	10(+-2)	-	-
Lotus corniculatus	-	-	-	-	2(+)	2(1)	-	-	-
Poa trivialis	-	7(+)	-	-	-	-	7(+-2)	-	-
Cirsium arvense	-	-	-	7(+)	2(2)	-	-	6(+)	-
Polygonum aviculare	5(+)	-	5(+)	-	2(+)	4(+)	3(+)	-	-
Plantago coronopus	-	-	5(+)	7(1)	6(+-1)	-	10(+-2)	19(1-2)	-
Spergularia marina	-	-	-	-	-	2(2)	-	6(+)	-
Scirpus maritimus	-	-	-	-	4(1-2)	-	3(1)	-	-
Phragmites australis	5(+)	-	-	-	15(+-1)	-	-	-	-

Addenda Ft: Hordeum secalinum 7(+), Stellaria media 7(+); Fe: Poa pratensis 5(+); Fa: Cirsium arvense 7(+); Jj: Festuca arundinacea 2(+), Taraxacum vulgare 2(1), Plantago major 4(+-1), Carex nigra 2(1), Holcus lanatus 2(2), Eleocharis palustre 2(1); Aj: Cerastium holosteoides 7(+), Odontites verna subsp. littoralis 7(+), Lotus tenuis 7(+), Puccinellia distans 7(1-2), Seneceo vulgaris 3(+)

1) see Table 19
2) transition from high to younger salt marsh: 21%
3) idem : 25%

to Beeftink (1965, 1977a) and particularly for communities of land reclamation areas to Dijkema (1975). Next the communities will be described shortly.

6.3.7.2 Communities of mud flats and low salt marshes (Table 19)
The initial growth of salt marshes and the lines of succession between the Salicornietum (Q), Spartinetum (S) and initial phases of the Puccinellietum (P, Ps) have been discussed in detail in chapter 6.3.2.

The first communities in succession from tidal flat to low salt marsh are two initial phases of the Puccinellietum maritimae with

Table 21. Floristic-sociological classifications of highest salt marshes and summer-polders on the mainland coasts and Halligen of the Danish, German and Dutch Wadden Sea.

Alliance	Agropyretum-Rumicion crispi			
Syntaxa	Agropyretum repentis maritimum	Poo-Lolietum	Potentillo-Festucetum arundinaceae	Ononido-Caricetum distantis
code	Re	Ru	Rr	Ro
number of relevés	23	39	4	4
geomorphology (ratio nat./dr./set.) [1]	4/6/- [2]	3/6/1 [3]	5/5/-	10/-/-
% of relevés with artificial drainage	30	51	50	-
grazing (ratio -/±/+/mowing) [1]	3/2/1/4	-/1/7/2	3/2/-/5	8/2/-/-
number of species	44	48	18	26
character-taxa Agropyro-Rumicion crispi				
Elymus repens (= Agropyron repens)	100(2-5)	62(+-3)	100(1-3)	25(+)
Leontodon autumnalis	57(+-2)	69(+-2)	-	50(+)
Potentilla anserina	30(+-2)	56(+-2)	25(1)	25(2)
Rumex crispus	4(+)	-	50(+)	-
Trifolium fragiferum	-	3(1)	-	25(2)
Odontites verna subsp. serotina	-	3(+)	-	25(1)
Lotus tenuis	9(+-1)	3(1)	-	25(+)
character-combination Poo-Lolietum				
Lolium perenne	26(1-3)	97(1-5)	25(+)	-
Trifolium repens	52(+-2)	92(+-3)	50(2)	75(2)
Taraxacum vulgare	22(+-2)	38(+-3)	-	-
Plantago major	4(1)	21(+-1)	-	-
Poa trivialis	13(1-3)	8(2-3)	-	-
Poa pratensis	4(1)	18(+-3)	-	25(2)
Ranunculus repens	-	10(+-1)	-	-
character-taxon Potentilla-Festucetum arundinaceae				
Festuca arundinacea	17(+-1)	5(1)	100(2-3)	
taxa Ononido-Caricetum distantis				
Ononis spinosa	9(+)	5(+-2)	-	100(1-3)
Carex distans	-	-	-	25(2)
Lotus corniculatus	-	-	25(+)	75(+-2)
taxa Asteretea tripolii and halo-nitrophilous taxa				
Festuca rubra	83(+-4)	85(1-3)	100(1-3)	100(2-3)
Agrostis stolonifera	35(+-2)	26(+-3)	50(1-2)	-
Juncus gerardii	9(+-1)	5(2)	-	100(+-3)
Armeria maritima	22(+-1)	10(+-1)	-	25(1)
Artemisia maritima	9(1)	3(+)	-	-
Odontites verna subsp. litoralis	4(+)	3(+)	-	-
Spergularia media	4(+)	3(+)	-	-
Triglochin maritima	9(+-2)	5(+-1)	-	-
Plantago maritima	13(1-2)	-	-	100(+)
Atriplex hastata	22(+-2)	8(+)	-	-
Atriplex littoralis	4(+)	3(+)	-	-
Elymus pycnanthus (= Agropyron pungens)	-	-	25(1)	25(1)
Matricaria maritima subsp. inodora	4(+)	3(+)	-	-
taxa Lolio-Cynosuretum				
Cynosurus cristatus	4(1)	3(1)	-	-
Hordeum secalinum	13(+-2)	18(1-3)	-	-
Bellis perennis	4(1)	26(+-3)	-	-
Dactylis glomerata	-	8(+-3)	25(+)	-
Cerastium holosteoides	26(+-1)	27(+-2)	25(+)	-
Plantago lanceolata	-	15(+-3)	25(2)	-
Vicia cracca	9(+-2)	10(+-2)	-	25(+)
Trifolium pratense	4(+)	8(+-1)	25(2)	25(+)
other taxa				
Phragmites australis	13(1-2)	3(+)	50(+-2)	75(+-2)
Cirsium arvense	35(+-2)	26(+-2)	25(1)	-
Achillea millefolium	4(+)	10(1-2)	25(2)	-
Dancus carota	4(+)	8(1-2)	50(1-3)	-
Bromus mollis	13(+-1)	27(+-1)	-	-
Polygonum aviculare	13(+)	10(+-2)	-	-
Alopecurus geniculatus	4(+)	3(+)	-	-
Stellaria media	4(+)	3(+)	-	-
Sonchus arvensis	4(+)	-	-	25(1)

Addenda Re: Juncus effusus 4(+), Juncus compressus 4(+), Limonium vulgare 4(+), Halimione portulacoides 4(+); Ru: Poa annua 5(+-2), Cirsium vulgare 18(+-1), Lathyrus pratensis 5(1), Glaux maritima 5(+-1), Aster tripolium 5(+), Puccinellia distans 3(2); Ro: Juncus maritimus 25(+), Centaurium pulchellum 25(1), Elymus arenarius 25(2), Honkenya peploides 25(2), Carex arenaria 25(1), Lathyrus japonicus 25(1)

1) see Table 19
2) 9% summer-polders
3) 21% summer-polders

resp. *Spartina anglica* (Ps) and *Puccinellia maritmae* (P). Both communities are dominated by tillering *Puccinellia maritimae* and there is a great floristic similarity.

Above mean high water level vegetation differentiates according to drainage and grain-size composition of the soil. The variant with *Limonium vulgare* (Pl) is found on some badly drained sites in mainland salt marshes (lightly grazed), but is more characteristic for the dune-islands and Halligen. The community will degenerate by intensive land-use such as draining (fig. 56; Hilgenriedersiel). In clayish basins and back-swamps the initial phase with *Spartina anglica* (Ps) will maintain (fig. 43).

Halimione portulacoides-dominated communities (Ph, H, Hf), on the contrary, develop on well-drained creek levees and terraces and on the equivalent sites in artificially drained salt marshes and on the well-drained Skallingen beach plain salt marsh (fig. 45). Domination of *Halimione portulacoides* (H, Hf) is promoted by light or no grazing for a longer period (Dijkema, 1975). Beeftink (1962, 1965) distinguishes a terminal phase of the Puccinellietum with *Halimione*

Table 22. Floristic-sociological classification of brackish marshes on the mainland coasts of the Danish, German and Dutch Wadden Sea (including some relevés on dune islands and Halligen).

Class Order	Asteretea tripolii Glauco-Puccinellietalia				
Alliance					Armerion maritimae
Syntaxa	Aster tripolium-sociation	Halo-Scirpetum maritimi	Phragmites communis-consociation	Agrostis stolonifera salina-sociation	Juncus maritimus Oenanthe lachenalii association
code	Bas	Bi	B	Bg	Bm
number of relevés	6	13	8	7	3
geomorphology (ratio nat./dr./set.) 1)	10/-/-	5/1/4	7/3/-	4/6/-	10/-/-
% of relevés with artificial drainage	0	46	13	100	33
grazing (ratio -/±/+/mowing) 1)	10/-/-/-	9/1/-/-	10/-/-/-	-/-/6/4	3/7/-/-
number of species	5	18	20	20	17
dominant taxa					
Scirpus maritimus	-	$\boxed{100(1-5)}$	50(1-2)	14(+)	-
Phragmites australis	-	8(+)	$\boxed{100(3-5)}$	14(1)	-
Agrostis stolonifera	-	-	50(1-2)	$\boxed{100(3-4)}$	33(2)
Juncus maritimus	-	-	-	-	$\boxed{100(3-5)}$
character-taxa Asteretea tripolii and Glauco-Puccinellietalia					
Aster tripolium	$\boxed{100(3-5)}$	46(+-2)	63(+-2)	71(+-1)	33(+)
Spergularia media	-	8(2)	25(+-2)	14(+)	33(+)
Triglochin maritima	-	15(2)	13(+)	43(+-1)	-
Plantago maritima	-	8(1)	-	14(2)	33(+)
character-taxa Puccinellion maritimae, Thero-Salicornion and Suaedetum maritimae					
Puccinellia maritima	100(1-2)	15(1-2)	38(+-3)	$\boxed{71(2-3)}$	-
Halimione portulacoides	-	8(2)	13(+)	-	33(+)
Suaeda maritima	-	8(1)	25(1)	-	33(+)
Salicornia brachystachya	-	31(+-2)	38(+-2)	-	-
Salicornia stricta	17(1)	8(1)	-	-	-
character-combination Armerion maritimae					
Festuca rubra	-	8(3)	38(+-2)	43(2)	100(2)
Armeria maritima	-	-	-	14(+)	33(+)
Juncus gerardii	-	-	-	29(1-2)	-
Glaux maritima	-	-	-	-	67(1)
taxa Agropyro-Rumicion crispi					
Elymus repens (= Agropyron repens)	-	8(1)	25(+-2)	14(2)	-
Alopecurus geniculatus	-	-	13(1)	29(+-1)	-
Leontodon autumnalis	-	-	-	57(+-2)	-
Taraxacum vulgare	-	-	-	29(+)	-
Potentilla anserina	-	-	-	-	33(+)
Carex distans	-	-	-	-	33(+)
other taxa					
Atriplex hastata	50(+-1)	38(+-2)	63(+-2)	43(+)	67(1-2)
Spartina anglica	83(+-2)	15(+-2)	-	-	-
Polygonum aviculare	-	8(+)	13(+)	-	-
Ranunculus scelleratus	-	-	-	43(+-1)	-
Cochlearia anglica	-	-	13(+)	-	33(+)
Spergularia marina	-	-	-	14(+)	33(+)
Oenanthe lachenelii	-	-	-	-	33(1)

Addenda Bi: Limonium vulgare 8(+), Elymus pycnanthus (= Agropyron pungens) 8(+); B: Festuca arundinaceae 13(2), Rumex crispus 13(+), Sonchus arvensis 13(1), Puccinellia distans 13(+); Bg: Trifolium fragiferum 14(1), Plantago major 14(+); Bm: Artemisia maritima 33(+)

1) see Table 19

portulacoides, which is considered as a variant of the Puccinellietum (Ph) here, because it is intermediary between the intensively grazed facies of *Puccinellia* (Pp) and the lightly grazed or ungrazed Halimionetum (H).

On clayish salt marshes the variant with *Aster tripolium* (Pas) will develop out of *Puccinellia*-graslands in absence of grazing or a few years after grazing has been stopped (successive mapping Lauwerpolder in Groningen). It should not be confused with the *Aster tripolium*-sociation, which occurs in estuaries as a pioneer community on bare mud.

Heavy grazing in the lower marsh zone leads to impoverishment of the vegetation diversity with only a facies of *Puccinellia maritima* (Pp) left, in which subdominance of *Salicornia* is a regression phenomenon. So the diversity in this zone is greatest with light grazing, causing differentiation of the vegetation according to geomorphological patterns in drainage and soil composition (fig. 43).

6.3.7.3 Communities of high salt marshes (Table 20)
With further silting up above mean spring tide level *Puccinellia maritima* is gradually replaced by *Festuca rubra*, in a later stage accompanied by *Agrostis stolonifera* and/or *Juncus gerardii*. The *Halimione portulacoides*-dominated communities are succeeded by the Artemisietum maritimae association on the same well-drained habitats (on a clayish soil, dependant on grazing intensity F, Ft and Fe; Fa on a more sandy soil). The community with dominance of *Artemisia maritima* (Ft) has been considered as a facies and not as an initial phase as in Beeftink's classification (1965): the facies of *Artemisia* (Ft) occurs on less grazed marshes in comparison with the typical form (F). Because of the great floristic similarity (Table 20) the facies with *Elymus pycnanthus* (=*Agropyron pungens*) (Fe) is included in the Artemisietum maritimae according to Feekes (1950).

The *Limonium vulgare* variant of the Puccinellietum (Pl) is succeeded by a variant of the Juncetum gerardii (Al) on both grazed and ungrazed salt marshes (50% of the relevés of type Al were moderately to heavily grazed) without artificial drainage, mainly on the Halligen and dune islands. Formerly this distinction was also made by Warming (1906) and Beeftink (1962). In later classifications of Beeftink (1965) and Westhoff & Den Held (1969) *Limonium vulgare* plays a part only within the Puccinellion, where it should develop without grazing.

On many grazed salt marshes closed Juncetum gerardii grasslands develop, either with the character species *Armeria maritima* (A, mainly on dune-islands, Halligen and in a narrow zone on both sides of cliffs of terraced mainland salt marshes) or without this species (J). Because of dominance of certain grass species, variants with *Festuca rubra* and *Juncus gerardii* (Aj and Jj, often on natural or less drained salt marshes) and variants with *Festuca rubra* and *Agrostis stolonifera* (Ag and Jg, mainly on artificial salt marshes) are distinguished. However, the ecological differences between the variants are not always clear. Apart from this division of the Juncetum gerardii the relevés could have been subdivided into an initial phase with halophytic taxa and a terminal phase accompanied by taxa of the Agropyro-Rumicion crispi

(Raabe, 1950).

On high salt marshes grazing has the reverse effect when compared with lower marshes: the diversity of vegetation is greater with moderate grazing (fig. 43). With light or no grazing communities of tall herbs dominated by *Artemisia maritima* (Ft), *Elymus pycnanthus* (=*Agropyron pungens*; Fe) or *Phragmites australis* will develop (the latter only where fresh water seeps from bordering sand-dune or Pleistocene areas).

6.3.7.4 Communities of the highest salt marshes and summer-polders (Tables 21 and 22)

With silting up to the storm-flood zone the halophytic species are gradually replaced by non-halophytic species of the Agropyro-Rumicion alliance. Construction of summer-dikes leads to the same communities more suddenly.

On the most intensively grazed and fertilized marshes along the mainland, in estuaries and on the Halligen the Poo-Lolietum (Ru) develops. The Poo-Lolietum also contains taxa of the Lolio-Cynosuretum, in which it is classified by many authors. Inside the sea-dikes the Poo-Lolietum occurs on heavily grazed and fertilized cultivated grasslands. Due to modern agricultural methods it has expanded strongly during the last decades. It is remarkable that on the highest salt marshes and in summer-polders the Poo-Lolietum is found under more natural circumstances (although agriculture has influenced the floristic compostion). The resemblance consists of the unstable environmental conditions in both areas. The Poo-Lolietum has not been found on the Danish salt marshes. On less grazed or on mowed sites the Agropyretum repentis maritimum (Re) or the Potentillo-Festucetum arundinaceae (Rr) are found. The latter especially in estuaries.

With light or without grazing a rough vegetation poor in species and dominated by *Elymus* (=*Agropyron*) *repens* (Re) will develop on these marshes (fig. 43). In estuaries a development to *Phragmites australis*-reed (B) may occur (Dollard near Nieuw Statenzijl). On the highest marshes it may play a part that, according to Christiansen (1937), Westhoff (1969), Schmeisky (1974) and Gray & Scott (1977), ungrazed areas get overgrown with a vegetation of higher, less saline zones as compared with grazed areas of the same level.

Species-rich grasslands with *Ononis spinosa* (Ro), which are characteristic for the dune-islands, are found on the few mainland sandy sites (Eiderstedt near St. Peter-Böhl and Nackhörn (Menke, 1969) and the Pleistocene to salt-marsh transition near Schobüll). The *Juncus maritimus-Oenanthe lachenalli* association (Bm) prefers moist sites in the same sandy areas (Eiderstedt; Raabe, 1970). The proposal of Adam (1977) to include the *Juncus maritimus-Oenanthe lachemalli* association in the Armerion maritimae has been followed. Without grazing rough communities poor in species and dominated by *Elymus pycnanthus* (= *Agropyron pungens*), including hybrids (Bakker in chapter 8.3) or *Phragmites australis* may develop.

6.3.7.5 Communities of brackish habitats (Table 22)

In estuarine salt marshes soil salinity varies in two gradients (chapter 6.3.6). In the brackish Dollard the resulting pattern of vegetation has been developed particularly well. In fig. 44 the pattern has been arranged along these salinity gradients. In the α-mesohaline part the *Aster tripolium*-sociation (Bas) acts as a pioneer community on bare mud. It can be distinguished from the *Aster*-variant of the Puccinellietum (Pas) by a coverage of *Aster* of more then 50%, whereas *Puccinellia maritima* just begins to settle. *Aster tripolium* grows in the sociation in its most optimal and vital way and may form stands of up to 250 cm in height. Seawards this pioneer zone passes into a Spartinetum (S), upstream first into a Halo-Scirpetum maritimi (Bi) and then into the *Phragmites australis* community (B). Above mean high tide level and with grazing halophytic grasslands follow, inwhich upstream species of the higher marsh shift towards low marsh levels, and form the *Agrostis stolonifera*-sociation (Bg). This brackish communities are characterized by halophytic character taxa of the higher syntaxa Asteretea tripolii and Glauco-Puccinellietalia and cannot be classified in one of its alliances.

Further silting up will lead to higher marsh communities (6.3.7.4).

6.3.8 Local patterns and distribution of mainland salt marshes and Halligen

6.3.8.1 Phytogeography

Phytogeographically the salt marshes of the Danish, German and Dutch Wadden Sea form a homogeneous area. A major phytogeographic boundary occurs north of Skallingen and corresponds with the northern extension of the Wadden Sea. At that place the Spartinetum townsendii, Halimionetum portulacoidis and Artemisietum maritimae reach their northern distributional limits (Beeftink, 1977). The *Juncus maritimus* community reaches its northern limit within the Danish Wadden Sea on the island of Rømø (Raabe, 1970). The Poo-Lolietum is not indigenously found on the Danish salt marshes. On salt marshes of the Wadden Sea no Mediterranean communities are found.

6.3.8.2 Terraced salt marshes

Since terraced salt marshes develop under wave-exposed conditions, they are the original type of salt marsh along the mainland coast. Nowadays this type is mostly restricted to older and higher salt marshes and summer-polders, extending along the mainland coast in a zone outside the dikes and often bordered by sedimentation fields at the seawards side. On the 1:100,000 map they are mostly recognizable by an erosion cliff, surrounding the types T1 and (part of) Sf. The development of terraced salt marshes was often stimulated by cutting drainage furrows (farmers' method). Old terraced salt marshes and summer-polders are found (see 1:100,000 map) in the Ho Bugt, along the Danish mainland between Darum and Ballum (fig. 46 and 47) and near Højer, in Schleswig-Holstein only north of Dagebüll and near Neufeld, from the Elbe-estuary to the Weser-estuary (fig. 51), along the East-Frisian mainland (fig. 52, 55, 56), locally in the Dollard (Dijksterhusen and Punt van Reide) , along the Dutch Groningen coast

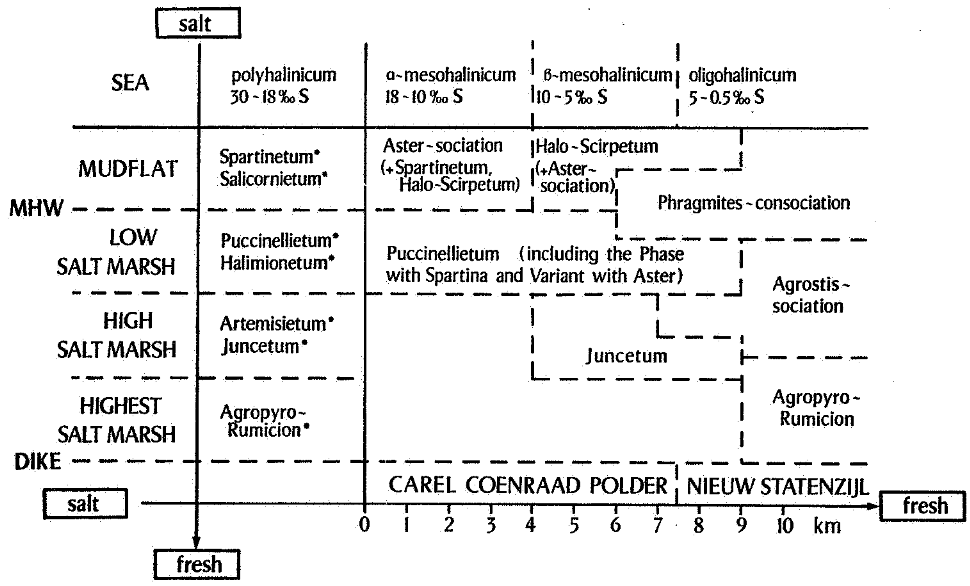

Fig. 44. The pattern of communities in the SW-Dollard, the Netherlands, arranged schematically according to the two gradients in salinity perpendicular to each other. * = this zone does not occur.

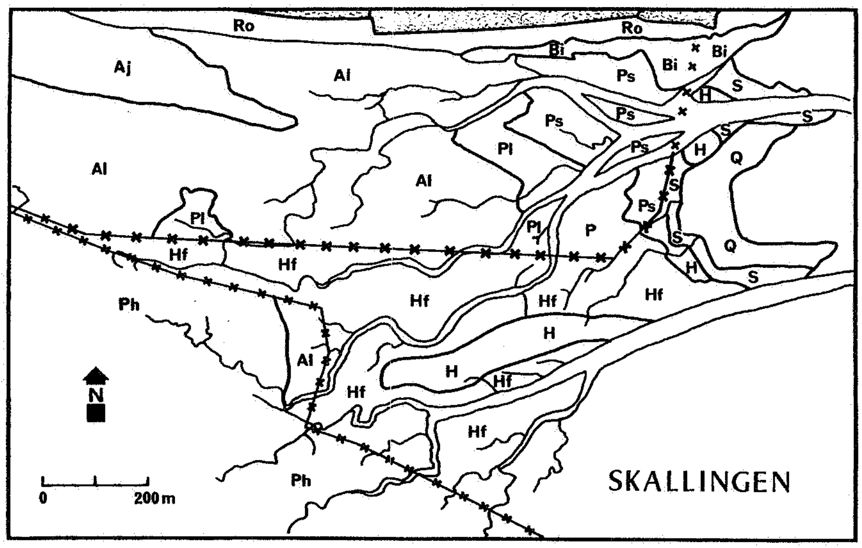

Fig. 45. Skallingen, Denmark. Natural salt marsh, developed on a sandy beach plain after construction of a sand-dike at the seawards side. The fence divides the mapped area in a central ungrazed part (H, Hf) and grazed parts north and south of it (Ps, Pl, Ph, Al, Aj, Ro). For explanation of legend units see p.197; other features p.209.

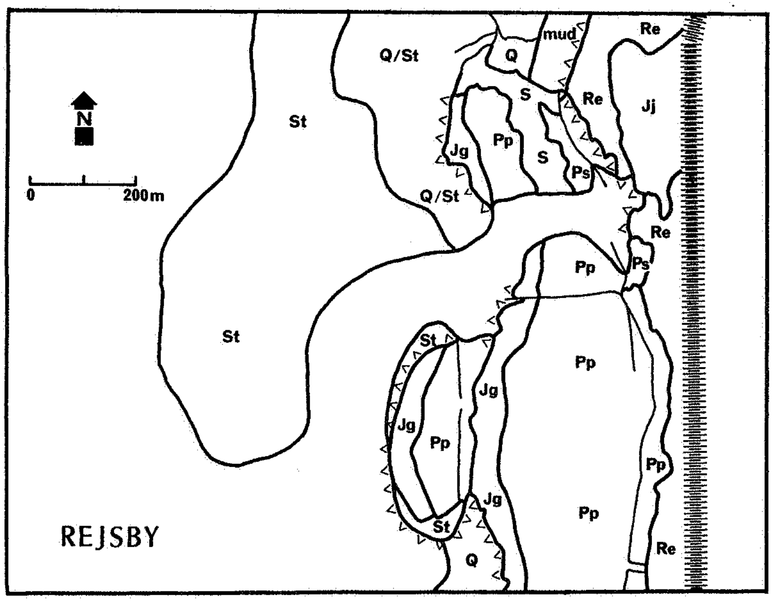

Fig. 46. Rejsby. Danish type of terraced salt marsh with an overgrown sand bar (St, Q) in front of it, successive terraces with erosion cliffs and back swamps with landpriels (cf. the profile of fig. 39). The salt marsh has a neglected system of drainage furrows and is grazed. The Festuca-Agrostis (Jg) and Puccinellia grasslands (Pp) are typical for mainland salt marshes. In a less drained back swamp Juncus gerardii (Jj) dominates.

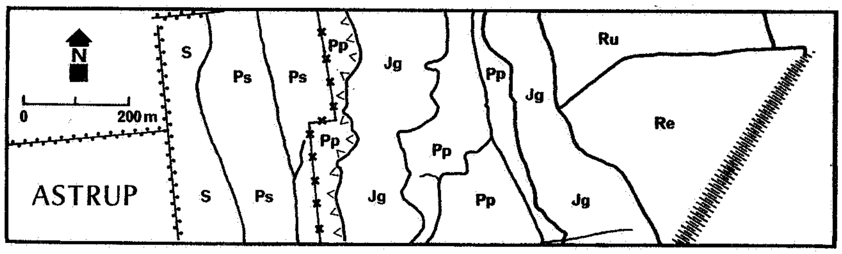

Fig. 47. Astrup. Danish type of terraced salt marsh with drained sedimentation fields (S, Ps, Pp) in front of it. On the landwards side of the fence grazing causes the transition from Spartina (Ps) to Puccinellia (Pp). The difference between the Lolium (Ru) and Elymus (= A- (= Agropyron) repens (Re) grassland (both occurring on a slope towards the geest) is due to a more intensive agricultural management (also ploughing and sowing?) of the first one.

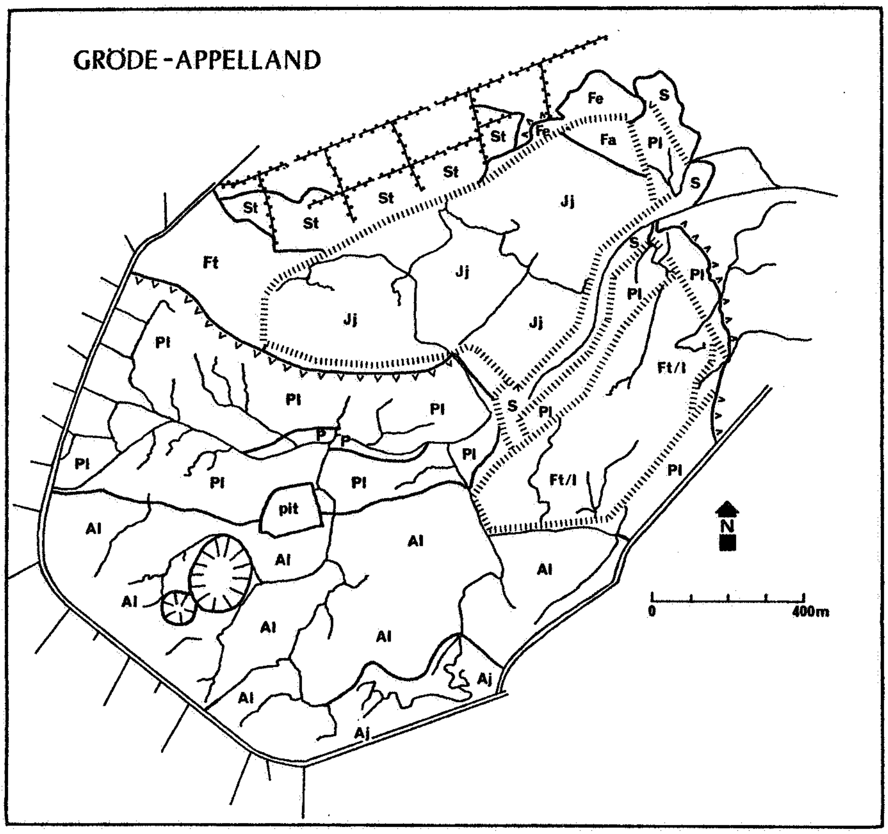

Fig. 48. Gröde-Appelland, Germany. Double-Hallig; the parts have been connected by a stone revetment, after which the intermediate area has been overgrown (Pl). The northern shore is protected by sedimentation fields. On Appelland (northern Hallig) there is a summer-polder with low dikes for hay-making (Jj), the remaining part is ungrazed and dominated by Artemisia maritima (Ft) or Elymus pycnanthus (= Agropyron pungens) (Fe). Gröde (southern Hallig) is grazed and the community with Limonium vulgare and Armeria maritima (Al) is typical for the Halligen.

(fig. 57, 58) and along the Dutch Frisian coast (fig. 59). The Schorren on Texel (fig. 60) and the "Vorland" near Oldsum on Föhr can be considered as naturally developed examples of terraced salt marshes. Within their terraced structure a well developed pattern of creek levees and basins with corresponding communities occurs.

In recent years many terraced marshes have been lost by embankments, especially in Schleswig-Holstein and Denmark south of Højer. Recent terrace building occurs along the Danish coast between Rejsby and Darum. These salt marshes have a typical Danish form with pioneer growth starting on the leeside of sand bars and they are characterized

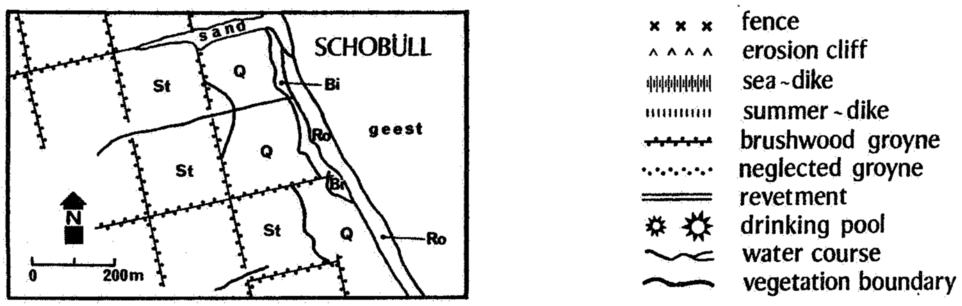

Fig. 49. Schobüll, Germany. Sedimentation fields bordering on a Pleistocene (geest) area. The fields without drainage furrows are overgrown with some Spartina tussocks (St), the drained fields with Salicornia (Q). Due to fresh water seeping from the adjacent geest area the zone close to the geest is covered by Scirpus maritimus (Bi). The vegetation of the sandy Ro-zone is similar to that of transitions to dunes.

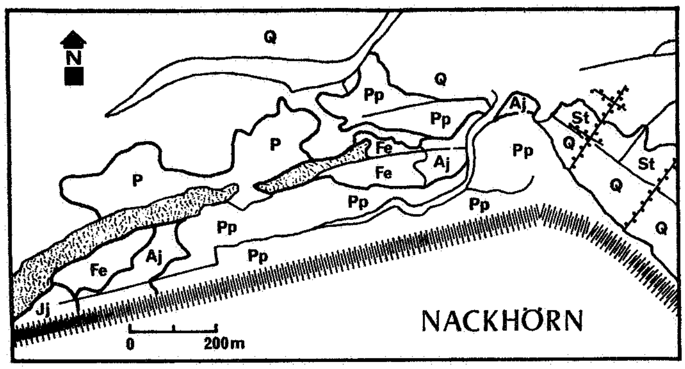

Fig. 50. Nackhörn, Germany. Sandy salt marsh, grazed and with an artificial drainage system. At the seawards side of the low yellow dunes Puccinellia pioneers on the wandering sand (P). The community with Armeria maritima (Aj) is common on sandy salt marshes.

by a "land priel" (fig. 38, 39, 46). Plant growth on the bars starts with scattered tussocks of *Spartina anglica* (St) and with a Salicornietum strictae (Q).

The terraced mainland salt marshes are mainly situated on a level where communities of the Juncetum gerardii and Agropyro-Rumicion crispi occur. On the mainland salt marshes the Juncetum gerardii is mainly represented by the subassociation without *Armeria maritima*: mostly the variant with *Agrostis stolonifera* and *Festuca rubra* (Jg) occurs and to a smaller extent the variant with *Juncus gerardii* (Jj). The latter often develops in less drained back swamps (fig. 46, 52), but

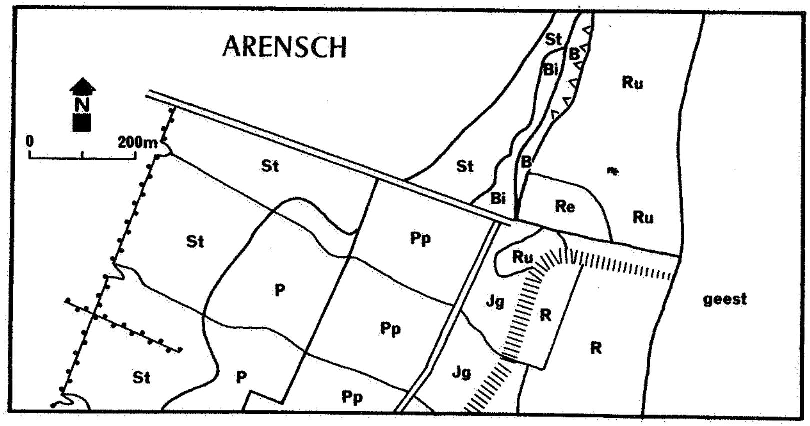

Fig. 51. Arensch, Germany. Natural terraced salt marsh, mainly clayish. The terrace has silted up very highly (MHW + 1.5 m) and the vegetation resembles that of inland pastures (Ru, Re). At the seawards side of the erosion cliff a brackish zone with Phragmites australis (B) and Scirpus maritimus (Bi) is found, due to fresh water seeping from the adjacent geest area. The southern part has summer-dikes, the cliff is fixed by a revetment and, in front of it, sedimentation fields with drainage furrows occur. The northern part is used for hay-making, the southern part for grazing.

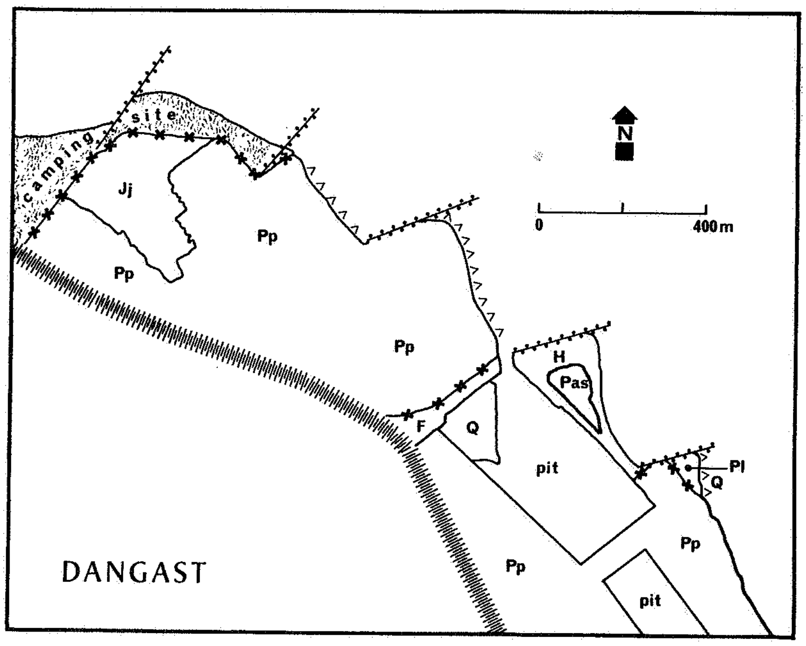

Fig. 52. Dangast, Germany. Terraced clayish salt marsh with small drainage furrows. The bad drainage favours Triglochin maritima and Limonium vulgare, but due to too intensive grazing by cattle regression with subdomination of Salicornia (Pp) takes place. At the seawards side of a clay pit some ungrazed areas occur (Pl, Pas, H).

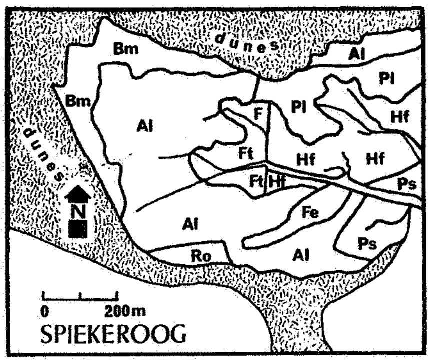

Fig. 53. Spiekeroog, Germany. Natural and sandy salt marsh with creek bank levees and basins. Hardly any grazing (horses). On the creek bank levees the vegetation is comparable with that of well drained and ungrazed mainland salt marshes (Hf, Ft); the community with Limonium vulgare (Pl, Al) is restricted to the less drained areas and is typical for the sand-dune islands.

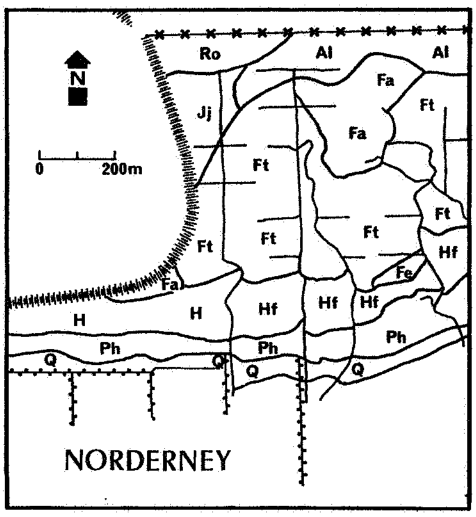

Fig. 54. Norderney, Germany. Sandy salt marsh with an artificial drainage system and light grazing. The eastern part has been developed naturally in the shelter of dunes. The western part along the dike has been developed with the help of sedimentation fields. The drainage system favours communities of creek levees with Halimione portulacoides (Ph, H, Hf) and Artemisia maritima (Ft, Fa) at the cost of Limonium vulgare (which occur there in Fa).

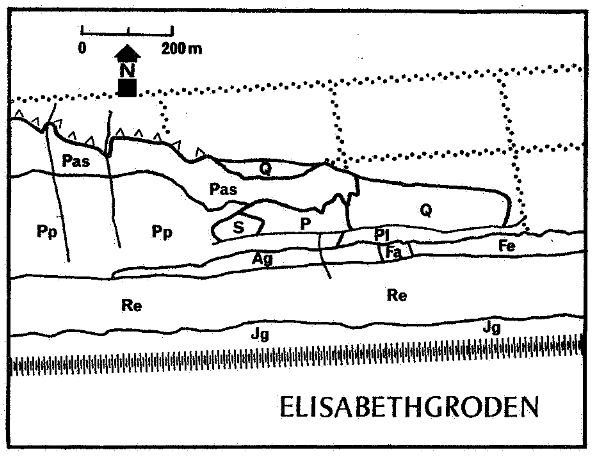

Fig. 55. Elisabethgroden, Germany. Narrow band of old terraced salt marsh along the dike (Jg, Re; used for hay-making) and a younger artificial, terraced salt marsh in the neglected sedimentation fields (ungrazed). The lack of grazing favours Aster tripolium (in Pp and Pas), which species is typical for the clayish mainland salt marshes.

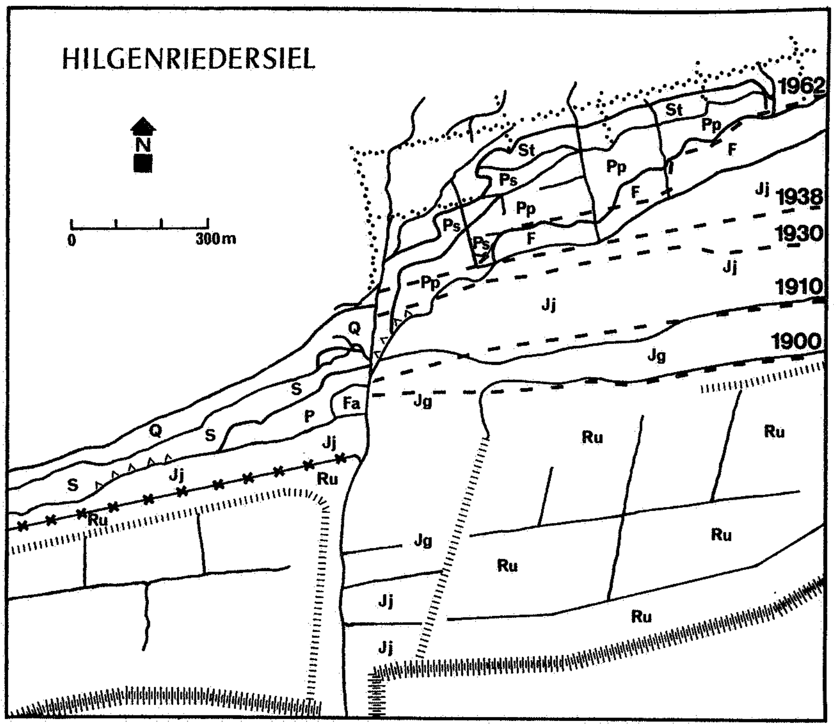

Fig. 56. Hilgenriedersiel, Germany. Eastern part: clayish artificial salt marsh with a loamy terrace in the central zone around the summer-dike; the accretion due to sedimentation fields and drainage furrows is indicated on the map; nowadays the upkeep of the sedimentation fields is neglected and in the outer zone erosion takes place. Rather heavily grazed with cattle. Western part: the artificially expanded salt marsh created on its western side a level favourable for natural salt marsh development; in recent years the natural and loamy salt marsh has been artificially drained, after which Limonium vulgare has decreased (cf. Heykena, 1967). Lightly grazed. - - - = foreland edge in former years (after Bauamt für Küstenschutz, Norden).

the environmental differences with the *Festuca-Agrostis* grasslands are not always clear (e.g. fig. 56). The communities of the Juncetum gerardii with *Armeria* (Aj, Ag) occur little along the mainland, especially on sandy parts (fig. 50) or in a narrow band along cliffs (fig. 46, 55). On the highest salt marshes and summer-polders along the whole mainland the Agropyro-Rumicion crispi is represented by the Agropyretum repentis maritimum (Re), the Poo-Lolietum (Ru; not on Danish salt marshes) and sometimes the Potentillo-Festucetum arundinaceae (Rr; e.g. near Arensch, Otterndorf and Elisabethgroden).

6.3.8.3 Sheltered mainland salt marshes

Most mainland salt marshes have an increasing height in landward

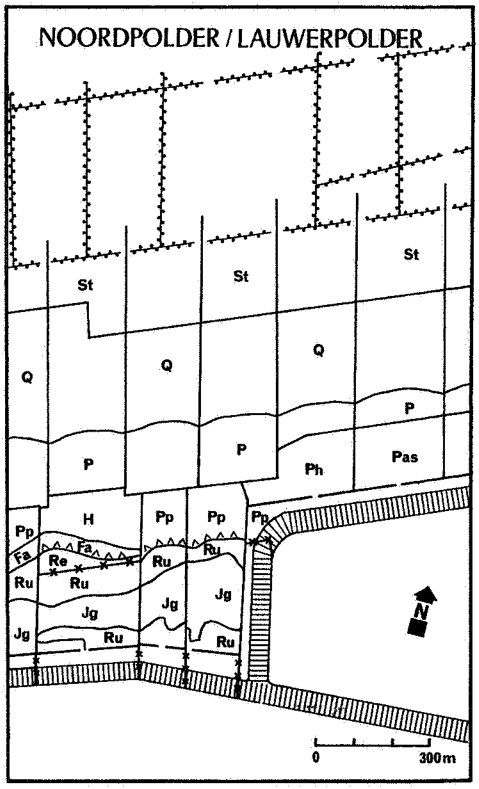

Fig. 57. Noordpolder/Lauwerpolder, the Netherlands. Old terraced clayish salt marsh with a drained artificial salt marsh (loam) in front of it (cf. the profile of fig. 41). Outside the fence in the western part Elymus (= Agropyron) repens (Re) dominates on the high sandy terrace and Halimione portulacoides (H) on the low and artificially drained salt marsh. The eastern low salt marsh is ungrazed as well and is characterized by Halimione (Ph) and Aster tripolium (Pas).

direction. This is the original type in sheltered bights (western parts of the Dollard and Jadebusen). They are artificially formed in salt marshes created with help of sedimentation fields. On the 1:100,000 map it can be seen that the so calles "land reclamation works" extend directly outside the mainland dikes or outside a zone of old terraced salt marshes between Ribe, Denmark and Zwarte Haan, the Netherlands and along connecting dams to Mandø, Rømø, Hamburger Hallig and Nordstrand. (More modestly they occur on some Halligen, most East-Frisian islands and on Mandø, Amrum, Pellworm and Nordstrand). Actually, they form the majority of the Wadden Sea salt marshes. Land reclamation areas may have a sheltering influence on the near-by coastal parts, resulting in natural, stable or extending salt marshes (e.g. west of Zwarte Haan and Hilgenriedersiel, fig. 56, and east of Nessmersiel and Westaccumersiel).

Nowadays the upkeep of drainage furrows and sedimentation fields has often been diminished and sometimes neglected (fig. 55, 56), because of a change in the aim of the works from reclaming new land to stabilization of the artificial salt marsh for coastal protection (Dijkema in chapter 8.5). Examples of sedimentation fields are shown in fig. 47, 48, 49, 50, 51, 54, 55, 56, 57, 58 and 59. Particularly in fig. 56 (Hilgenriedersiel) the effect of land reclamation works on the landscape is shown clearly: due to these works the salt marsh

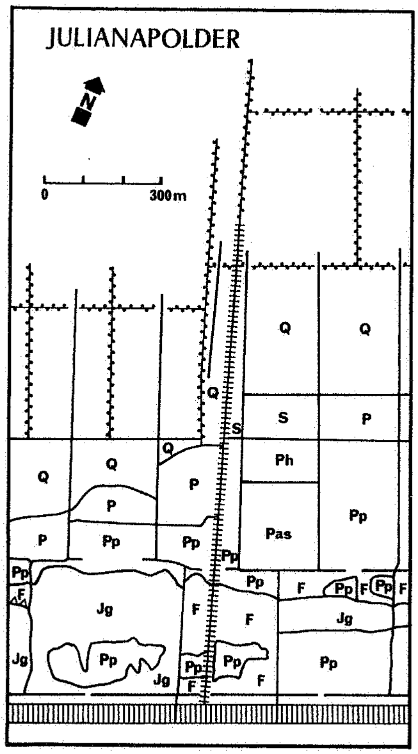

Fig. 58. Julianapolder, the Netherlands. Terraced clayish salt marsh with a drained artificial salt marsh (clay-loam) in front of it. The Puccinellia islands (Pp) in the terraced salt marsh are the remains of old clay pits. An ungrazed field is characterized by Halimione portulacoides (Ph) and Aster tripolium (Pas).

in the eastern part of the mapped area extended considerably but after the works were stopped in 1961 (pers. comm. Bauamt für Küstenschutz, Norden) erosion takes place in the outer zone of the marsh (cf. König, 1949; Forschungsstelle, 1973).

Along the mainland the communities of the mud flats, low salt marshes and of a part of the high salt marshes largely occur on these artificial sites. The distribution of the communities is determined by the level of the marsh, the salinity of the submerging water, the intensity of the artificial drainage, the grazing- or mowing management and the soil characteristics (fig. 43 and 44). These factors vary in space in such a way, that most communities can be found. The pioneer communities (S, Q) and the initial phases of the Puccinellietum (Ps, P) are common throughout the entire area, except for eroded salt marshes. Generally, communities of well-drained areas (compare fig. 53 with 54) are favoured (communities with *Halimione portulacoides*, and *Artemisia maritima*; Ph, H, Hf, Ft). For that reason and probably as a result of the more clayish soil the variants with *Limonium vulgare* of the Puccinellietum (Pl) and of the Juncetum gerardii (Al) are very rare along the mainland coast (fig. 52, 55, 56). The variant with *Aster tripolium* (Pas) is restricted to ungrazed mainland salt marshes with a clayish soil (fig. 55, 57, 58). Heavy grazing often causes the development of the Facies of *Puccinellia maritima* (Pp) or *Festuca rubra-Agrostis stolonifera*-grasslands (Jg) (fig. 46, 47, 50,

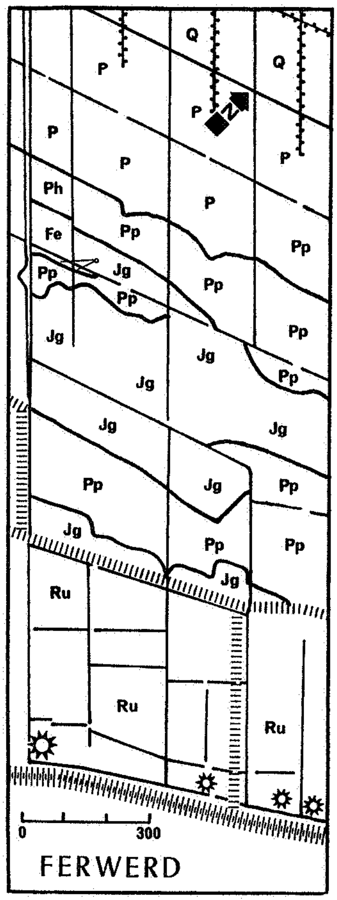

Fig. 59. Ferwerd, the Netherlands. Summer-polder with drinking pools and a terraced, artificial salt marsh in front of it. The greater part is grazed, except for a small part to the west (Fe, Ph). The loamy terrace is indicated by a high salt marsh community (Jg). It has no erosion cliff because of further accretion in front of it (sedimentation fields with drainage furrows).

51, 52, 56, 57, 58 and 59). Along the Dutch Frisian and Schleswig-Holstein coasts ungrazed or lightly grazed sites are hardly found. The Dutch Groningen coast, on the contrary, has a very diverse halophytic vegetation due to a great spatial variation in grazing management by a large number of local farmers (Dijkema, 1975).

6.3.8.4 Estuaries and other brackis habitats

For the vegetation on estuarine salt marshes is referred to "Communities of brackish habitats" in chapter 6.3.7.5 and to fig. 44. Reed marshes with *Scirpus maritimus* (Bi) and *Phragmites australis* (B) are restricted to brackish and tidal freshwater parts in the estuaries Varde Aa, Eider, Elbe, Weser and Ems-Dollard, near sluices (e.g. Høјer, Ballum), in places where fresh water seeps from adjacent dune or Pleistocene areas (Amrum near Norddorf, Schobüll, SW-Eiderstedt, Arensch) and in drinking pools (e.g. Friesland between Holwerd and Zwarte Haan). The *Agrostis stolonifera salina*-sociation (Bg) is only known from the β-mesohaline and oligohaline parts of the estuaries Varde Aa, Eider (König, 1957b), Elbe near Neufeld (Raabe & Usinger,

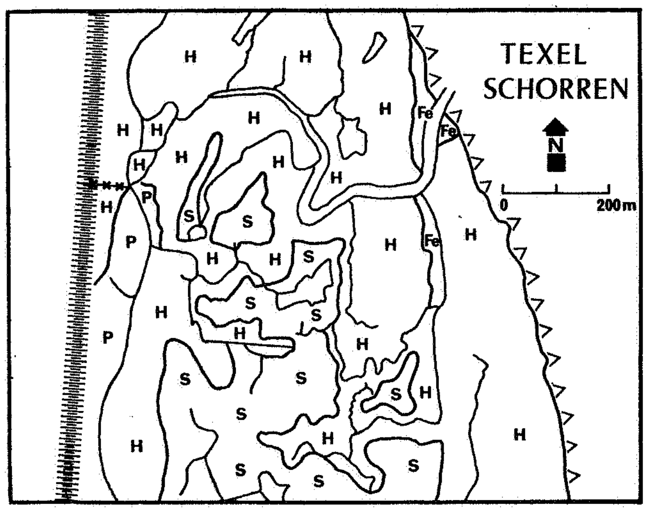

Fig. 60. Texel - Schorren, the Netherlands. Unspoiled natural salt marsh, at the exposed seawards side with terrace building (height about 70 cm + MHW) and a small erosion cliff. In former years this exposed side should have been protected by a sand bar. Within the terraced structure a well developed pattern of creek levees and basins with corresponding communities occurs. The terrace is dominated by Elymus pycnanthus (= Agropyron pungens) (Fe) and the creek bank levees by Halimione portulacoides (H). Higher creek bank levees have an Artemisia maritima vegetation (Hf, Ft; not mapped). The clayish basins are dominated by Spartina anglica (S). Between the creek levees and basins Limonium vulgare may occur. This salt marsh can be considered as a natural example of mainland salt marshes.

1969) and Dollard (Fresco, 1966). The *Aster tripolium*-sociation is only known from one site: the (α-) mesohaline part of the SW-Dollard (Fresco, 1966) and in former years in the Jadebusen and the Leybucht (Forschungsstelle, 1973). The absence of the *Aster*-sociation in other estuaries, considering the α-mesohaline parts, may be due to their less sheltered position (and less favourable soil conditions) and the construction of revetments. Communities with *Halimione portulacoides* or *Limonium vulgare* are missing in estuaries. Most estuarine salt marshes are used for moderate to heavy grazing or hay-making. In the German part of the Dollard, the Weser and the south bank of the Elbe stone revetments have been built (see 1:100,000 map).

6.3.8.5 Halligen

Halligen are small salt-marsh islands with a morphology and vegetation intermediate between mainland and dune-island salt marshes. In the North-Frisian Wadden Sea they include Hooge, Norderoog, Süderoog, Langeness, Oland, Gröde, Habel, Hamburger Hallig, Nordstrandischmoor and Südfall. Further Jordsand (Denmark), Helmsand and Neuwerk (near the Elbe mouth) and Griend (the Netherlands) can be considered as

"Halligen". All Halligen have been reduced in surface by erosion. Nowadays, they are mostly defended by stone revetments, on the relatively sheltered parts by sedimentation fields and in the case of Griend by an artificial sand ridge.

The vegetation of the Halligen corresponds with the scheme of fig. 43. For the major part the Halligen consist of natural salt marsh, including well- and less-drained habitats. Characteristic are higher salt-marsh communities with *Limonium vulgare* (Al) and *Armeria maritima* and *Juncus gerardii* (Aj and Jj) (König, 1957a). The halophitic communities suffered from intensive land use (decreasing of *Limonium vulgare*) and construction of summer-dikes (development of Agropyro-Rumicion crispi-pastures on Hooge and parts of Oland and Langeness). The most splendid examples of Halligen are Gröde (fig. 48: with "Allmende" = open range grazing, and a small summer-polder for haymaking), Nordstrandischmoor and some of the smaller ones.

References

Adam, P., 1977. On the phytosociological status of Juncus maritimus on British salt marshes. Vegetatio 35: p. 81-94.

Anonymus, 1975. Noord-Friesland Buitendijks. Landelijke Vereniging tot Behoud van de Waddenzee, Harlingen.

Beeftink, W.G., 1959. Some notes on Skallingens saltmarsh vegetation and its habitat. Acta Bot. Neerl. 8: p. 449-472.

Beeftink, W.G., 1962. Conspectus of the phanerogamic salt plant communities in the Netherlands. Biol. Jaarboek Dodonaea 30: 325-362

Beeftink, W.G., 1965. De zoutvegetatie van Z.W.-Nederland, beschouwd in Europees verband. Med. Landbouwhogeschool Wageningen 65-1: 167 pp.

Beeftink, W.G., 1966. Vegetation and habitat of the salt marshes and beach plains in the South-Western part of the Netherlands. Wentia 15: p. 84-109.

Beeftink, W.G., 1968. Die Systematik der europaischen Salzpflanzengesellschaften. In: R. Tüxen (ed.). Pflanzensoziologische Systematik. Junk, The Hague: p. 239-272.

Beeftink, W.G., 1977a. The coastal salt marshes of western and northern Europe: an ecological and phytosociological approach. In: V.J. Chapman (ed.). Wet Coastal Ecosystems. Elsevier, Amsterdam: p. 109-155.

Beeftink, W.G., 1977b. Salt marshes. In: R.S.K. Barnes (ed.). Handbook on the applied ecology and management of the coastline. Wiley, Chicester: p. 93-121.

Bracker, H.H., 1978. "Greed"-Grasnarben vor den Deichen. Nord-Friesland 45/46: p. 27-34.

Christiansen, W., 1937. Beobachtungen an Dauerquadraten auf der Lotseninsel Schleimunde. Schr. Naturwiss. Ver. Schleswig-Holstein 12: p. 69-84.

Dircksen, J., 1968. Die wichtigsten Pflanzen - Gesellschaften der Insel Trischen. Natur und Heimat 28: p. 184-190.

Dijkema, K.S., 1975. Vegetatie en beheer van kwelders en landaan-

winningswerken aan de waddenzeekust van Noord-Groningen. Med. Werkgroep Waddengebied 2: 49 pp.
Eerde, L.A.AE. van, 1942. De landaanwinning van het Noorderleegs Buitenveld. T.N.A.G. reeks 2, 59: p. 1-23.
Ellenberg, H., 1956. Aufgaben und Methoden der Vegetationskunde. Stuttgart, Ulmer: 136 pp.
Feekes, W., 1950. Bouw en plantengroei. In: G.A. Brouwer e.a. Griend, het vogeleiland in de Waddenzee. Martinus Nijhoff, 's-Gravenhage: p. 82-187.
Fresco, L.F.M., 1966. De slikken en kwelder van de Dollart. Vegetatie en landschap. Lab. v. Plantenoec., Haren, Rapport: 44 pp.
Forschungsstelle Norderney, 1973. Zur Ausbreitung und Gesellschaftsbildung von Spartina townsendii an der ostfriesischen Küste. Forschungsstelle Norderney, Jahresbericht 1972, Band 24: p. 219-239.
Glopper, R.J. de, 1967. Over de bodemgesteldheid van het Waddengebied, Van zee tot land 43. Willink, Zwolle: 67 pp.
Gray, A.J. & R. Scott, 1977. The ecology of Morecambe Bay. VII. The distribution of Pucinellia maritima, Festuca rubra and Agrostis stolonifera in the salt marshes. J. Appl. Ecol. 14: p. 229-241.
Hartog, C. den, 1958. De vegetatie van het Balgzand en de oeverterreinen van het Balgkanaal. Wetensch. Med. K.N.N.V. 27: 28 pp.
Heykena, A., 1970. Die Vegetation des Vorlandes bei Hilgenriedersiel. Forschungsstelle Norderney, Jahresbericht 1968, Band 20: p. 87-104.
Hoek, C. van den, et al., 1979. The role of algae and seagrasses in the ecosystem of the Wadden Sea: a review. In: W.J. Wolff (ed.). Flora and vegetation of the Wadden Sea. Report 3 of the Wadden Sea Working Group. Balkema, Rotterdam: p. 8-118.
Iversen, J., 1953. The zonation of the salt marsh vegetation of Skallingen in 1931-1934 and in 1952. Geogr. Tidsskr. 52: p. 113-118.
Jakobsen, B., 1954. The tidal area in South-Western Jutland and the process of the salt marsh formation. Geogr. Tidsskr. 53: p. 119-141.
Jakobsen, B., 1964. Vadehavest morfologi. En geografisk analyse af vadelandskabets formuvikling met saerlig hensyntagen til Juvre Dybs Tidevansomraade. Folia Geogr. Dan. 11: p. 1-176.
Jakobsen, B. & K.M. Jensen, 1956. Undersøgelser verdrørende landvindingsmetoder i Det Danske Vadehave. Resume paa engelsk. Geogr. Tiddsskr. 55: p. 21-61.
Kamps, L.F., 1962. Mud distribution and land reclamation in the eastern wadden shallows. Rijkswaterstaat comm. 4, Den Haag: 73 pp.
Klement, O., 1953. Die Vegetation der Nordseeinsel Wangerooge. Veröff. Inst. Meeresforschung Bremerhaven 2: p. 279-379.
König, D., 1948. Spartina townsendii an der Westküste von Schleswig-Holstein. Planta 36: p. 34-70.
König, D., 1949. Gefährdetes Neuland an der schleswig-holsteinischen Westküste bei Husum. Umschau in Wissenschaft und Technik 49: p. 243-245.
König, D., 1957a. Die Pflanzenwelt von Norderoog. In: Fünfzig Jahre Seevogelschutz. Verein Jordsand, Hamburg: p. 113-124.

König, D., 1957b. Einige ökoligsche Bemerkungen über das Eiderwatt. Deutsche gewässerkundliche Mitteilungen 1: p. 87-91.

König, D., 1960. Beitrage zur Kenntnis der deutschen Salicornien. Mitt. der Flor. - soz. Arbeitgemeinschaft, N.F. Heft 8: p. 5-58.

Lafrenz, P., 1957. Ueber die Pflege und Nutzung des Anwachses und der Deiche an der Dithmarscher Küste. Die Küste 6: p. 94-129.

Meesenburg, H., 1971. Spartinas Kolonisation og udbredelse langs Ho Bugt. Geografisk Tidsskrift 71: p. 37-45.

Menke, B., 1969. Vegetationskundliche und vegetationsgeschichtliche Untersuchungen an Strandwällen. Mitt. Flor. - soz. Arbeitsgem. N.F. 14: p. 95-120.

Mikkelsen, V.M., 1949. Strandengene i Danmark og deres flora. Naturens Verden 1949: p. 290-308.

Møller, J.T., 1963. Vadehavet mellem Mandø og Ribe Å. Folia Geografica Danica 8: p. 1-40.

Olsen, H.A., 1959. The influence of the Rømø Dam on the sedimentation in the adjacent part of the danish Wadden Sea. Geogr. Tidsskr. 58, Guidebook Denmark Int. Geogr. Congres: p. 119-140.

Postma, H., 1954. Hydrography of the Dutch Wadden Sea. Archs. néerl. Zool. 10: p. 405-511.

Raabe, E.W., 1950. Ueber die Vegetationsverhältnisse der Insel Fehmarn. Mitt. Arbeitsgem. Flor. Schl.-Holstein und Hamburg 1: 106 pp.

Raabe, E.W., 1970. Die Wanderung von Juncus maritimus an der jutischen Westküste. Kieler Notizen 8: p. 9-11.

Raabe, E.W. & H. Usinger, 1969. Vegetation der Elbmündung vor Neufeld. Vegetation map, Landesstelle für Vegetationskunde, Kiel, not published.

Runge F., 1973. Die Pflanzengesellschaften Deutschlands. 4/5 Aufl., Verlag Aschendorff, Münster: 246 pp.

Schmeisky, H., 1974. Vegetationskundliche und ökoligsche Untersuchungen in Strandrasen des Graswarders vor Heiligenhafen/Ostsee. Thesis, Göttingen: 103 pp.

Schwabe, A., 1972. Vegetationsuntersuchungen in den Salzwiesen der Nordseeinsel Trischen. Abh. Landesmuseum Naturkunde Münster, Westfalen 34: p. 9-22.

Straaten, L.M.J.U. van & P.H. Kuenen, 1957. Accumulation of fine grained sediments in the Dutch Wadden Sea. Geol. Mijnbouw 19: p. 329-354.

Tüxen, R., 1937. Die Pflanzengesellschaften Nordwestdeutschlands. Mitt. Flor. soz. Arb. Gem. Niedersachsen 3: 170 pp.

Tüxen, R., 1955. Das System der Nordwestdeutschen Pflanzengesellschaften. Mitt. florist. - soz. Arb. Gem., N.F. 5: p. 155-176.

Tüxen, R., 1956. Vegetationskarte der Ostfriesischen Inseln: Baltrum. Bundesanstalt für Vegetationskartierung, Stolzenau (Weser).

Tüxen, R. et al., 1957. Die Pflanzengesellschaften des Aussendeichlandes von Neuwerk. Mitt. Flor. soz. Arb. Gem. N.F. 6/7: p. 205-234.

Verhoeven, B. & J. Akkerman, 1967. Buitendijkse mariene gronden, hun opbouw, bedijking en ontginning. Van Zee tot Land 45. Willink, Zwolle: 93 pp.

Vries, D.M. de, 1940. De plantengroei van de aanslibbingen in het noorden van Nederland. In: W. Feekes, A. Scheygrond & D.M. de Vries. Botanische landschapsstudies in Nederland. J.B. Wolters, Groningen: p. 47-100.

Warming, E., 1906. Dansk plantevaekst. 1. Strandvegetationen. Gyldendal: 325 pp.

Westhoff, V., 1947. The vegetation of dunes and salt marshes on the Dutch islands of Terschelling, Vlieland and Texel. Summary thesis: 131 pp.

Westhoff, V., 1969. Langjährige Beobachtungen an Aussüssungs-Dauerprobeflächen beweideter und unbeweideter Vegetation an der ehemaligen Zuiderzee. In: R. Tüxen (ed.). Experimentelle Pflanzensoziologie. Junk, Den Haag: p. 246-253.

Westhoff, V. & A.J. den Held, 1969. Plantengemeenschappen in Nederland. Thieme, Zutphen: 324 pp.

Westhoff, V. & E. van der Maarel, 1973. The Braun-Blanquet approach. In: R.H. Whittaker (ed.). Handbook of Vegetation Science. Part V. Junk, Den Haag: p. 617-726.

Wiemann, P. & W. Domke, 1959. Vegetationsübersicht der Ostfriesischen Insel Spiekeroog. Inst. f. Allgem. Botanik Hamburg, Vegetation map.

Wohlenberg, E., 1938. Biologische Kulturmassnahmen mit dem Queller (Salicornia herbaceae L.) zur Landgewinnung im Wattenmeer. Westküste 1: p. 52-104.

Wohlenberg, E., 1953. Sinkstoff, Sediment und Anwachs am Hindenburgdamm. Die Küste 1953: p. 31-94.

Zonneveld, I.S., H.A.M.J. van Gils & D.C.P. Thalen, 1979. Aspects of the I.T.C. Approach to vegetation survey. Documents phytosociologiques N.S. 4: p. 1029-1063.