

# Morphology and vegetation of a dune system in SE Denmark in relation to climate change and sea level rise

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## Abstract

Recordings by the Danish Meteorological Institute show, that the mean temperature of Denmark has remained fairly constant and the mean precipitation in winter has increased very slightly during the last c. 100 years, and that the relative sea level rise in Danish waters amounted to between +9 cm and -3 cm during the same period of time.

For the W Baltic area a doubling of CO<sub>2</sub>-level in the atmosphere is predicted to cause an increase in mean temperature by 3-4°C, an increase in length of growing season by c. 55 days, an increase in aridity, and a sea level rise of between 25 and 165 cm. Based on recent observations of morphology, soil and vegetation of a W Baltic dune system, possible effects of these changes upon vegetational composition, phytogeography, nutrient economy, stability, and ground water level of coastal dunes are discussed.

## Coastal dunes in Denmark in relation to exposure, climate and sea level

### *Distribution of coastal dunes in relation to exposure*

The largest dune areas of Denmark are found along the highly exposed W and N coasts of Jutland (Kuhlman 1969) (Fig. 1). These dunes, which have been described by Warming (1907), Bocher (1954) and Heyken (1965), constitute a part of the more or less coherent belt of dunes, stretching from the northernmost point of Jutland to Holland.

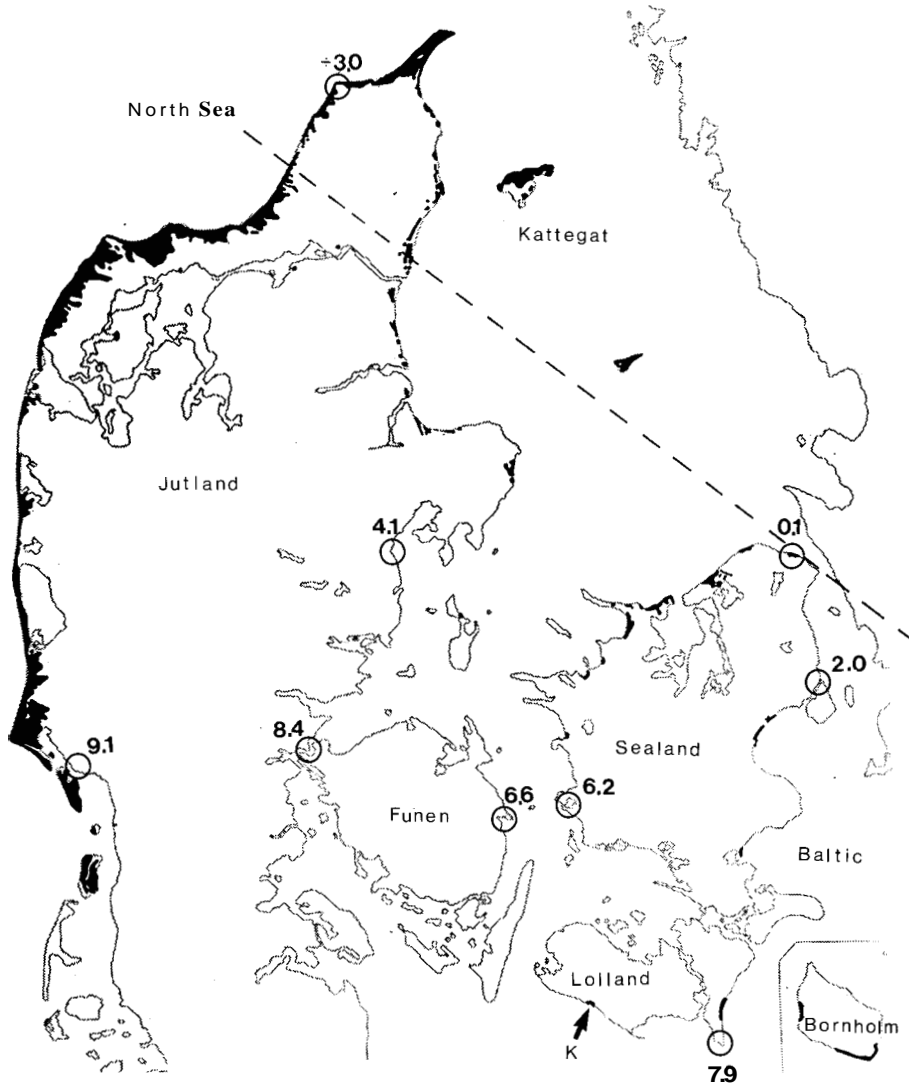
Along the coasts of the eastern Danish waters and of the Baltic, scattered dune areas are found, which are generally lower than those of the W coast of Jutland, due to less amounts of available sand and to less exposure to wind and sea. These dunes,

which have been described by e.g. Bocher (1952), Gravesen and Vestergaard (1969), Larsen (1955-56), may be connected with W Baltic dune areas, described by Olsson (1974) from S Sweden, and by Hundt (1985) from Rügen, Germany.

The CaCO<sub>3</sub>-content of Danish coastal dunes is mostly less than 1%.

### *Regional differences in coast climate*

Danish coasts can be divided into an oceanic part (W and N Jutland) with a relatively narrow annual temperature amplitude and high precipitation, and a more continental part (the SE Danish coasts) with a wider annual temperature amplitude and lower precipitation (Jacobsen 1989). This climatic pattern more or less coincides with the pattern of exposure.



**Fig. 1.** Coastal dunes of Denmark, based on a map by Kuhlman (1969). The figures present the rise in relative sea level in cm, 1890-1968. (Data from Thomsen and Hansen 1970.) K: position of the Kramnitse dune area studied.

The climatic differentiation is reflected in the distribution of several sandy coast plant species (Vestergaard 1989, Vestergaard and Hansen 1989). Examples of oceanic species, in Denmark occurring only along the W coast of Jutland, are *Calystegia soldanella* (L.) R.Br. and *Oenothera ammophila* Focke. Restricted to the SE coasts are continental species like *Petasites spurius* (Retz.) Reichenb. and *Silene viscosa* (L.) Pers.

Within Denmark a north-south difference in length of the growing season, defined as number of

days per year with a mean temperature of above  $+6^{\circ}\text{C}$ , of about 20 days exist (Jacobsen 1989). In the SE part of the country, the growing season is about 205 days. The relatively short growing season in N Jutland is reflected in the occurrence of several arctic-boreal coast plant species like *Mertensia maritima* (L.) S.F. Gray, *Carex maritima* Gunnerus, etc. (Vestergaard 1989).

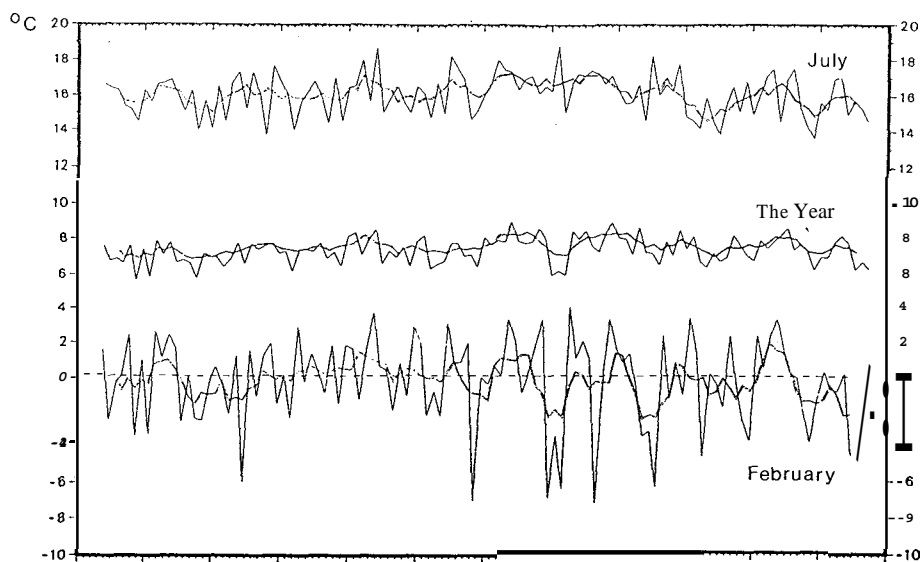
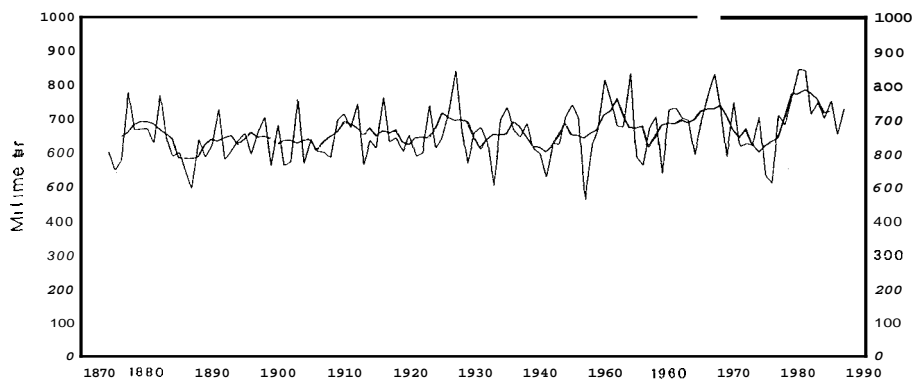


Fig. 2. Variation in the mean temperature of July, February and the Year, of Denmark 1873-1987. Thick lines denote five years running average. (From the Danish Meteorological Institute 1988.)



### Change in climate *from* 1870 to 1985

According to Jacobsen (1989) the mean annual temperature of Denmark in the period 1931-1960 varied geographically from 8.0-8.5°C along the coasts to below 7.5°C in the inland, with a country mean of just below 8°C. Fig. 2 shows, that this value, with some fluctuations, has been rather constant in the period 1873-1987. The same applies to the February and July means, even if the fluctuations for these months are bigger. No significant

temperature trend is thus observed from 1873 to 1987.

Mean annual precipitation has been strongly fluctuating during the period 1873-1987 (Fig. 3), but a very weak increase can be traced, from below 700 mm/year until 1950 to about 700 mm/year from 1950 onwards. According to data from the Danish Meteorological Institute (1988), this is due to increase in precipitation during the winter months November to January.

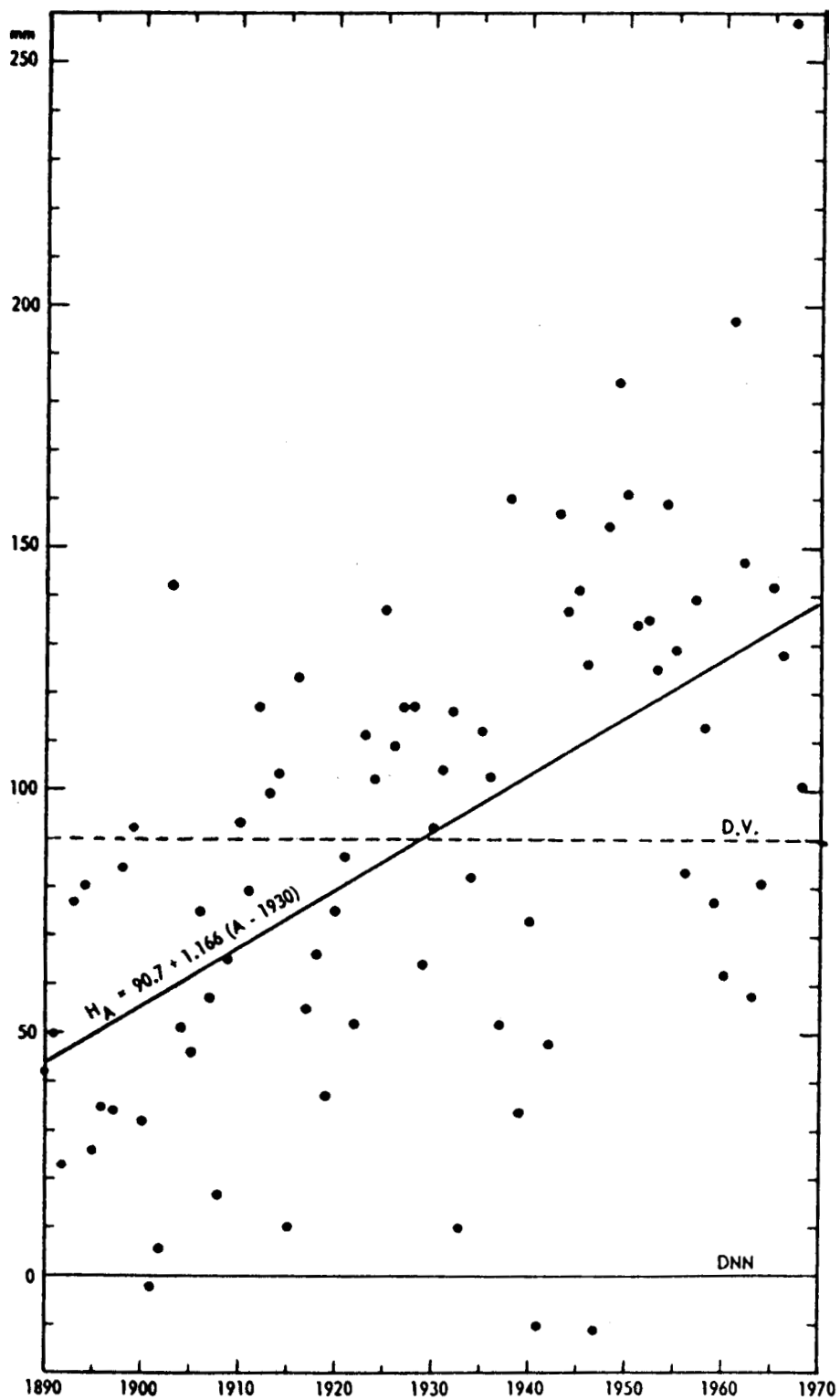


Fig. 4. Annual mean values of sea level at Esbjerg, the Wadden Sea, plotted against time. The tilting line shows sea level rise. D.V. = 'Daily Water' (mean sea level 1890-1968); DNN = Danish Normal Zero level. Further explanation in the text. (From Thomsen and Hansen 1970.)

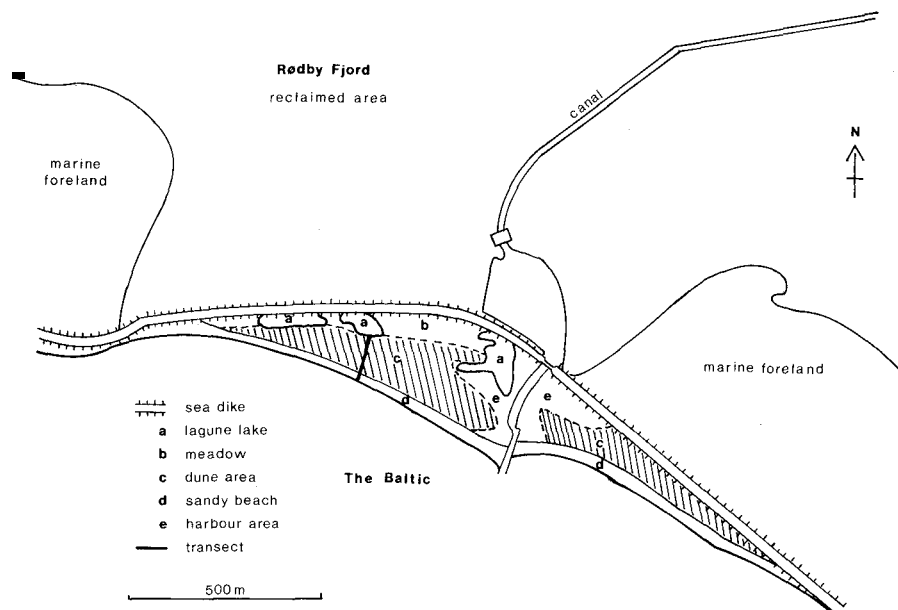


Fig. 5. Sketch map, showing the dune area at Kramnitse. The thick line marks the position of the transect studied.

### Sea level changes along Danish coasts

Since the middle of the 19th century monthly and annual means of sea level in relation to a zero-level (Danish Normal Zero, DNN) have been measured at a number of stations along the Danish coasts, by the Danish Meteorological Institute. These data were until 1964 published in the Association d'Océanographie Physique, Publication Scientifique No.s 5, 10, 12, 19, 25 and 26, and from 1965 to 1968 by Thomsen and Hansen (1970).

Fig. 4 gives an example of annual mean sea level figures, from 1890 to 1968, as measured at a specific station. The values fluctuated very much from year to year. To estimate a possible general trend in the fluctuations an equation,  $H_A = C + \alpha(A - A_0)$ , was applied (Thomsen and Hansen 1970), where  $H_A$  (called 'Normal Sea Level') = height of zero-level above DNN in the year  $A$ . The parameters  $C$  (height of zero-level above DNN in the year  $A$ ) and  $\alpha$  (annual mean sea level rise) are locality-specific constants, determined from the annual mean sea level values (Egedal 1934).

The change in  $H_A$  from 1890 to 1968 is shown in Fig. 4 as the tilting line. The relative sea level rise at that specific station amounted to 91.3 mm. In a

similar way change in relative sea level at the other stations was calculated. The results are shown in Fig. 1.

The highest values of relative sea level rise were found at the Wadden Sea and at the W Baltic. Towards the NE, the relative sea level rise declined and was about zero along a line from N Sealand to N Jutland, indicated at Fig. 1. NE of this line the relative sea level actually declined during the period 1890-1968. This pattern fits well into the more general one, published by Dietrich and Koster (1974) for the Baltic area as a whole.

The relative sea level changes found in Danish waters result from two components: 1. an eustatic sea level rise of about 11 cm/100 years, caused by melting of inland ice (Dietrich and Koster 1974), and 2. a regional postglacial isostatic crust movement.

### The dune area of Kramnitse

#### Site and methods

With the objective of analysing the relations between dune morphology, soil, vegetation, climate, and climatic change, a dune area at Kramnitse at

Grass/herbs (number)	0	3	6	8	10	11	10	11	11	13	14	12	14	6	12	11
Panerophytes (number)										1	1	2		3		1
Grass/herbs (cover-%)	0	30	80	70	90	100	95	100	100	75	70	90	90	100	100	100
Mosses (cover-%)	0	0	0	0	0	0	0	0	100	50	95	100	100	0	5	80
Inclination (°)	-	7	1	0	0	1	0	0	0	8	1	0	0	6	0	0
Org. matter (%)	0.20	.20	.20	.2	0.4	0.4	0.4	1.6	1.3	2.7	1.8	2.7	3.8	7.7	5.9	4.7
CaCO <sub>3</sub> (%)	0.80	.50	.30	.2	0.2	0.3	0.1	0.1	0.1	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
pH	6.5	6.5	6.8	6.7	6.5	6.7	6.7	6.3	5.7	5.6	5.3	5.5	5.3	4.2	4.4	4.2

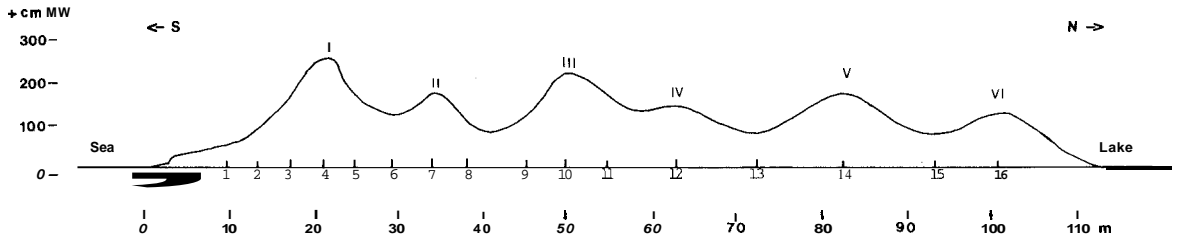


Fig. 6. Morphology, soil and vegetation characteristics of the transect studied. I-VI denote dune ridges. The figures 1-16 along the basis line denote plot nos. Spearman Rank Correlation between soil factors and the horizontal distance of the plots from 0 m (N = 16): CaCO<sub>3</sub>:  $r_s = -0.94$ ,  $P < 0.001$ . pH:  $r_s = -0.86$ ,  $P < 0.001$ . Organic matter:  $r_s = 0.97$ ,  $P < 0.001$ .

the Baltic coast of Lolland was selected (indicated with 'K' in Fig. 1).

In Fig. 5, the most important landscape elements of the locality are shown. The dune system originated from a barrier system delimiting a shallow water area, Rødby Fjord. This water area was reclaimed after the construction of a sea dike, about 3.5 m high, in 1873-78, after a storm surge catastrophe in 1872 (Vestergaard 1983). The dune system to the W of the outlet is composed of several more or less parallel dune ridges.

Climatic data of the locality for the period 1931-1960 (Jacobsen 1989): Mean July temperature: about 17°C, mean February temperature: about 0°C, length of growing season: about 205 days/year, mean annual number of hours of sunshine: about 1750 h, mean frost-free period: April 10 to November 20, mean annual precipitation: 500-550 mm. Actual evapotranspiration of the area amounts to about 450 mm/year (Aslyng 1961). The climate can be characterised as semihumid (*i.e.* humid, but with a short period of rainfall deficit during the growing season) or even subcontinental (Pedersen 1962).

The relative sea level rise of the area amounted to about 8 cm from 1890 to 1968 (10.3 cm/100 years) (Fig. 1).

In June 1988 vegetation and morphology of the

dune system were described in a transect, about 110 meter long (Fig. 6). Along the transect 16 sampling plots, each (2x4) m<sup>2</sup> in area, were established, in which presence of all vascular plants were recorded, and the total cover of vascular plants and of mosses was estimated in Y<sub>0</sub>. Following Iversen (1936), the vascular plants, except woody species, were grouped into biological types: xerophytes (plants, growing in dry habitats, able to tolerate drought for at least part of their lives (Woodell 1973)) and mesophytes. For each plot the average inclination of the surface was estimated, and a soil sample, depth 0-6 cm, was taken, on which pH (water suspension, soil:water vol. ratio 1:1), organic matter (loss on ignition, 550°C, 6 h, Y<sub>0</sub> of dry weight) and CaCO<sub>3</sub> (in %) were measured. The morphology of the dune ridge system was described by a levelling along the transect, in relation to mean seawater level (MW). Correlation between the soil factors and the horizontal distance of the plots from 0 m was tested by Spearman Rank Correlation (Siegel 1956).

#### Results of the transect analysis

The results of the transect analysis are shown in Fig. 6. The dune system consists of six dune ridges (I-VI), which represent a succession from a strand-

line and embryonic dune to a fixed dune with shrubs.

Survey of the plots 1-16:

- 1: Sandy beach with no vegetation (outside the transect line scattered strandline annuals were found).
- 2: Embryonic dune dominated by *Elytrigia junceiforme* A.& D. Love and with *Leymus arenarius* (L.) Hochst., like embryonic dune vegetation elsewhere along Danish and North Sea coasts (Doing 1985).
- 3-4: Mobile dune dominated by *Ammophila arenaria* (L.) Link and with *Ammocala magrostis baltica* (Fluegge ex Schrad.) P. Fourn. 10 species (8 xerophytes, 2 mesophytes). Important species are *Lathyrus japonicus* Willd., *Artemisia campestris* L. and *Senecio vernalis* L.
- 5-16: Represent dune fixation in different stages of succession. 35 species (15 xerophytes, 16 mesophytes, 4 woody species). Important species are the xerophytes *Ammophila arenaria* (non-flowering), *Artemisia campestris*, *Hieracium umbellatum* L., *Poa pratensis* L., *Carex arenaria* L., *Corynephorus canescens* (L.) Beauv., and the mesophytes *Bromus hordaceus* L., *Senecio vernalis*, *Anthoxanthum odoratum* L., *Arrhenatherum elatius* (L.), Beauv. ex J.& C. Presl, *Polypodium vulgare* L., and the shrub *Rosa rugosa* Thunb.

The progressive succession from ridge I to VI was indicated by an increase in cover of mosses, increasing development of scrubs, increasing soil organic matter content, and decreasing soil pH and CaCO<sub>3</sub>-content. The slacks between the ridges appeared dry, with no botanical indication of even temporal damp conditions.

#### *Age and stability of the dune system*

When a map from 1841 at 1:20000 is compared with recent maps and air photographs, it appears, that the outermost (1841) dune ridge corresponds with the recent dune ridge III, so, the age of dune ridge I and II seems to be less than 147 years and the age

of ridge III-VI more than 147 years. In fact, the formation of ridge I and II may have been initiated or at least influenced by the construction of a pier at Kramnitse during the 1870ties, which may have changed the pattern of deposition of marine sand.

The age of ridge III-VI can be estimated from the content of organic matter in the upper soil layer (cf. Ranwell 1972). According to recordings by Salisbury (1925), who correlated soil organic matter and dune age, at Blakeney Point, a locality rather similar to the Kramnitse area in CaCO<sub>3</sub>-content of the sand and in rainfall, an organic content of 2.7%, as found in dune ridge III at Kramnitse, corresponds to an age of about 350 years, and an organic content of 7.7%, as found in ridge V, corresponds to an age of about 470 years.

Ranwell (1972) defines two types of dune system: a prograding type, adding ridge to ridge, which stabilizes in situ, and an eroding type, which may remain unstable for centuries before the dune is permanently fixed by vegetation. The dune system at Kramnitse seems mainly to have been formed according to the prograding type. At present, however, there is no indication of formation of new seaward ridges in front of the outermost dune ridge. The system as a whole seems to be rather stable, apart from the embryonic dune and mobile dune. If the system is in fact subjected to a gradual change, due to the continuous rise in sea level, the development seems to be in balance with the sea level rise.

#### *Effects of climate on soil and vegetation*

The high stability of the dune system at Kramnitse is confirmed by the soil development. In inland direction, significant, unidirectional decline in CaCO<sub>3</sub>-%, caused by leaching by rainfall (Ranwell 1972), and in pH, and increase in soil organic matter, were observed (Fig. 6). This indicates, that the surface of the fixed dune ridges is stable, and shows, that no larger amounts of sand have more recently been blown into the inner ridges due to erosion of the front ridge, and that no 're-modelling' of the existing dunes has taken place.

The effect of the macroclimate of the study area

Table 1. Climatic change, estimated for the W Baltic area, at a doubling of the CO<sub>2</sub>-level in the atmosphere, according to the OSU-GCM Scenario B for the Northern Hemisphere and Europe.

	Increase in mean temperature	Increase in precipitation	Increase in potential evapotranspiration
Winter	4°C	–	7 mm × 3 months × 4°C = <b>84</b> mm
Spring	3°C	–	7 mm × 3 months × 3°C = <b>63</b> mm
Summer	3-4°C	no significant	7 mm × 3 months × 3.5°C = <b>74</b> mm
Autumn	3-4°C	–	7 mm × 3 months × 3.5°C = 74 mm
Year	–	< 10% (< 55 mm)	295 mm

on the vegetation may mainly be seen in a context of phytogeography, by determining the flora of the geographical region as a whole. Of special interest in connection with a changing climate is the possible occurrence of species, which at the site in question are approaching their limit of geographical distribution and therefore may be sensitive to even minor changes in the environment. The spectrum of geographical distribution patterns of the dune flora of Kramnitse is very broad. In fact only one of the transect species approaches its geographical distribution limit at Kramnitse: *Silene viscosa*, a continental species of SE distribution in Europe, which in Denmark outside the S coast of Lolland occurs very scattered in the SE parts of the country, obviously conditioned by the subcontinental climate of that area (Pedersen 1962).

The microclimate of dunes is usually very diverse due to the varied morphology, causing local differentiation in irradiance and shelter (Boerboom 1964, Ranwell 1972, Boorman 1977, Hundt 1985). Besides differences in age, the site-to-site variation in the vegetation of the Kramnitse dunes mostly seems to be determined by differentiation in microclimate. This can be illustrated by comparison of slopes with opposite aspect. Plot 9 represents a dry S-facing slope, the vegetation of which is characterised by xerophytes, especially *Sedum acre* L., a leaf succulent, conditioned by the locally arid conditions (*i.e.* precipitation < potential evapotranspiration) at least during parts of the growing season, due to high temperatures during the day. Plot 11 represents a N-facing slope, the vegetation of which is characterised by mesophytes, especially *Polypodium vulgare*, due to lower amplitudes in

temperature and higher relative humidity (*cf.* Boerboom 1964).

### Possible effects of future change in climate

Climatic changes at the W Baltic area, predicted at a doubling of the CO<sub>2</sub>-level in the atmosphere, according to the OSU-GCM Climate Scenario B for the Northern Hemisphere and Europe, applied by the LICC (Boer and Groot 1990), are shown in Table 1. The calculation of potential evapotranspiration was based on the condition, that each degree of increase in temperature contributes equally to the potential evapotranspiration in summer and in winter.

The increase in potential evapotranspiration combined with only a minor increase in precipitation may change the climate from the present semi-humid type towards a more arid type of climate.

#### *Possible effects of increase in temperature and aridity*

Effects on vegetation of increase in aridity  
In dry dune habitats, like the Kramnitse area, an increase in aridity generally will disfavour mesophytes in competition with xerophytes. In the mobile dune (plots 3-4) which is almost completely dominated by xerophytes, this may not cause much change in vegetation. In the fixed dune (plots 5-16) on the contrary, where the mesophytes constitute more than half of the species, increase in aridity gradually may cause a quantitative, later also a

qualitative, change in the species composition, in favour of the xerophytes.

Among the xerophytes a differentiated response to increase in aridity may be seen, depending on their specific water interception strategy (Boorman 1977). Deeprooted xerophytes, like *Ammophila arenaria*, *Galium verum* L., *Lathyrus japonicus*, *Carex arenaria* and *Artemisia campestris* (cf. Iversen 1936), exploiting deeper, more moist, sand layers, may be less influenced by increased aridity than species with more superficial root systems, like *Corynephorus canescens* and *Sedum acre*, as especially the uppermost layer of the dune sand is exposed to drying by strong heating. In *Sedum acre*, however, the very superficial root system (4-6 cm) is compensated by strong leaf succulence.

Increase in aridity may cause a decline in primary productivity of the dune vegetation. The decline may, however, to some degree be compensated by stimulation of photosynthesis due to the higher CO<sub>2</sub>-level in the atmosphere (Huis 1989).

#### Increase in length of the growing season

By adding the estimated increase in mean temperature at 2 x CO<sub>2</sub>, to the figures of the mean temperature of Denmark for the period 1873-1987, obtained from the Danish Meteorological Institute (1988), it can be estimated, that the mean growing season of Denmark will increase by about 55 days (the second half of March, the first half of April and the month of November). It can be expected, that the prolonged growing season will have a strong impact to the functioning of dune ecosystems, e.g. by changing the phenological relationships between the species and the changing the rate of decomposition and leaching of nutrients.

Phytogeographically, an increase in aridity as well as a prolonged growing season may cause immigration of southern species and a wider distribution of continental xerophytes, already present (e.g. *Silene viscosa*), in a northward direction, on the condition that suitable habitats are present along the coasts. Vice versa, species with a more oceanic or northern distribution may be suppressed along their southern limit.

Effects on soil development and nutrient cycling  
A possible effect of increase in temperature may be an increased litter decay rate and a faster mineralization and release of available nutrients. A higher evapotranspiration from vegetated surfaces will probably reduce leaching of CaCO<sub>3</sub> and nutrients from the upper soil layer, due to diminished downward soil water movement. These processes may improve the nutrient economy of the generally nutrient-poor dune habitat.

#### Possible effects of an increase in sea level rise

Global warming, corresponding to a doubling in CO<sub>2</sub>-level in the atmosphere, may imply a global rise in sea level of between 25 and 165 cm (Huis 1989).

With reference to the dune area at Kramnitse, an acceleration in the sea level rise may influence the dune system in at least two ways:

1. The present relative stability of the dune system, representing a state of balance between geomorphological and vegetational processes, apparently in a relative balance with the slow rise in sea level up to now, may be broken. The dune system may change from a prograding type of system into an eroding type, characterised by increasing erosion of the mobile dune ridge during storm situations, and landward sand movement (Ranwell 1972), creating instability in the fixed dune area behind the mobile dune.

2. The ground water level of the dune system may change. According to the model of Bakker (1990) for ground water flow in dune areas with a low-lying hinterland, the dune area at Kramnitse will contain a more or less lens-shaped body of fresh ground water above brackish and salt ground water. The actual dimension of the freshwater body is not known, but it is supposed to be very limited, regarding the limited width and height of the dunes (Fig. 6).

The effect of the sea level rise on the ground water level in dunes will depend on the balance between a decline in ground water level caused by a possible narrowing of the dune system due to erosion, and a rise in ground water level caused by the

rising sea level (*cf.* Meulen 1990). The net effect on the ground water level at Kramnitse of a minor additional sea level rise due to climate change, *e.g.* 25 cm, can at present not be predicted. A sea level rise of *e.g.* 1 m or more may cause inundation of parts of the dune system, depending on the pattern of erosion and accretion, which may be changed also by the rising sea level.

## Conclusions

Increased aridity and prolonged growing season, due to future increase in local and regional temperatures, caused by a doubling of the CO<sub>2</sub>-level in the atmosphere, are expected to influence dune vegetation and soil, 1. by favouring xerophytes in the competition with mesophytes; 2. by changing the phenological relationships between the species; 3. by causing immigration of southern species and depression of more northern and atlantic species, especially those nearing their limit of geographical distribution; 4. by causing a decrease in soil leaching and increase in litter decay rate and mineralization, improving the nutrient economy of the dune habitat.

With special reference to the dune system at Kramnitse, future acceleration in sea level rise might influence the dunes, 1. by changing the dune system from a prograding, relatively stable system into an eroding, more unstable system, 2. by changing the ground water level and even by causing inundation of part of the dune area.

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