ON THE CONTRIBUTION OF AIR-BORNE SALT TO THE GRADIENT CHARACTER OF THE VOORNE DUNE AREA

CLARA J. M. SLOET VAN OLDRUITENBORGH

Afdeling Natuurbehoud en Natuurbeheer, Landbouwhogeschool, Wageningen, Meded. nr. 18

ELS HEERES

Biologisch Station "Weevers' Duin", Oostvoorne

SUMMARY

The distribution of air-borne salt in a distinctly zonated coastal dune area has been investigated by means of 27 simple measuring instruments, placed in 4 transects, perpendicular to the coastline: two in a northwest-southeastern line, the other two in a southwest-northeastern line.

The pattern of distribution proved to be determined by wind velocity, distance from the sea, wind direction, height above N.A.P. and shelter by surrounding vegetation. Most salt was deposited during high wind velocities. The influence of rainfall was difficult to establish because periods of high rainfall usually coincide with those of high winds.

It is stressed that the income of nutrient elements from sea-spray is only half of the significance of air-borne salt as a contributor to the gradient system of the dune environment. For the existence of gradients in space and time and thus for biological diversity the leaching by rain and any other decrease of these elements is just as essential.

1. INTRODUCTION

Within the scope of a larger study on dune shrub vegetations, the present project was carried out to investigate the contribution of one of the environmental components to the gradient system of the Voorne dune area. The special situation of these dunes is given in chapter 2.

Shrubs in general have been recognized, together with the outskirt-communities as a characteristic vegetation-complex of border areas (Van Leeuwen 1966). They are bound to the "limes divergens" type of environment, which is determined by a spatial complex gradient of environmental factors. The vegetation associated with the "limes divergens" is differentiated in structure and rich in species. In the Netherlands they reach their largest extension in the coastal dunes and their highest diversity is found in the dune area of Voorne.

Much attention has recently been paid to the dune-landscape as a system of gradients (a.o. Van der Maarel & Westhoff 1964; Van der Maarel 1966; Sloet van Oldruitenborgh & Adriani 1969). It is suggested in their papers that the dune-vegetation as a whole as well as the floristic composition of the different communities is at least partly determined by the internal variation of environmental components. Therefore the analysis of ecological factors in this type of ecosystem should be concentrated on the range and variation of these factors in space and time or, in other words, on a relative, rather than on an absolute quantitative basis. The distribution of air-borne salt, which is supposed to be an important ecological factor in the coastal area is dealt with in this paper from this point of view. The variation in space and time of this distribution in the Voorne dunes will be detectable by means of a network of measuring points throughout the area.

An additional reason for investigation of the deposition of marine salt in this region is the fact that considerable changes will be caused in the near future, by the rapid extension of the industrial- and harbour area of Rotterdam. This development will take place in front of the present coastline, northwest of Voorne, and will influence wind velocity and supply of air-borne salt in the outer dunes. Moreover changes in the salinity gradients in the estuaries and coastal waters of the Delta region are to be expected after the closure of the sea-arms. Voorne will be particularly effected by the closure of the Haringvliet in 1970 (Peelen 1967).

From the scientific as well as from the nature conservation point of view it is important to follow these changes in the environment and their impact on the natural vegetation in the area. The Research Group Coast of Voorne of the Foundation for Dune Research (S.W.D.) is investigating here.

The distribution of air-borne salt in coastal areas is treated by many authors (Leeflang 1938; Oosting & Billings 1942; Woudenberg 1960; Fujiwara & Umejima 1962; Edwards & Claxton 1964; Etherington 1967), mostly for agricultural or sylvicultural purposes. The direct and indirect effects on plants are discussed, such as the damage to buds and foliage (which is sometimes heavy during gales, especially in spring and summer (Edlin 1957; Edwards & Claxton 1964), and the contribution to the nutrient content of the soil (Etherington 1967).

Air-borne salt is apparently of marine origin and the majority of the salt-particles is carried inland by high winds in droplets of sea water, which are formed by the bursting of bubbles at the sea surface (Woodcock 1952).

The results of measurements of air-borne salt, mentioned in all preceding papers show a considerable decrease of salt deposition in the first few hundred meters from the coastline and a less pronounced and irregular decrease further inland depending on topography, windbreaks, wind velocity etc. (Oosting & Billings 1942; Fujiwara & Umejima 1962; Edwards & Claxton 1964).

2. THE AREA OF INVESTIGATION

The dune area of Voorne is situated some 30 km southwest of Rotterdam in the northern part of the Delta region in the estuary of Rhine and Meuse. The northern part of the area has a northwestern exposition to the sea, the southern part, bordering the Haringvliet, a southwestern exposition (*fig. 1*). The salinity of the surrounding water shows great fluctuations during the year, depending largely on the discharge of the rivers (Peelen 1967). The salinity of the seawater on the northwestern side amounts to 10–15$^0/_{00}$ at low river discharge, 5,5–10$^0/_{00}$ at average discharge and 3–5,5$^0/_{00}$ at high river discharge (all samples taken from

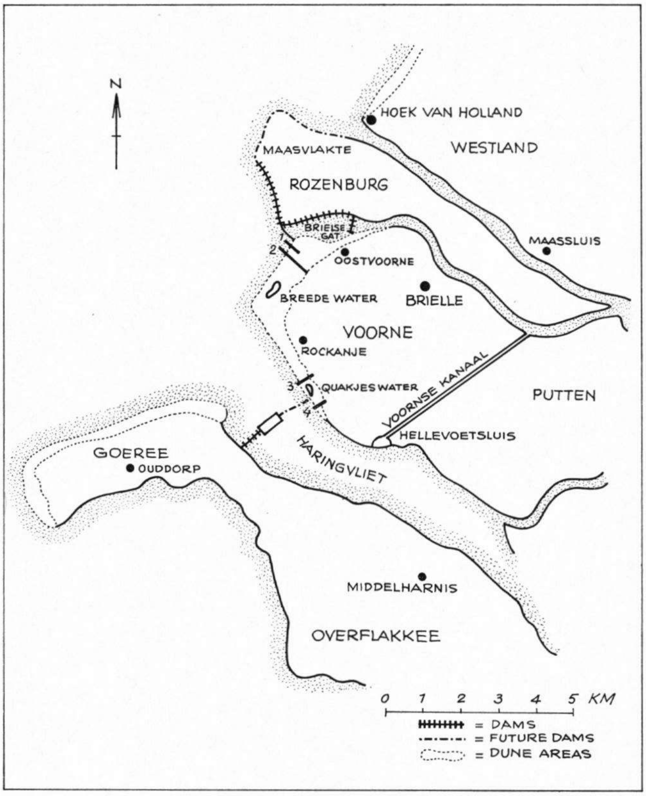


Fig. 1. The area of investigation with the four transects of measuring points.

the surface at midtide). On the southwestern side these data are: 10–15$^0/_{00}$; -53$^0/_{00}$ and 1–3$^0/_{00}$ respectively. As the amount of chlorids, carried inland by the wind is determined to a certain extent by the percentage of chlorids of the surface water near the coast, it is clear that the east-west salinity gradient in and near the rivermouth and its shifting with the river discharge will provide an ever changing source from which the air-borne salt originates. In the north the "Maasvlakte" industrial- and harbour area is growing rapidly and will form a considerable windbreak for the northwestern winds in the future. This will result in an overall decrease in salt deposition.

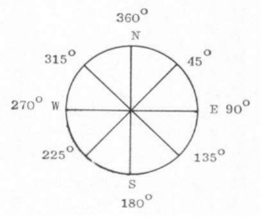
The area as a whole shows a distinct zonation of rather low ridges and dune slacks which are older in age and more complex in topography and vegetation at increasing distance from the sea. The vegetation of the coastal ridge consists of pioneer *Ammophila arenaria* communities; the ridges and dry dune complexes more inland show a continuous and differentiated series of shrub-communities with *Hippophae rhamnoides, Ligustrum vulgare, Crataegus monogyna-Rhamnus catharticus* as the dominant species respectively. *Salix* spec. div. -*Betula verruco-*

sa shrub and, locally *Phragmites communis* marshes occur in the primary dune slacks and the wetter parts in the older dunes. In the inner dunes and in the 4th transect one finds smaller areas with dune grassland communities. Four transects are laid out in the area (*fig. 1*). The position of the measuring points is given in *table 1.*

Table 1. The position of the measuring points in the dune area of Voorne.

Transect	Nr. pot	Distance from the sea in m.	Height above N.A.P. in m	Surrounding vegetation	Sheltering vegetation: direction–distance	
1	12	0	2,2	–	–	
	13	40	7,5	*Ammophila arenaria*	90–180°	<10 m
	14	100	2,5	Low[1] *Salix repens* shrub	–	
	15	150	4,5	Low *Hippophae-Salix* shrub	–	
	16	300	3	*Phragmites communis*	on all sides	<10 m
	17	400	8	Interm.[2] *Ligustrum-Hippophae*	–	
2	18	0	2,4	–	–	
	19	40	9	*Ammophila arenaria*	90–180°	<10 m
	20	250	3	Low *Salix repens* shrub	–	
	21	400	5	Interm. *Hippophae-Salix* shrub	270–360° 90–135	<10m, >10m
	22	500	4	High[3] *Betula-Salix* shrub	on all sides	<10 m
	23	600	7	Interm. *Hippophae-Ligustrum* shrub	–	
	24	750	5,5	Interm. *Hipp.-Ligustrum* shrub	90–180°	<10 m
	25	1000	4,5	Mixed *Crataegus-Ligustrum* shrub	90–180° 270–360°	<10 m, >10 m
	26	1300	6	High *Crataegus-Populus* shrub	315–90°	<10 m
	27	1500	6,5	Dune grassland	90°	<10 m
3	5	0	6	*Ammophila arenaria*	–	
	6	20	11	*Ammophila arenaria*	–	
	7	150	3	*Salix-Calamagrostis*	90–180°	<10 m
	8	225	10	Low *Hippophae* shrub	–	
	9	300	4	High *Crataegus-Rhamnus* shrub	270–45°	<10 m
	10	400	6	Low *Crataegus-Ligustrum* shrub	–	
	11	500	13	Low *Hippophae-Rubus caesius* shrub	0–45°	<10 m
4	1	20	9	Low *Hippophae-Berberis* shrub	–	
	2	30	6	High *Berberis-Crataegus* shrub	on all sides	<10 m
	3	100	7	Dune grassland	–	
	4	200	8	Dune grassland	–	

1. low shrub 1,5 m
2. intermediate shrub 1,5–2,5 m
3. high shrub 2,5 m



3. METHODS

Since correlations between data obtained with different types of measuring instruments were very high (EDWARDS & CLAXTON 1964) and since for several reasons our instruments had to be as simple as possible, it was decided to use an apparatus of the following construction, which is comparable to the "wet-candle" of AMBLER & BAIN (1955): *viz.* an open jam jar attached between four nails on a pole, 1,5 m above ground level. A 20 cm long pillar was anchored in the middle of the jar by means of plastic crosswise supports so, that 10 cm of the pillar, wrapped in blotting paper was exposed to the wind (*fig. 2*). No attempt was made to prevent the rain from falling on the target as the principal issue was to collect comparable data on the total amount of salt in a limited area, either transported by wind or dissolved in rain water.

The jars with their contents were taken into the laboratory every 2 weeks during the period from 25–10–1966 to 26–10–1967 and replaced at the same time by clean and empty ones.

In the laboratory the blotting paper was left in the rainwater for two hours and in case of little rainfall filled up with distilled water. Then the quantity of water was reduced by evaporation or filled up to an amount of 50 ml. The NaCl content of the 50 ml solution was titrated with silver nitrate using potassium chromate as an indicator. The NaCl content is expressed in mg/jar/2 weeks.

The KNMI (Royal Netherlands Metereological Institute) at De Bilt kindly

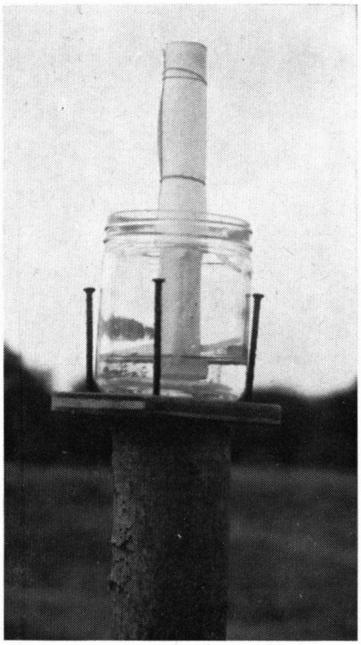


Fig. 2.

placed at our disposal the rainfall data of Oostvoorne (Drinking-water catchment area of Brielle) and data on wind direction and wind velocity of Hoek van Holland.

4. RESULTS

Although the area is rather inaccessible and well protected as a nature reserve, recreation and vandalism of local youth have slightly disturbed the programme. During the period of investigation several jars with their contents disappeared, especially during the first few months. The instrument on the beach of transect 4 had to be removed in december 1966 because of the construction of a supply road for the Haringvliet dam. A source of error was the influence of birds, which left their faeces on the "resting spots". These deviations are left out of consideration. No or very little salt deposition was recorded during periods of only northeastern, eastern, southeastern and southern winds. In total 19 measuring periods of 2 weeks were taken into account:
1966: 27–10; 10–11; 24–11; 8–12; 1967: 5–1; 19–1; 2–2; 16–3; 13–4; 27–4; 11–5; 25–5; 8–6; 20–7; 3–8; 17–8; 28–9; 12–10; 26–10.

The data on wind velocity, available in knots/sec. as hourly measurements have been converted according to the Beaufort-scale into figures expressing the numbers of hours/2 weeks, that wind of certain velocity and direction occurred. It was directly apparent that wind velocities from 5 to 9 (inclusive) were affecting the amount of salt deposit to a measurable extent (5 = 8–11 m/sec; 6 = 11–14 m/sec; 7 = 14–17 m/sec; 8 = ±17–21 m/sec; 9 = ±21–24 m/sec; velocities of 10 and more did not occur).

4.1. Salt deposit and wind velocity

By far the largest amount of salt was deposited during periods of high winds. Therefore the measuring periods have been arranged according to their wind velocity. This has been done for each wind velocity from 5 to 9 (inclusive). Only the sum of western, northwestern and southwestern winds has been taken into account. From these five series one average rank order of the periods has been drafted (*fig. 3*).

To investigate the relation between salt deposit and wind velocity, rank correlation (according to Spearman) has been determined between total salt deposit (in all jars) and the above mentioned rank order of measuring periods: $r = 0{,}95$ for $n = 19$; significant for $P < 0{,}05$. In the same way rank correlation between the salt deposit in the different jars separately and the wind velocity is significant too.

4.2. Salt deposit and distance from the sea

The distance from the sea may be considered as the major factor in building up the salt gradient in a coastal area (*table 2*). The salt recordings of the well-exposed jars on top of the dune ridges and other places of higher elevation

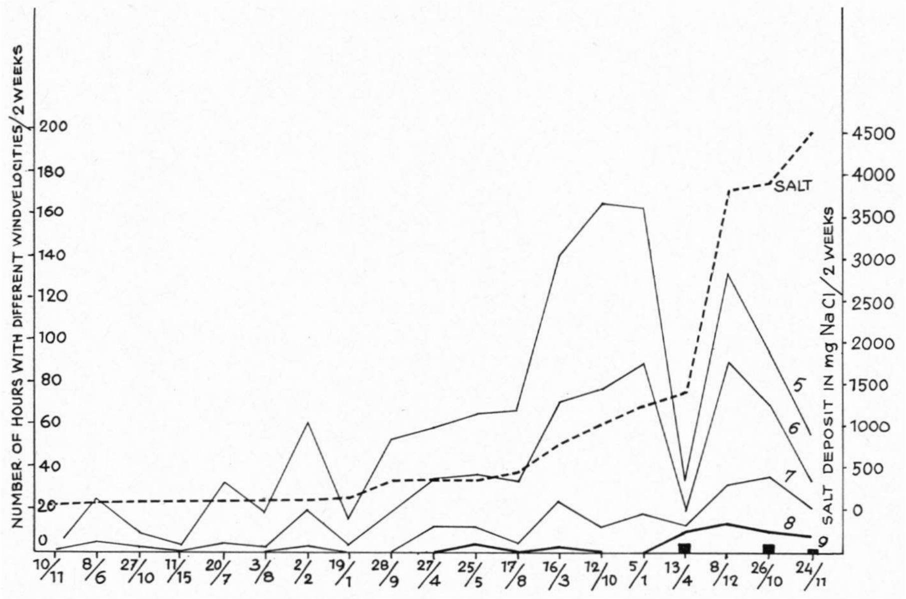


Fig. 3. Total salt deposit of all measuring points and wind velocity in 19 measuring periods.

Table 2. The amount of NaCl deposit (in mg/jar/2 weeks) in transect 2 and the total deposit of all 27 jars.

transsect 2 nr. jar.	18	19	20	21	22	23	24	25	26	27	total 27 jars.
date											
10–11–66	6	5	4	2	1	3	2	3	1	2	73
8– 6–67	5	5	3	2	2	2	2	2	2	4	93
27–10–66	3	5	3	2	2	3	2	2	2	2	92
11– 5–67	6	5	4	3	3	3	3	3	3	5	99
20– 7–67	11	6	4	2	2	3	2	2	1	2	104
3– 8–67	22	12	4	2	0	2	2	1	2	1	105
2– 2–67	5	7	4	3	2	4	2	2	2	4	118
19– 1–67	8	9	10	3	3	4	3	2	3	4	126
28– 9–67	15	14	18	7	5	6	8	7	5	9	338
27– 4–67	30	26	17	10	6	6	7	6	5	10	341
25– 5–67	24	25	11	8	4	10	7	4	5	7	370
17– 8–67	28	31	17	9	4	11	8	5	5	9	430
16– 3–67	63	35	32	17	25	21	16	9	10	14	817
12–10–67	81	101	31	14	5	20	10	4	11	17	1061
5– 1–67	83	120	52	23	15	35	26	20	15	28	1245
13– 4–67	98	79	65	32	20	45	30	27	25	41	1418
8–12–66	262	384	105	63	28	100	40	52	30	43	3810
26–10–67	273	230	94	58	29	78	59	33	42	76	3914
24–11–66	453	321	153	73	41	118	92	72	59	92	4499

form a distinct series, correlating exactly with the distance from the sea, but the intermediate values of less exposed jars are much lower. *E.g.* the second point of transect 4, situated just behind the coastal ridge at only 30 m from the beach in a small pit, surrounded by dense and high shrub vegetation, catches the lowest amount of the whole transect (only 1/4 of the amount of the jar on top of the coastal ridge, less than 10 m away). The rather high number of measuring points in this limited area calls for a closer scrutiny with respect to topography and shelter from the surrounding vegetation.

Exposure is determined mainly by: distance from the sea, height above N.A.P and distance to the nearest sheltering vegetation in the line of the salt-bearing wind. A distance of less than 10 m and a height of at least 3 m have been used as criteria for considering a surrounding vegetation as "sheltering" (*table 1*). It seems justified to draw up a rank order of the measuring points according to the exposure, with the aid of these 3 factors.

Rank correlation between total salt deposit and exposure as measured in this way is significant: transect 1: $r = 0,95$, $n = 6$, $P < 0,05$; transect 2: $r = 0,98$, $n = 10$, $P \leqslant 0,05$; transect 3: $r = 0,90$, $n = 7$, $P < 0,05$; transect 4: $r = 1$, $n = 4$.

Generally, the same is true for separated periods: transect 1: 90%, transect 2: 85%, transect 3: 80%, transect 4: 90% significant correlations.

4.3. Salt deposit and wind direction: comparison of the four transects

Due to the exposition of the coastline to the sea, the wind from various directions will have a different effect on the salt deposit in the four transects. The measuring jars on top of the coastal ridge are therefore compared for their salt recordings in periods with strong prevailing wind from southwestern + western and northwestern + northern winds respectively. Generally, transect 4 has the lowest figures. This corresponds with the inland position and the low salt content of the water in the corresponding part of the Haringvliet.

The data of transect 1 and 2 are roughly similar, whilst transect 3 shows an irregular pattern: sometimes the values are higher, sometimes they are lower than those of transect 1 and 2, depending on the wind direction. Higher values were recorded on 8–12, 16–3, 25–5, 17–8 and 26–10 under strong southwestern and western winds; lower on 5–1, 13–4 and 24–11 when predominantly northwestern and northern winds occurred.

4.4. Salt deposit and rainfall

In the year of investigation the periods of high winds (northern, northwestern, western and southwestern) usually coincided more or less with those of highest rainfall, e.g.: 24–11 (1,3), 8–12 (2, 4), 17–8 (3, 9), 26–10 (4, 1), 13–4 (5, 2), 25–5 (6, 6), 5–1 (7, 7). The numbers in brackets stand for the rank numbers of rain and wind respectively. Consequently no clear distinction can be made between salt from the droplets of seawater, carried inland by the wind, and salt dissolved in rainwater and mostly transported at higher altitudes and thus over greater distances. Still, there is some indication that strong winds are more important in this respect than rain: e.g. in the period preceding 16–3 (strong southwestern wind) little rain and a high salt deposit was recorded, which indicates the importance of the wind. However, these few data do not allow definite conclusions.

5. DISCUSSION

The heterogenous distribution of salt deposit in coastal areas has been sufficiently demonstrated; the results of the investigation on marine salt deposition in the area of Voorne confirm the phenomena described earlier by various authors. Influence of wind velocity, wind direction, distance from the sea and, interfering with the latter, shelter caused by topographic and vegetational features, has been shown to be important for the pattern of distribution. This pattern can be expressed as a number of spatial gradients: a macro-gradient from the foreshore to the inland dunes and, within the macro-gradient, many micro-gradients in every direction, which provide all possible habitats as for the incoming sea-spray elements. Additionally, the everchanging income in the course of the year provides an instability, which can be expressed as numerous gradients-in-time.

However, the pattern of distribution as a result of the income from sea-spray is only a part of the significance of air-borne salt as a contributor to the gradient complex of the dunes. For the enormous amounts of chlorids that are deposited in such an area would soon provide an overall surplus that would result in levelling down the environment in this respect. Gradients in the environment and consequently in the vegetation show their utmost diversity when very much and very little (approaching to zero) of any component are both available at a short distance from each other. ETHERINGTON (1967) a.o. gives some figures on the fluctuations of different nutrient elements in a sandy oligotrophic dune system: $CaCO_3$ is leached by rainwater and the content in the upper soil layer decreases with the distance from the sea. K is also leached down but the total K remains at a constant level in soils of all ages and exchangeable K increases with age. Na and Cl are both washed down rapidly. It is suggested by Etherington that the income of nutrient elements from sea-spray may compensate for the leaching-loss by rain.

With respect to the existence of gradients and thus for biological diversity one may, however, as well put it the other way round: the leaching by rain and the uptake by the vegetation may balance the income of nutrient elements from sea-spray. The decrease of nutrient elements in the upper soil layer may be considered as an essential reverse process to preserve continuously the "deficiency" (in terms of areas "without" certain elements). Besides a large number of environmental components in general the low level of nutrient elements is essential for the development of differentiated communities (Voorne brochure, 1968).

The present study deals with the distribution of the income of salt; similar investigations on the rate of leaching should be done to complete the picture of the range of fluctuations and spatial distribution.

In view of the results of former studies (e.g. EDWARDS & CLAXTON 1964) which pointed out that quantitative differences in successive years could be considerable, while qualitatively they showed the same tendency, one year of investigation seems sufficient to obtain an impression of the relative amount of salt deposit. In a limited way a continuation of the project will be effectuated in the future to follow the influence of the expansion of the Maasvlakte area.

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