The morphological development of the Wadden Sea Island of Jordsand since the storm surges in 1976

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Jordsand is the smallest island in the Danish Wadden Sea. For centuries it has been eroded by the sea and is expected to have disappeared at the turn of this century. Since 1972 the authors have carried out investigations of erosion and accumulation on the island. In this paper a brief statement of the morphological development of the island is given for the period 1976-88. Furthermore, the development of two adjacent morphological elements, the high-sand and the erosion basin, is described.

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Keywords:*tidal morphology, coastal erosion.*

The island of Jordsand is located in the southern part of the Danish Wadden Sea within the tidal area of Lister Dyb, about 2.5 km north of the Danish-German frontier and about 5 km west of Jutland's continental coastline with largest fetch in a northwestern direction through Lister Dyb (fig. 1). For centuries Jordsand has been eroded by the sea (M. Jespersen & E. Rasmussen, 1976). Thus, it had a size of about 40 ha in 1807, 18 ha in 1873, 8 ha in 1936, 2 ha in 1976 and 1 ha in 1988 (fig. 2). In the following, the morphological development of the island is described for the period 1976-88, primarily based on detailed surveys made by the authors in 1976, 1982 and 1988. The description of the two adjacent morphological elements, the high-sand and the erosion basin is based on surveys from 1972 and 1988.

The storm surges 1976

At the beginning of 1976 two storm surges struck the Danish Wadden Sea. The first one occurred on January 3 and reached a maximum water level of 4.92 m DNN (Danish Ordnance Datum) which caused great damages in the area. The dikeless Jordsand was completely inundated, and the Game Biology Station's observation hut was partly destroyed, but the island itself was not damaged more than in ordinary gale situations. This appears from a registration 1972-76 of the retreat of the western side of Jordsand (fig. 3). As seen, did the greatest retreat take place from 1973 to 1974, and not from 1975 to 1976 as might be expected.

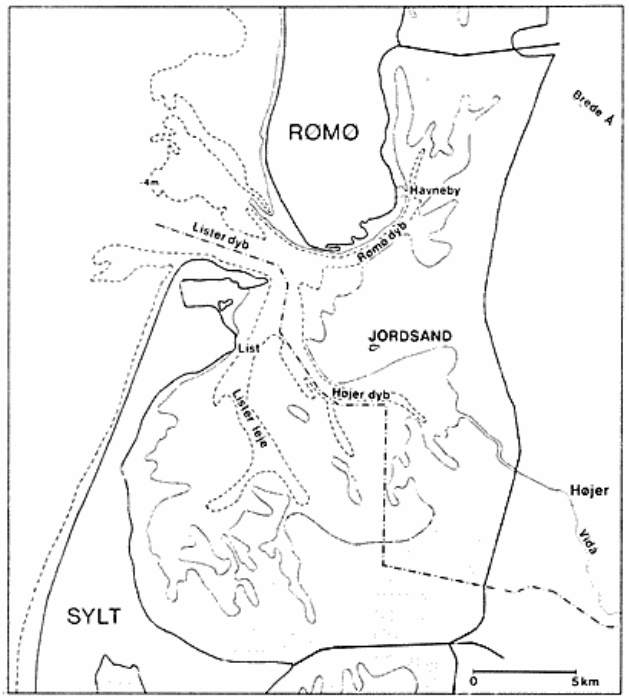

Fig. 1. The southernmost part of the Danish Wadden Sea; tidal flats indicated as dotted area.

Fig. 1. Den sydlige del af Det Danske Vadehav. Det prikkede areal er vade.

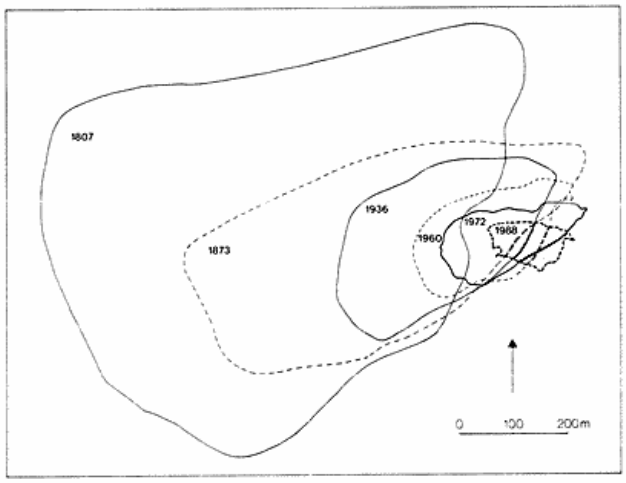

Fig. 2. The erosion of Jordsand from 1807 to 1988.

Fig. 2. Jordsands nedbrydning fra 1807 til 1988.

The reason why the storm surge did not affect the island itself may be due to the fact that the vigorous wave activity took place above the level of the island's surface and thus mainly hit the piled observation hut. The serious threat against the existence of Jordsand is not the storm surges occurring from time to time, but rather the erosion caused by the high-tides with high-water levels of about 2 m DNN that follow more ordinary western gale situations.

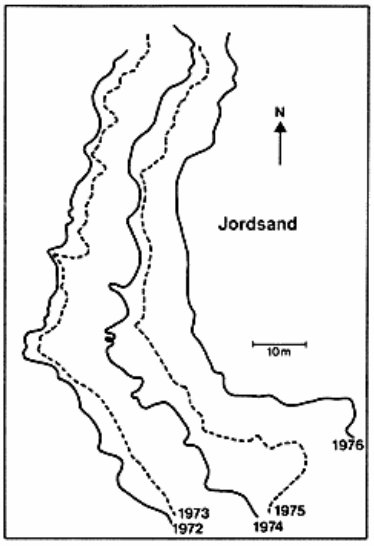

Fig. 3. The retreat between 1972 and 1976 of the western side of Jordsand.

Fig. 3. Tilbagerykningen af Jordsands vestside fra 1972 til 1976.

Coast protection on Jordsand

Since the beginning of the 1970s it has been considered to try to stop the erosion of Jordsand in order to maintain the island as a bird sanctuary. In 1975 a coast protection plan was elaborated by the Danish Game Biology Station. The plan was initiated the following year together with a reconstruction of the observation hut.

The coast protection measures consist of 14 sedimentation basins fenced by brushwood groynes. The basins were established during a 3-year period: in 1976 the first six basins were established on the exposed west coast; in 1977, further five basins were made, and in 1978 this part of the plan was completed by three basins on the east coast.

In 1983 Jordsand's coastline was further protected by brushwood groynes established in a 6-7 m broad zone on the western bank of the island. During the following years these protection measures were extended and had a length of about 150 m in 1986.

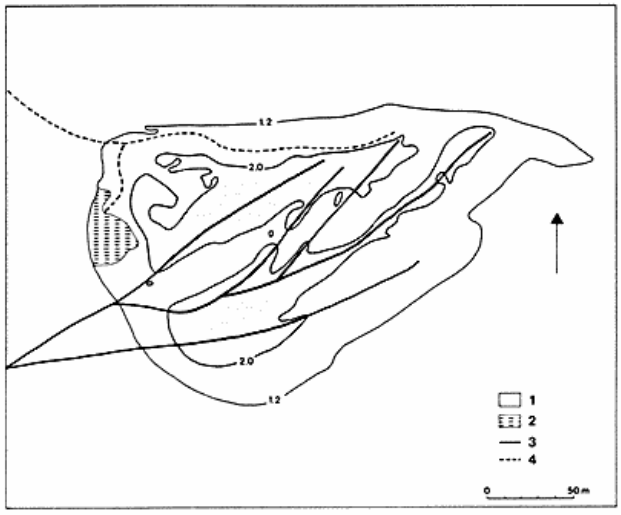

Fig. 4. Geomorphological map of Jordsand 1976. 1: area above 2 m DNN (cf. fig. 5). 2: salt marsh. 3: recurved spits. 4: former course of the tidal creek "Jordsandsloen".

Fig. 4. Geomorfologisk kort over Jordsand 1976. 1: areal over 2 m DNN (jvf. fig. 5). 2: marsk. 3: krumodder. 4: tidligere løb af tidevandsrenden "Jordsandsloen".

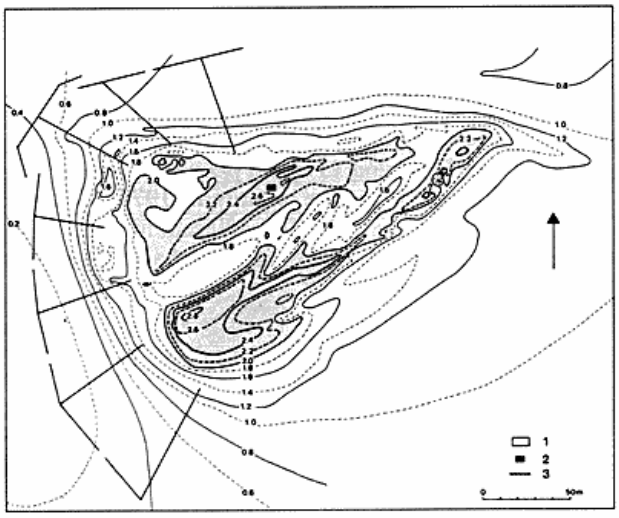

Fig. 5. Contour map of Jordsand 1976. 1: area above 2 m DNN (Danish Ordnance Datum). 2: observation hut. 3: brushwood groynes.

Fig. 5. Højdekort over Jordsand 1976. 1: areal over 2 m DNN (Dansk Normal Nul). 2: observationshytte. 3: faskingærde.

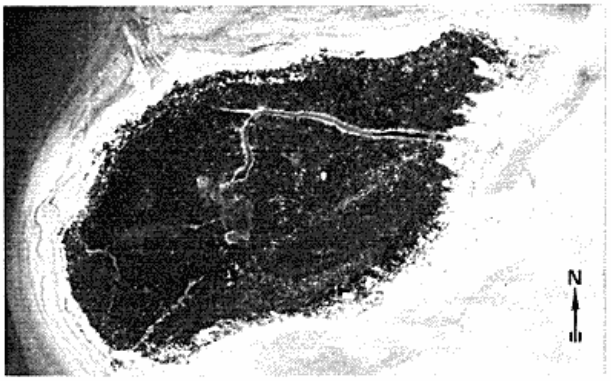

Fig. 6. Aerial photo of Jordsand 1960. The tidal creek "Jordsandsloen" is seen as a channel in function and with outlet at the east side of the island. Approximate scale 1:4300. Reproduced with permission from the Geodetic Institute, No A /89.

Fig. 6. Flyvebillede af Jordsand 1960. Tidevandsrenden "Jordsandsloen" ses som en fungerende rende med udløb på øens østside. Omtrentligt målestoksforhold 1:4300. Reproduceret med tilladelse A /89, Geodætisk Institut, 1989.

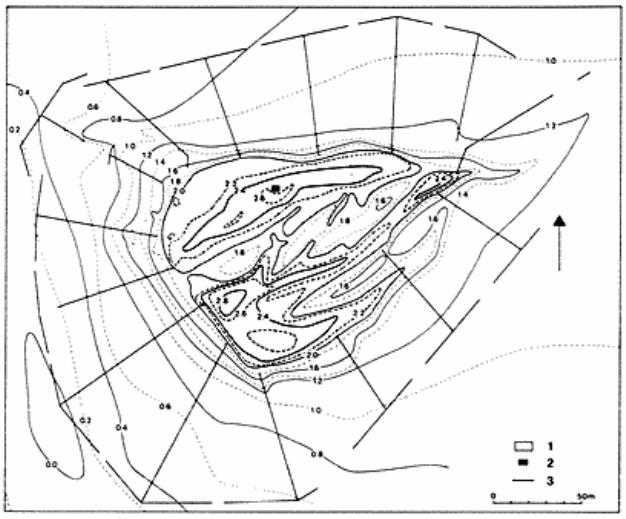

Fig. 7. Contour map of Jordsand 1982. 1: area above 2 m DNN. 2: observation hut. 3: brushwood groynes.

Fig. 7. Højdekort over Jordsand 1982. 1: areal over 2 m DNN. 2: observationshytte. 3: faskingærde.

Jordsand 1976

Formerly Jordsand was a 'hallig', i.e. an undiked marsh island. In 1976 this designation was no longer justified, as only about 700 m^2 of marshland were left (fig. 4). Present-day's Jordsand is a new formation created on the leeside of the original hallig.

The new Jordsand consists of beach ridges mainly shaped as recurved spits separated by depressions. The recurved spit system is the main factor determining the relief of Jordsand. The contours on the map (fig. 5) show very distinctly both ridges and shallows. In 1976 only the distal parts of the recurved spits were still there, but on the basis of measurements made by the authors in 1973 and by L. Edelberg in 1944 it was possible to reconstruct those parts of the recurved spit system which erosion had removed (fig. 4).

Formerly, a conspicuous element in the topography of Jordsand was a tidal creek, the so-called "Jordsandslo". Reliable measurements of this tidal gully exist from as far back as 1805 (The Royal Danish Academy of Sciences and Letters), and on an aerial photography from 1960 (fig. 6) the remnants of it can still be recognized as a creek in function. In 1976 only a minor part of it can be distinguished in the course of the contour lines in the northwestern part of the island (figs. 4 and 5).

The development of Jordsand 1976-88

As mentioned, the next detailed survey of Jordsand was made in 1982 (fig. 7). A comparison between the contour maps from 1976 and 1982 reveals a considerable loss of area on the western part of the island, whereas the recurved spit system has continued to grow on the southeastern part. Neither in area nor volume can this increase counterbalance the loss, however.

The erosion on the western part of the island has caused that the sedimentation basins have become inappropriately large, and simultaneously the deepest part of a surf hole migrating towards the east has reached as far as the outermost brushwood groynes. As the development on the western part of Jordsand is decisive for the destiny of the island, a special investigation has been made of erosion and sedimentation in the sedimentation basins during the period 1976-82. The recordings were made in 1976, 1980, and 1982 along three parallel lines at 50-m intervals (fig. 8).

In the sedimentation basins a low tidal flat and a high tidal flat can be observed below and above 0.6 m DNN (Danish Ordnance Datum), respectively. During the period 1976-80 a distinct difference could be registered along all three lines between the development of the low and the high tidal flat. While the latter was eroded, the low tidal flat was everywhere in accretion. Along the three lines the average accumulation was from north to south 5 cm, 8 cm, and 12 cm. This accretion on the lower levels might justify a certain optimism for the island's future. In the period 1980-82 the development changed completely, however, when the low tidal flat broke down along all three lines, viz. from north towards south: 9, 11, and 7 cm on an average.

From 1976 to 1982 the overall development showed a positive trend only for the low tidal flat along the southernmost line where an average accumulation of 5 cm

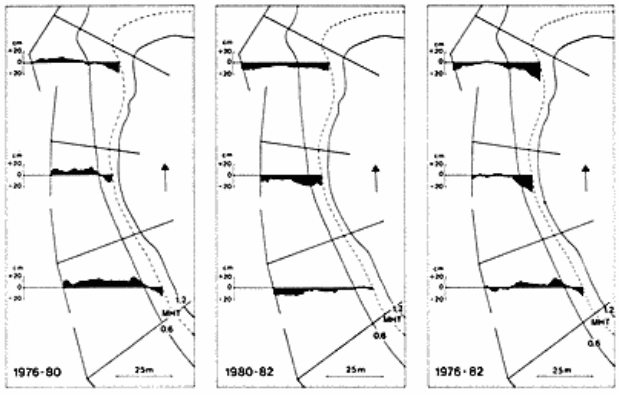

Fig. 8. The development of tidal flats in the sedimentation basins on the west coast of Jordsand. Erosion and accumulation in cm are shown along three lines for the periods 1976-80, 1980-82, and 1976-82; map basis from 1976 (cf. fig. 5). MHT = mean high-water level.

Fig. 8. Vadeudviklingen i slikgårdene på Jordsands vestkyst. Langs tre linier er vist erosion og akkumulation i centimeter for perioderne 1976-80, 1980-82 og 1976-82. Kortgrundlag fra 1976 (jvf. fig. 5). MHT = middelhøjvandslinie.

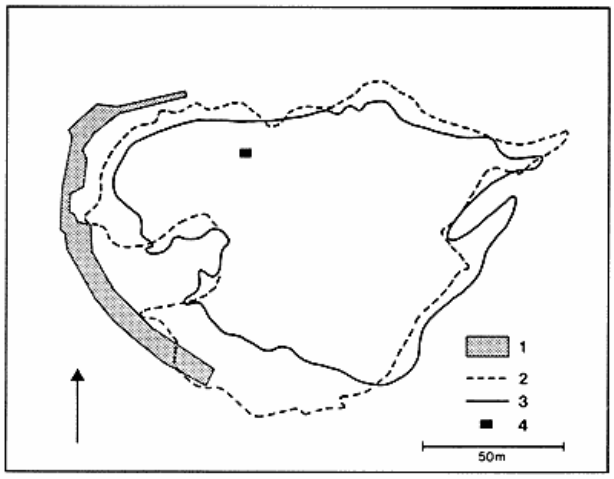

Fig. 9. Attempts to protect the west coast of Jordsand. 1: bank protection (piles and brushwood fascines). 2: vegetation boundary 1983. 3: vegetation boundary 1986. 4: observation hut.

Fig. 9. Forsøg på beskyttelse af Jordsands vestkyst. 1: faskinbælte. 2: vegetationsgrænse 1983. 3: vegetationsgrænse 1986. 4: observationshytte.

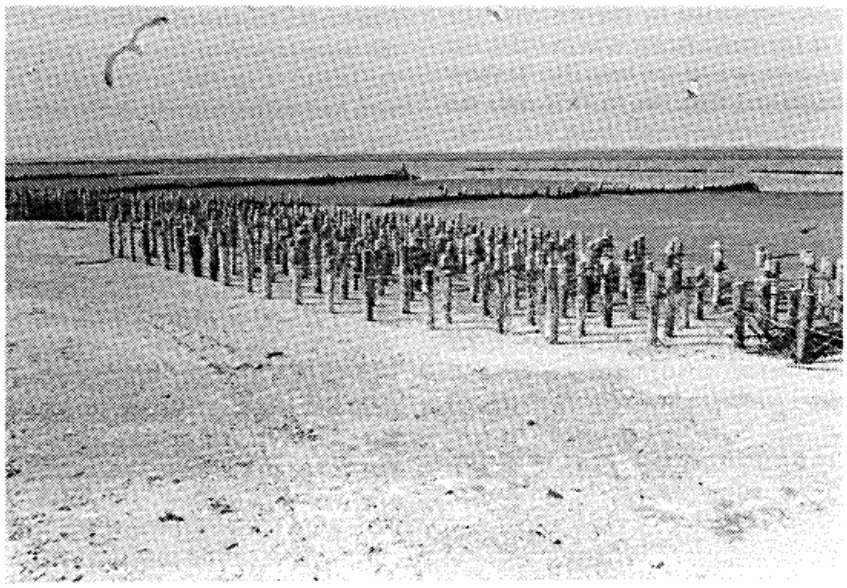

Fig. 10. Damage on the bank protection on the west coast of Jordsand 1986, most of the brushwood has been washed away. In the background sedimentation basins.

Fig. 10. Beskadigelse af faskinbælte på Jordsands vestkyst 1986. Fyrrefaskinerne mellem faskinpælene er bortskyllet. I baggrunden ses slikgårde.

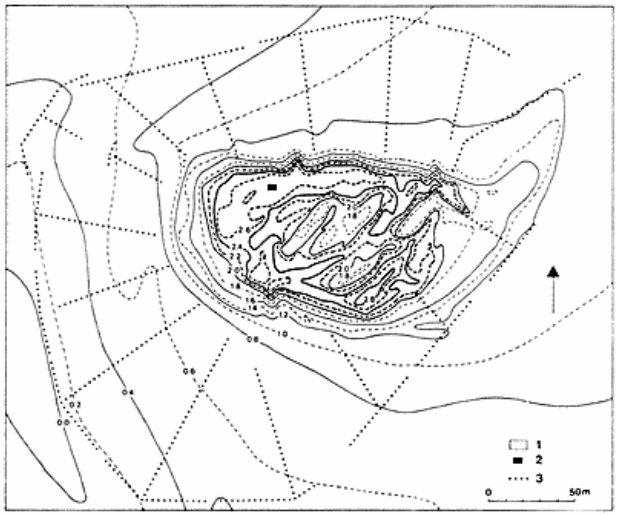

Fig. 11. Contour map of Jordsand 1988. 1: area above 2 m DNN. 2: observation hut. 3: brushwood groynes no longer maintained.

Fig. 11. Højdekort over Jordsand 1988. 1: areal over 2 m DNN. 2: observationshytte. 3: faskingærde, hvis vedligeholdelse er opgivet.

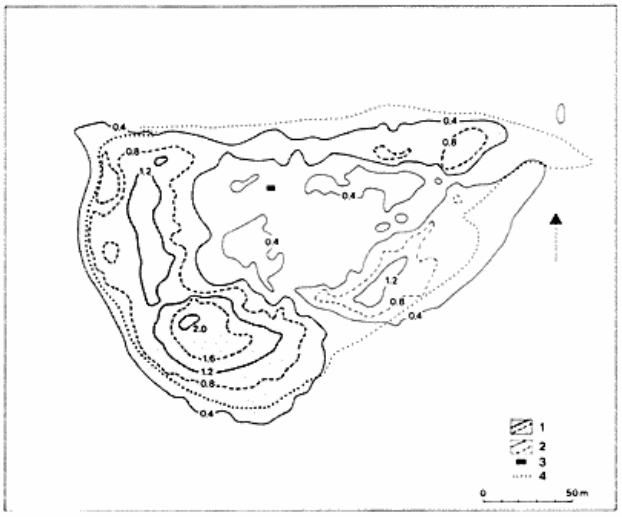

Fig. 12. Erosion and accumulation on Jordsand 1976-88. Changes in level indicated in meters. 1: area with erosion. 2: area with accumulation. 3: observation hut. 4: the 1.2 m contour line 1976, cf. fig. 5.

Fig. 12. Erosion og akkumulation pd Jordsand 1976-88. Koteforskelle angivet i meter. 1: omrdde med erosion. 2: omrdde med akkumulation. 3: observationshytte. 4: 1.2 m højdekurven mdlt 1976, jvf. Fig. 5.

could be measured. Along the two other lines the development was negative with either stagnant or eroded low tidal flat. At the higher levels, erosion predominated the tidal flat where 35 cm was highest value of registered lowering.

Due to the unsuccessful coastal protection until 1982 it was, as already mentioned, attempted to stop the erosion by establishing brushwood groynes along the west coast just below the vegetation line (fig. 9). This was made just after the last residue of the relatively erosion-resisting marsh had been removed by the sea with the result that the island now consisted only of easily erodible sand. A large number of piles were hammered down and between them brushwood fascines were securely fastened with rope. Neither this attempt to protect the coast was a success. The retreat of the west coast did not stop; thus the vegetation line was in 1986 observed 5- 20 m farther towards the east than in 1983. A special investigation was made in 1985-86 with detailed profile measurements both years. The profiles showed an erosion of 15- 20 cm both in front of, within and behind the bank protection. This was greatly damaged as most of the brushwood had been washed away (fig. 10). This negative development continued also the following year, so in 1987 it was decided to give up the maintenance of both bank protection and brushwood groynes around the sedimentation basins.

In 1988 a new detailed survey of Jordsand was undertaken (fig. 11). A comparison between the elevation maps from 1976, 1982, and 1988 shows that in spite of the bank protection the erosion on the island's west side was even greater in the period 1982-88 than observed 1976-82. Moreover, the southern side of the island was now attacked over a distance of 70 m. The erosion of the southwestern corner had caused that 90 m of the youngest, southernmost recurved spit had now disappeared, hereof two thirds during the last 6-year period. Within these six years the easternmost part of the spit did not grow in length, but both in height and width. Besides, another recurved spit is under formation on the east side of the island; this can be followed as a low ridge about 100 m towards northeast. Finally, the general breaking down of the north side is resumed as was the case also in the years prior to 1976 (Jespersen & Rasmussen, 1976).

On the basis of the contour maps from 1976 and 1988 a map has been elaborated showing the total result of the marine erosion and accumulation during the whole 12-year period (fig. 12). On this map positive and negative changes in level greater than 0.4 m are shown. The contours have been drawn by interpolation between figures indicating the difference between levels from the surveys in 1976 and 1988. The western side of Jordsand is attacked by an erosion greater than 0.4 m down to level 0.8 m DNN in 1976, whereas the corresponding erosion on the north side is found above level 1.6 m DNN. On the northern side only few localities with erosion greater than 0.8 m

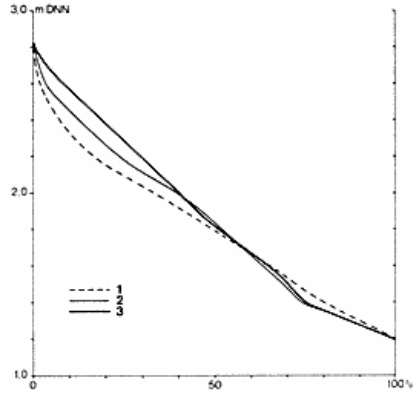

Fig. 13. Hypsographic curves for Jordsand of the area above 1.2 m DNN. 1: 1976. 2: 1982. 3: 1988.

Fig. 13. Hypsografiske kurver for Jordsand. 1: 1976. 2: 1982. 3: 1988.

can be observed, and here it is the distal parts of the recurved spits that have been eroded away. On the west side the values are the double. The highest values here represent the erosion of the young recurved spit mentioned above, while the highest accumulation of more than 1.2 m expresses the growth in height of the eastern part of the same spit. The large area with accumulation greater than 0.4 m represents the most recent accretion of the recurved spit system, while the minor areas with accumulation in the interior of the island is evidence of a filling up of the depressions between the recurved spits.

The changes in elevation on Jordsand due to erosion and accumulation have been investigated by constructing hypsographic curves for the area lying above 1.2 m DNN in 1976, 1982, and 1988 (fig. 13), which is not identical with that covered by vegetation, but is the area not overwashed by mean spring-tide high-water level.

The hypsographic curves show that in both of the periods 1976-82 and 1982-88 a conspicuous increase has taken place of the percentage share of the higher levels; accordingly, the island is increasingly characterized by areas located above 2 m DNN. The reduction in area is thus to some extent compensated by an increase in elevation. The compensation is modest, however, which appears from an investigation of the changes in volume within the area above 1.2 m DNN for the whole period 1976-88. This shows an accumulation of 900 m^3 above the 2-m level. The total loss of volume is thus 3600 m^3, corresponding to 20 % of the volume in 1976.

Development of the erosion basin and the high-sand

In 1988 the island's vegetation-covered area was reduced to 0.9 ha against 1.9 ha in 1976. The average annual loss is thus 800 m^2. If this development continues, the island will have disappeared around the turn of the century (Jespersen & Rasmussen, 1985). The disappearance of the island should not imply a cease of the investigations, however, but instead they should be concentrated on the two other main elements of the area: the erosion basin and the high-sand. So far, complete surveys have been made hereof in 1972 and 1988 (fig. 14).

At low water, the erosion basin appears as a water-filled undrained depression in the tidal flat. Towards northwest and south the basin is bordered by thresholds, which in 1972 were located just under 0.4 m DNN and just above 0.3 m DNN, respectively. In 1988 these thresholds had increased to roughly 0.45 m DNN towards the northwest and just above 0.4 m DNN towards the south. Thus the delimitation of the undrained basin corresponded roughly to the course of the 0.3 m contour in 1972 and to the 0.4 m contour in 1988. In 1972 the basin covered 3.5 ha, had a bottom level of 0.1 m DNN and a volume of 2300 m^3, while the corresponding values in 1988 were: 4 ha, -0.2 m DNN and 6900 m^3 (all figures rounded off). From 1972 to 1988 the area has thus only increased by about 15 %, whereas the increased depth of the basin and the higher thresholds have resulted in a trepling of the basin volume. During the same period the basin migrated about 50 m towards the east.

In 1972 the erosion basin consisted of a large depression just west of the island and an elongated channel farther towards the northwest. The depression has been carved out of the surf off the island, whereas the channel is a so-called flood channel shaped by the flood current in a NW-SE direction corresponding to the direction of the maximum fetch towards Jordsand through Lister Dyb (Jespersen & Rasmussen, 1976). The form complex of surf depression and flood channel has existed for a long time and can be clearly distinguished on airphotos from 1954. It had then much the same appearance as in 1972, but was located 140 m farther west. On an average, the basin has migrated 8 m eastwards every year from 1954 to 1972. From 1972 to 1976 it continued to migrate almost without changing its shape. In 1976 the deepest parts of both flood channel and surf hole were found about 20 m farther eastward than in 1972. The following years essential morphological changes occurred; thus, in 1982, the complex only consisted of an elongated surf hole being deepened. The flood channel has disappeared as a result of a gradual accumulation from 1976 to 1982. The migration towards the east has continued, however, as the deepest part of the surf hole has moved about 30 m towards the sedimentation basins. The next 4 years, until 1988, the surf hole does not migrate farther eastwards, however, but the deepest part of the basin remains just west of the brushwood groynes during the whole period (figs. 7 and 11). The appearance of the basin has been steadily chan-

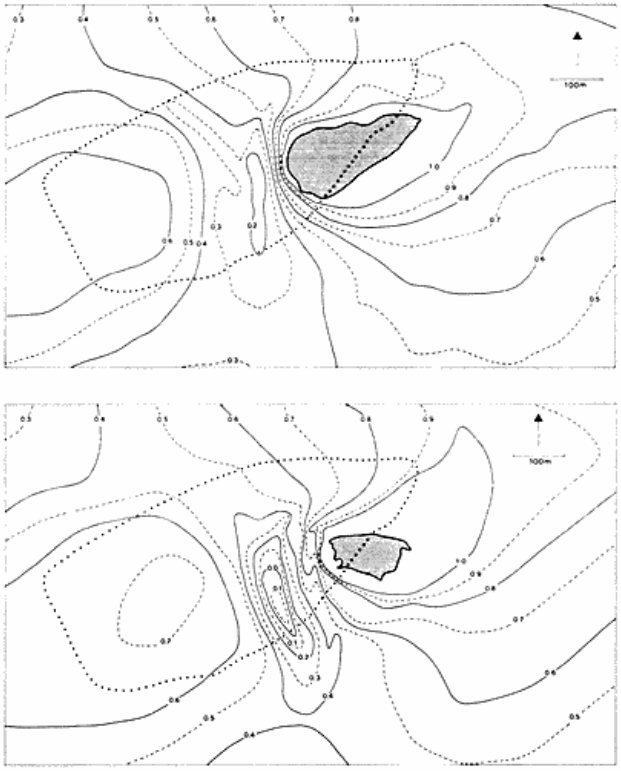

Fig. 14. Contour map of the tidal flat area around Jordsand surveyed in 1972 (top) and 1988. Elevation in meters in relation to DNN. The dotted area is the island of Jordsand, the dotted line indicates its coast line in 1873 (cf. fig. 2).

Fig. 14. Højdekort over vadeområdet omkring Jordsand opmålt i 1972 (øverst) og 1988. Højdeangivelser i meter i forhold til DNN. Det prikkede areal er øen Jordsand, den prikkede linie øens kystlinie i 1873 (jvf. fig. 2).

ging during these years with continued deepening. Presumably this is a consequence of the groynes nearby, as it is a general experience from exposed coasts that erosion is taking place just outside a brushwood groyne, mainly due to wave reflection. As mentioned, the coast protection is no longer maintained, so the deepening as well as the slowdown of the migration of the erosion basin must be assumed to stop within a fairly short span of time.

While the erosion basin is the dominating morphological element off the western side of Jordsand, the island is on the other sides surrounded by a high-sand, which is vegetationless sand flat located above mean high water level. By and large, the delimitation of the high-sand off Jordsand corresponds to the course of the 1.0 m contour line. Part of the high-sand constitutes the basis of the island's recurved spits, and during long periods without flooding, which often occur with southeasterly winds, sand may be observed drifting from the high-sand up upon the recurved spits which increase in height by the formation of small dunes.

A comparison between the surveys in 1972 and 1988 shows that the high-sand has changed conspicuously. From a width in 1972 of roughly 25 m off the island's north side and 50-75 m off the southeastern side, the high-sand's eastern part has increased remarkably towards NNE and is here extending 200-250 offshore. During the period 1972-88 a total of 2.5 ha tidal flat has developed into high-sand and simultaneously 0.8 ha of the island has been eroded down to high-sand level. While the high-sand area has thus increased by 3.3 ha, its western part has been eroded away with a consequent loss of 0.75 ha, and at the same time Jordsand has extended towards the SE upon 0.25 ha of former high-sand. The net gain has been 2.3 ha, and as the high-sand in 1972 covered 2.8 ha, the 5.1 ha registered in 1988 means almost a doubling during this period.

It will be of great interest to follow the further development of the high-sand during the next years, particularly in relation to the migration of the erosion basin as this presumably must be decisive for the existence of the high-sand east of Jordsand after erosion has removed the island. So far, the eroded Jordsand west of the basin has nowhere been replaced by a high-sand, as the terrain has only been built up to a tidal flat level of 0.6-0.7 m DNN. Future will show whether an isolated high-sand will constitute an equilibrium form at this place, or be as unstable a formation as the island of Jordsand has proved to be.

Resumé

Jordsand, der er den mindste danske vadehavsø (fig. 1), er under stadig nedbrydning (fig. 2). Nærværende artikel omhandler udviklingen siden stormfloderne i 1976. Ved stormfloden den 3. januar blev øens observationshytte ødelagt. Selve øen led derimod ikke skade i noget usædvanligt omfang (fig. 3). Den trues primært af nedbrydningen i almindelige vestenvindssituationer. I 1976 blev anlæggelse af slikgårde påbegyndt med det formål at standse nedbrydningen.

En opmåling i 1976 viser, at størstedelen af Jordsand er opbygget af krumoddesystemer, mens øens oprindelige marsk er næsten helt borteroderet (fig. 4 og 5). Resterne af en tidevandsrende "Jordsandsloen" (fig. 6) kan kun i ringe omfang erkendes.

En opmåling i 1982 (fig. 7) viser, at øens vestside har lidt et betydeligt arealtab, der ikke kan opvejes af en vækst af krumoddesystemet på sydøstsiden. En undersøgelse af erosion og akkumulation i slikgårdene på vestsiden af øen i perioden 1976-82 viser en overvejende negativ udvikling (fig. 8). I 1983 blev kystsikringen derfor udbygget med et faskinbælte (fig. 9), som imidlertid heller ikke formåede at standse nedbrydningen (fig. 10). I 1987 blev kystsikringsarbejderne definitivt opgivet.

En opmåling i 1988 (fig. 11) viser, at Jordsand nu nedbrydes både på vest-, syd- og nordsiden, mens der stadig er tilvækst i øens østlige del (fig. 12). I perioden 1976-88 er øens højdefordeling ændret (fig. 13), samtidig med at areal og volumen er reduceret.

I 1972 og 1988 er udført kortlægning af erosionsbassinet og højsandet ved Jordsand (fig. 14). Erosionsbassinet er vandret mod øst under uddybning, medens højsandets areal er næsten

fordoblet, især som følge af en betydelig vækst af højsandets østlige del. Det er dog tvivlsomt, om højsandet vil kunne eksistere efter øens udslettelse.

ACKMOWLEDGEMENTS

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fordoblet, især som følge af en betydelig vækst af højsandets østlige del. Det er dog tvivlsomt, om højsandet vil kunne eksistere efter øens udslettelse.

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