Acta Bot. Neerl. 37(2), June 1988, p. 279–290

Inundation and the distribution of plant communities on Dutch river dikes

K. V. SÝKORA, E. SCHEPER and F. VAN DER ZEE

Department of Vegetation Science, Plant Ecology and Weed Science, Agricultural University, Bornsesteeg 69, 6708 PD Wageningen, The Netherlands

SUMMARY

The relationship between the distribution of plant communities occurring on river dikes and the inundation by river water is described. The distribution of many species is restricted to the non-flooded upper part of the dike slope, while their lowest distribution limit coincides with the highest water-level for the growing season for the year preceding the recording of the vegetation.

The phytosociological elements show the same distribution pattern in all five transects studied and can be clearly ordered by means of detrended correspondence analysis as well as by their relative inundation values:

—hardly flooded: Koelerio–Corynephoretea, Festuco–Brometea and Mesobromion.

—slightly flooded: Arrhenatheretum and Trifolion medii.

—flooded: Arrhenatherion, Molinio–Arrhenatheretea, Artemisietea, Lolio-Cynosuretum and arable weeds.

—considerably flooded: Ranunculo–Alopecuretum, Bidentetalia, Molinietalia, Phragmitetea and Lolio–Plantaginetum.

Typical 'fluviatile' plant communities are strongly declining on river dikes. (Re) Introduction of these communities by means of special construction measures (e.g. the application of suitable soil) and special management practices is only possible above 2–2·30 m below 'normative water level'.

Key-words: Arrhenatherion, dike vegetation, inundation, Mesobromion.

INTRODUCTION

The main river valleys in The Netherlands have been assigned to a single plant geographical district, the 'Fluviatile district' (Sloff & van Soest 1938, 1939). About 250 Phanerogams are characteristic of this district, i.e. about 20% of the total Dutch flora, and about 100 species are restricted to it.

Most of the fluviatile species occurring on river dikes belong to the grasslands of warm, dry, base-rich and generally calcium-rich soils, the Medicagini–Avenetum pubescentis De Leeuw 1936, and to the relatively dry sub-associations of the hay meadows belonging to the Arrhenatheretum elatioris Br.–Bl. 1925 and the pastures of the Lolio–Cynosuretum (Br.–Bl. et De Leeuw 1936) R.Tx. 1937 em. Van Leeuwen et Westhoff apud A. Bakker 1965 (Westhoff & den Held 1969).

Due to intensive agricultural practices in particular and to former dike improvements, these communities have declined considerably during the last decades (Sýkora & Liebrand 1987).

In The Netherlands the river dikes have a total length of 1002 km (Hoofddirectie Rijkswaterstaat 1986). Following the great flood in 1953 it was decided that all sea dikes and all river dikes should be improved. In 1986, 600 km of river dike had yet to be heightened and widened. The strengthening is due to be completed in 1998.

Because of the large-scale mechanical disturbance, these dike constructions produce serious negative effects on the landscape as well as on the vegetation. A committee was set up to study the possibilities of reducing these effects. In 1977 it proposed the application of so-called 'optimal projects' in order to spare the landscape as much as possible, without ignoring the safety aspects. At the same time it expressed the necessity of researching into the possibilities of conserving or restoring the endangered plant communities on river dikes (Technische Adviescommissie Waterkeringen 1985, 1986).

In 1984 a vegetation survey started at our division. The aim of this study was to give directives for the construction of the dikes and for management of the dike slopes in order to allow the re-introduction or the conservation of valuable plant communities. The cause and extent of the decline of these communities, their relationships with the environment and with the management was studied. In addition, the distribution of the roots and the significance of the different plant communities was studied with regard to the prevention of erosion (Sýkora 1985; Sýkora & Zonderwijk 1986; Sýkora & Liebrand 1986; Technische Adviescommissie Waterkeringen 1986).

In this paper we demonstrate the relationship between the distribution of the dike vegetation and the period of inundation. Apart from having a synecological significance these data may be of value for dike construction. Execution of special construction and management directives below the level of tolerance to inundation of the plant community to be re-introduced will be ineffectual.

METHODS

The vegetation

Five locations were selected along the rivers IJssel, Waal, Rhine and Maas. The selection was based on the presence of well-developed fluviatile grasslands. At each location a transect was made, perpendicular to the dike, from the top downward into the river foreland.

The transects were sampled by means of contiguous quadrats at right angles to the transect line and sized 0·5 × 2 m in three of the transects and 0·5 × 4 m in the other two transects. For estimation of the quantitative occurrence of each species the Braun–Blanquet scale, as refined by Barkman *et al.* (1964), was used. The altitude of all quadrats was measured in Amsterdam ordnance datum in order to relate these altitudes to the data on the fluctuation of the free water-level of the river as given by the Department for the Maintenance of Dikes, Roads, Bridges and the Navigability of Canals (Rijkswaterstaat).

In addition, for three of the locations, a frequency method was used to record the vegetation. The species occurring in sample plots of 10 cm^2 were recorded along contour lines with intervals of 1 m. The distance between the contour lines was 25 cm. Their length was 25 m in two cases and 17 m in the other case.

Detrended Correspondence Analysis (DECORANA, Hill 1973, 1979) was used for the ordination of all relevés from all transects together. The syntaxonomic status of the

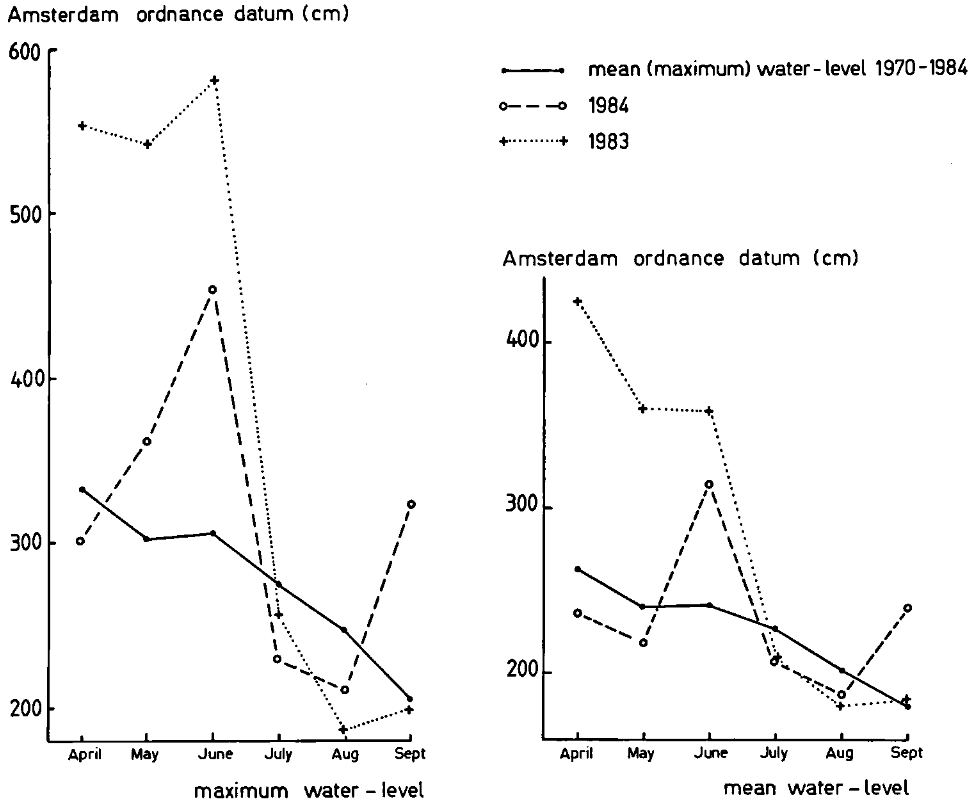

Fig. 1. Maximum and mean water levels per month in 1983 and 1984 compared with the mean over the last 15 years.

species was plotted in the ordination diagram. The correlation between the axes scores and the Ellenberg indicator values (Ellenberg 1978) was calculated and regression lines were drawn.

For each relevé the percentage occurrence of the phytosociological elements was calculated by dividing the number of species belonging to one phytosociological element by the total number of species occurring in the relevé, multiplied by 100. This value was used to draw smoothed curves of the distribution of the phytosociological elements along the transects. Smoothed curves of the distribution of the main species were drawn using the frequencies measured by means of the contour lines.

The results of the ordination and the relative inundation values (RI, see *Hydrology*) are based on all relevés of all transects. As for the other results, the same conclusions can be drawn for all the transects studied. In order to reduce the number of figures only the figures belonging to one transect (IJssel) are presented in this paper.

Species nomenclature follows Heukels & van der Meijden (1983). The nomenclature of the syntaxa follows Westhoff & den Held (1969).

Hydrology

The total number of days of inundation in the growing season (1 April–1 October) was calculated for each quadrat and each contour line for 1983 and 1984, respectively. The

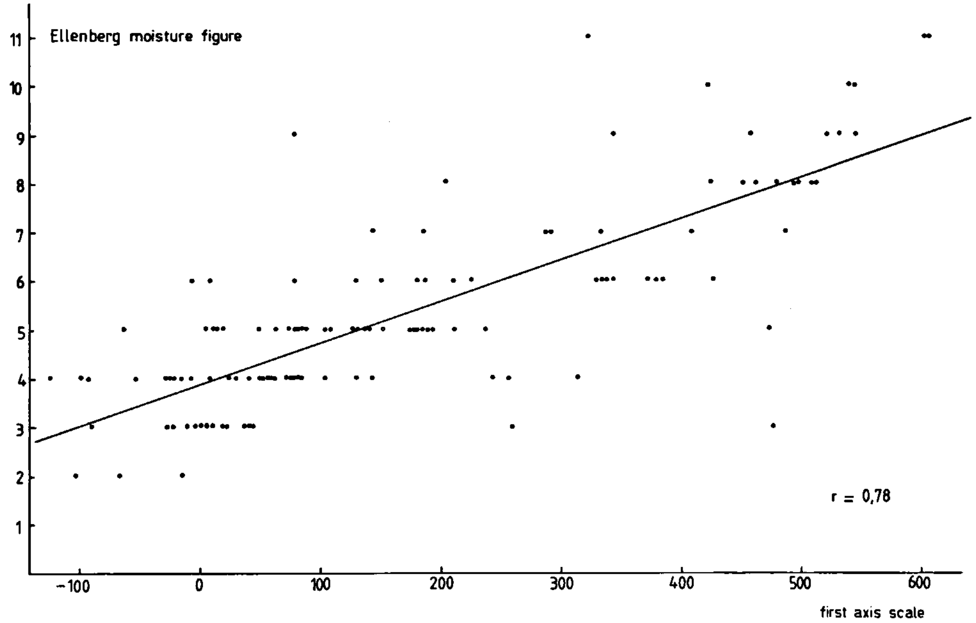

Fig. 2. Relation between the moisture figures (Ellenberg 1978) and the scale of the first axis of the species ordination.

Table 1. Texture; 1 = upper part of the transect, 2 = upper middle part or middle part, 3 = lower middle part or lower part, 4 = lower part; s = sand, sls = slightly loamy sand, vls = very loamy sand, sl = sandy loam, ls = loamy sand, ll = light loam, l = loam, hl = heavy loam, lc = light clay

	Sampling sites			
	1	2	3	4
Transect IJssel 1	sl	ll	sl	lc
Transect IJssel 2	vls	l	hl	
Transect Waal	ls	l	l	
Transect Rhine	sls	l	sl	
Transect Maas	s	sls	s	

Table 2. Total nitrogen (mg kg^{-1} soil)

	Sampling sites			
	1	2	3	4
Transect IJssel 1	93	151	167	335
Transect IJssel 2	164	240	304	
Transect Waal	178	264	356	
Transect Rhine	99	224	225	
Transect Maas	87	107	31	

Table 3. Organic matter content (%)

	Sampling sites			
	1	2	3	4
Transect IJssel 1	2·9	5·2	5·4	10·0
Transect IJssel 2	6·4	6·8	10·0	
Transect Waal	6·1	7·6	15·5	
Transect Rhine	5·5	7·8	7·9	
Transect Maas	3·2	3·3	1·3	

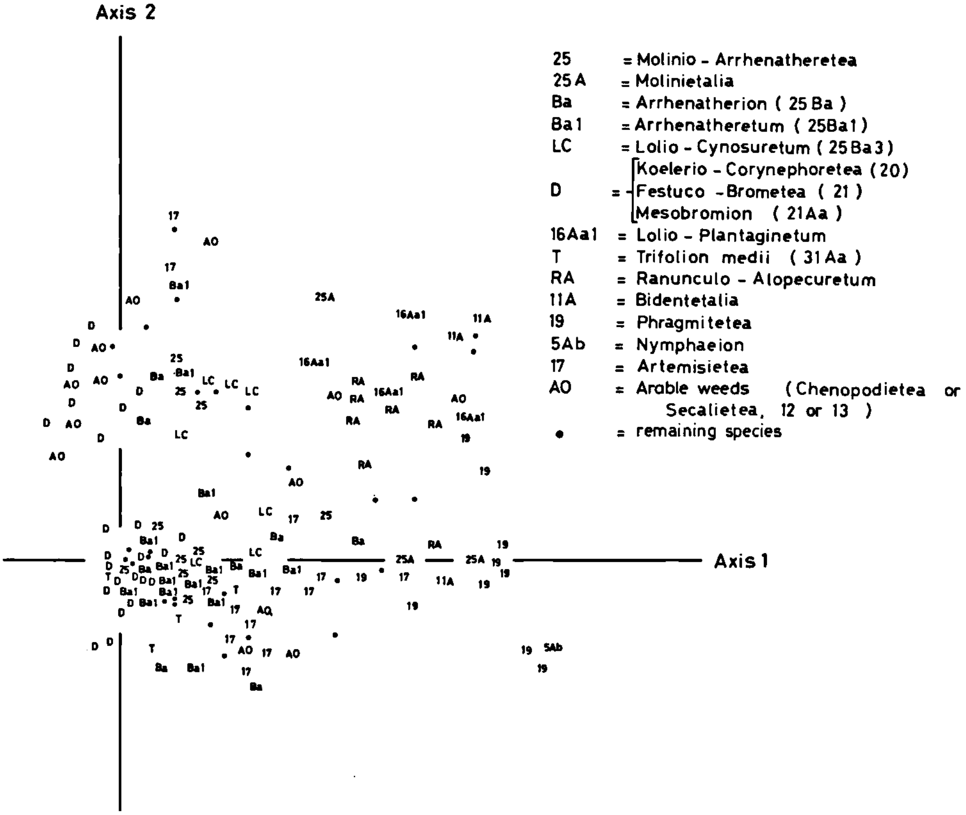

Fig. 3. Ordination diagram in which the syntaxonomical status of the species is indicated.

basic data on the free water-level were taken from the monthly reports as given by the Department for the Maintenance of Dikes, Roads, Bridges and the Navigability of Canals (Rijkswaterstaat). The year 1984 was the year prior to that in which the vegetation had been recorded and 1983 appeared to be the year with the highest water-level during the preceding 15 years (Fig. 1). The highest water-level for both years is indicated in Figs 4 and 5.

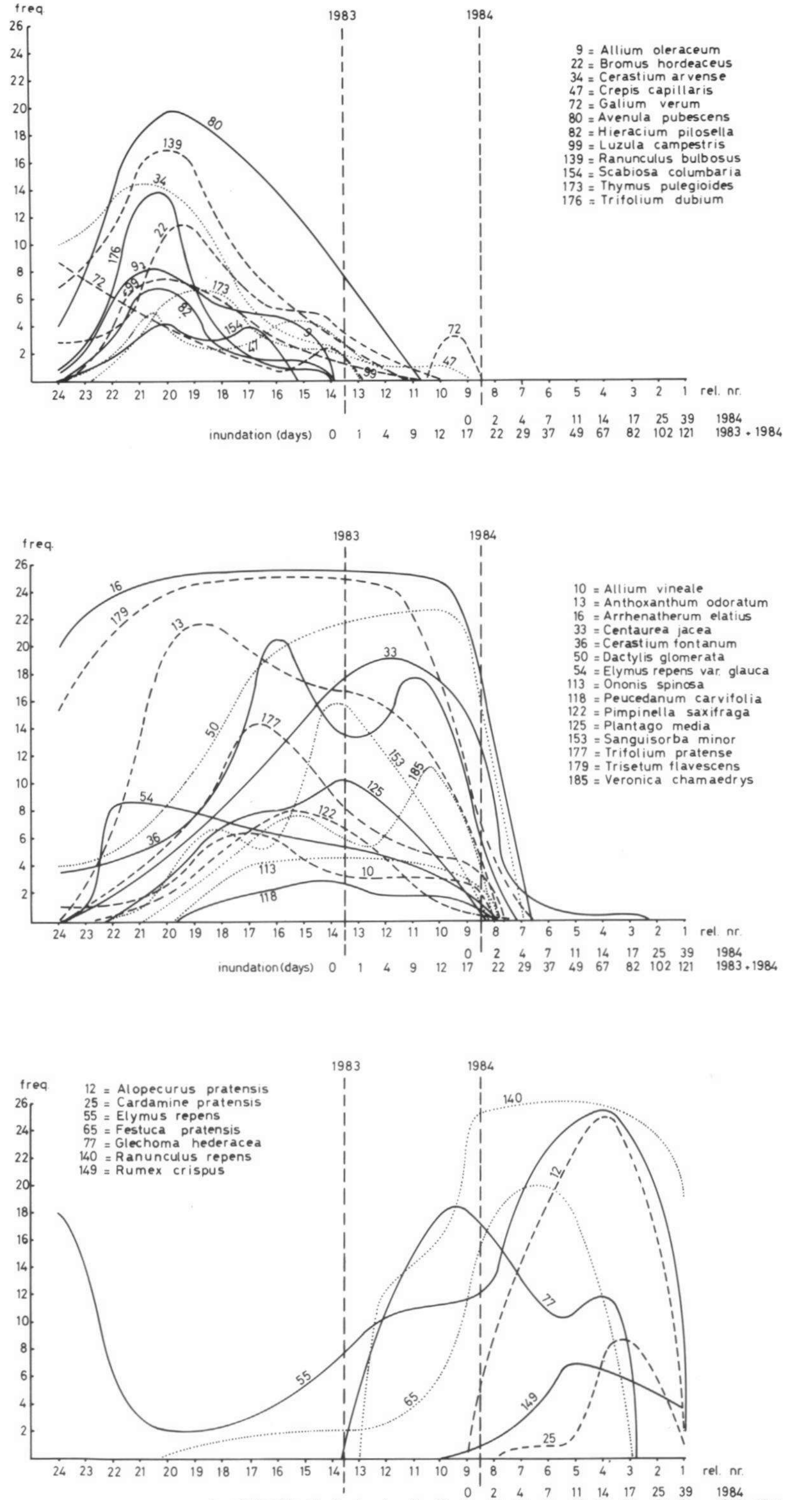

Fig. 4. Frequency distribution of a selection of species from the top of the dike (left) downward into the river foreland (right). The highest water-level reached in the growing season of 1983 and 1984 is indicated as well as the flooding period in days.

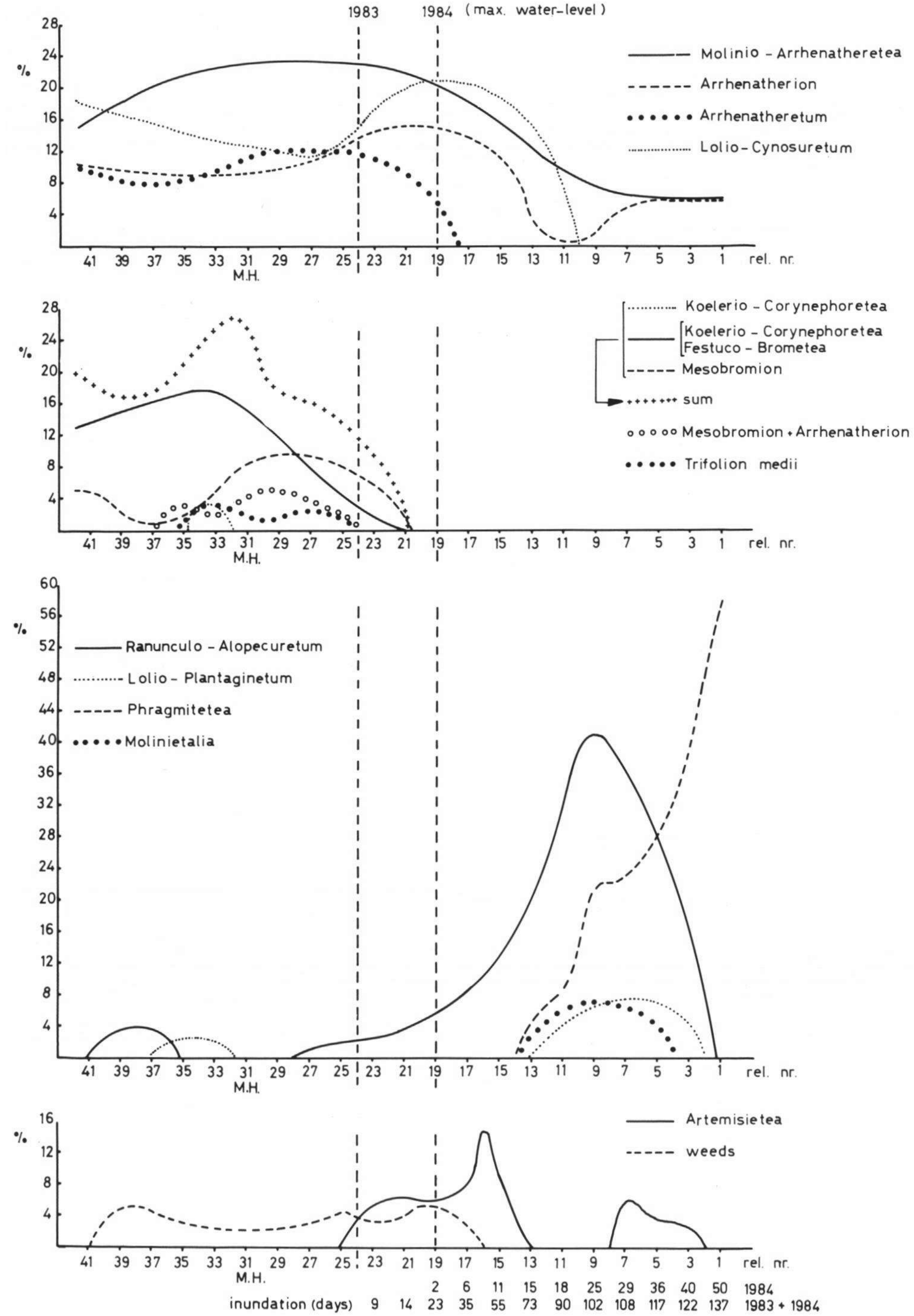

Fig. 5. Distribution of the phytosociological elements from the top of the dike (left) downward into the river foreland (right). The highest water-level reached in the growing season of 1983 and 1984 as well as the flooding period in days is indicated. M.H. = Normative water-level.

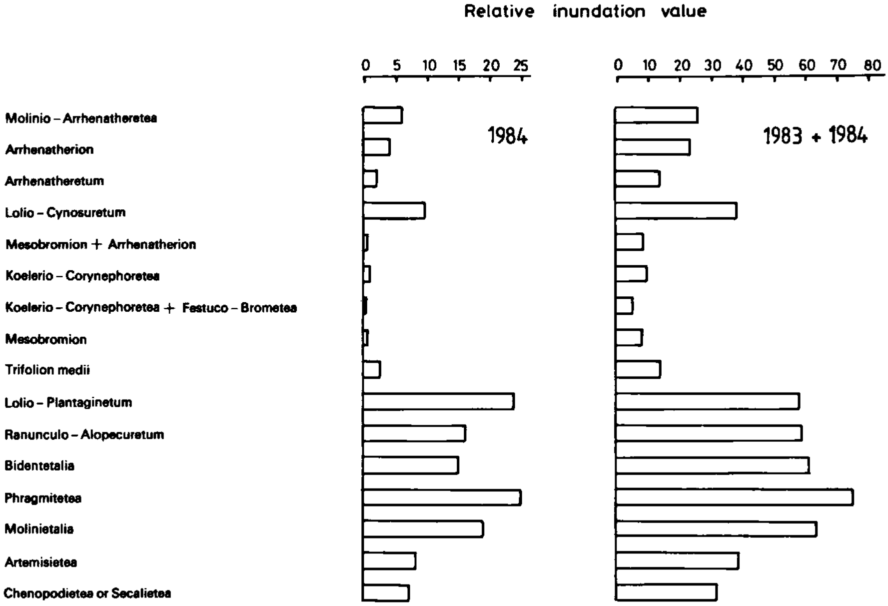

Fig. 6. Relative inundation values (days) of the different phytosociological elements in 1984 and in 1983+1984.

For each species a relative inundation value (RI) was calculated (Sýkora 1983). This value is a measure of the extent to which a species has been exposed to flooding. It was calculated by determining the average number of days (X) during which each species was flooded in any transect, adding up these values and then dividing them by the number of observations. This can be expressed as:

$$X_1 = \mathrm{h}p + \mathrm{l}p/2$$

in which hp = the inundation period at the highest position in transect l and lp = idem at the lowest position in transect l. The relative inundation value is calculated as follows:

$$\mathrm{RI} = (X_1 \rightarrow n)/n$$

in which n = the number of transects in which species A occurs. If the range of a species continued above or below the limits of the transect, the inundation period registered at one of the extremes of the transect had to be used in the calculations.

In all numerical methods used above the extended scale of Barkman *et al.* (1964) was transformed into a 1–9 numerical scale according to the ordinal transformation (van der Maarel 1979).

Soil analysis

Soil samples were collected from three or four sampling sites along each transect at a depth of 2–12 cm. Each sample was composed of a mixture of 12 sub-samples taken within a sampling plot of 1 m^2. They were analysed for exchangeable Na, K, Mg, PO_4, NO_2 and NO_3 after extraction for 2 h at room temperature with 0·01 M $CaCl_2$ in a 1:10 soil solution ratio; for measurements of total-N and total-P see Houba *et al.* (1985). Subsequently, in the same samples, the pH of the sample in water was determined, the percentage organic matter according to Kurmies, and the percentage $CaCO_3$ according to Scheibler. Texture was estimated using a field method.

RESULTS

Ordination

The relevés are clearly ordered along the first axis according to their altitude, relevés from the upper part of the transects occur on the left side of the diagram while relevés from the lower part occur on the right side.

The correlation between the Ellenberg indicator values for moisture and the first axis (Fig. 2) is highly significant ($r=0{\cdot}78$, $n=115$). Species characteristic of dry soil are gradually displaced by species characterizing moist and wet conditions. The correlation between the nitrogen indicator values and the first axis although significant is considerably less ($r=0{\cdot}49$, $n=115$). No correlation with other indicator values could be demonstrated.

Along the second axis the relevés of the transect from the river Maas are clearly separated from those of the other transects.

In three of the transects (along the IJssel and the Waal) the loam and clay content is shown to increase in a downward direction. In the other two transects (Rhine and Maas) the soil is heaviest in the middle part of the transect (Table 1).

In all transects with exception of the Maas transect the total N content (Table 2) and the organic matter content (Table 3) are shown to increase downwards.

In the species ordination (Fig. 3), species characteristic of the Koelerio–Corynephoretea Klika apud Klika et Novák 1941, Festuco–Brometea Br. Bl. et R.Tx. 1943 em. R.Tx. 1961 and Mesobromion (Br.-Bl. et Moor 1938 em. Oberd. 1949 pro suball.) Oberd. 1957 occur at the utmost left side of the diagram, followed by species characteristic of the Molinio–Arrhenatheretea R.Tx. 1937, the Arrhenatherion elatioris Br.-Bl. 1925 and its subordinate communities and by the Trifolion medii Th. Müll. 1961.

Species characteristics of the Ranunculo–Alopecuretum geniculati R.Tx. 1937, the Bidentetalia Br.-Bl. et Tx. 1943 and the Phragmitetea R.Tx. et Preising 1942 occur at the right side of the first axis. The species characterizing the Artemisietea vulgaris Lohm., Preising et R.Tx. 1950 em. Lohm. *et al.* 1962 take a middle position. Weed species (Chenopodietea Br.-Bl. 1951 or Secalietea Br.-Bl. 1951) mainly occur on the left side and are most frequent in the upper left part of the diagram which corresponds with the more sandy, more loose and thus easily disturbed upper part of the Maas transect.

Species distribution

In Fig. 4 the distribution of a selection of species occurring in one of the IJssel transects is drawn from the top of the dike (left) downward into the river foreland (right). The highest water level in the growing season of the preceding year (1984) and in the year with the most extreme water-level over the last 15 years (1983) is indicated.

There is a remarkable coincidence between the lower distribution limits of a number of species and the upper water-level (Fig. 4B). These species are characteristic of the Molinio–Arrhenatheretea (*Anthoxanthum odoratum, Centaurea jacea, Cerastium fontanum* and *Trifolium pratense*), the Arrhenatherion (*Dactylis glomerata, Crepis capillaris* and *Allium vineale*), the Arrhenatheretum (*Arrhenatherum elatius, Peucedanum carvifolia* and *Trisetum flavescens*) and the Koelerio–Corynephoretea + Festuco–Brometea (*Pimpinella saxifraga* and *Galium verum*) and the Meso–Bromion (*Elymus repens var. glauca, Ononis spinosa, Plantago media* and *Sanguisorba minor*).

Other species occurring with their highest frequencies above the extreme water levels of both 1983 and 1984 (Fig. 4A) are *Allium oleraceum, Cerastium arvense, Avenula pubescens,* *Hieracium pilosella, Ranunculus bulbosus* and *Thymus pulegioides* (Koelerio–Corynephoretea + Festuco–Brometea), *Trifolium dubium* (Arrhenatherion), *Luzula campestris* (Mesobromion + Arrhenatherion) and *Bromus hordeaceus. Scabiosa columbaria, Trifolium dubium, Hieracium pilosella* and *Allium oleraceum* were not found beneath the 1983 extreme water-level.

The coincidence between the upper distribution limit of species and the highest water-level in 1984 is less clear (Fig. 4C). The upper limits of *Cardamine pratensis, Rumex crispus* and *Alopecurus pratensis,* coincide with the highest level in 1984. *Ranunculus repens, Elymus repens* and *Festuca pratensis,* although most frequently beneath this level, also occur above the zone inundated in 1984.

The relationship between the distribution and the flooding in the other transects is similar. In all transects most species disappear and are replaced by other species at the maximal water level of 1984. The composition of the actual vegetation appears to be more strongly related to the flooding of the preceding year (1984) than that of the maximum water level of 1983, the year with the highest water level recorded over the last 15 years.

Phytosociological elements

Figure 5 shows the distribution of the phytosociological elements on the dike slope of one of the transects (IJssel).

Phytosociological elements not inundated in 1984 are the Koelerio–Corynephoretea, Festuco–Brometea, Mesobromion and Trifolion medii (Fig. 5B). This applies to all transects but one; in the sandy Maas transect the lowest quadrats containing these elements were flooded during 4 days.

The Arrhenatheretum element is almost restricted to the zone not flooded in 1984. The lowest quadrat containing this element was flooded from 0 to 8 days in four of the transects and during 14 days in the case of the sandy Maas transect. The Molinio–Arrhenatheretea, the Arrhenatherion and the Lolio–Cynosuretum species occur all over the transects (Fig. 5A).

The phytosociological element of the Ranunculo–Alopecuretum occurs optimally in the inundated zone. Species of the Phragmitetea and the Molinietalia are restricted to flooded quadrats (Fig. 5C).

The so-called nitrophilous tall herbs of the Artemisietea have their optimal occurrence in the quadrats in the neighbourhood of the high-water mark where organic matter is deposited (Fig. 5D).

Relative inundation value

The relative inundation value (RI, Fig. 6) is a measure of the mean number of days during which a phytosociological element has been flooded.

Species from the Koelerio–Corynephoretea, Festuco–Brometea and Mesobromion were hardly flooded during the growing season. The RI values of the Arrhenatheretum and the Trifolion medii, although still very low, are slightly higher than in the case of the former elements.

The RI values of the phytosociological elements Arrhenatherion, Molinio–Arrhenatheretea, Artemisietea, Lolio–Cynosuretum and of species from weed communities are again higher.

The highest RI values have been found in the case of the Lolio–Plantaginetum, Ranunculo–Alopecuretum, the Bidentetalia, the Molinietalia and the Phragmitetea.

DISCUSSION

The vertical distribution of the species as well as of the different phytocoena is clearly correlated with soil moisture (Fig. 2) and with flooding (Figs 4 and 5). The boundary zone in which many species disappear is very narrow and coincides with the extreme water-level in the growing season of the year preceding the sampling of data.

As the lower quadrats are flooded by nutrient-rich river water, the nutrient status of the soil increases in a downward direction. While nutrients are removed from the upper part of the dike slope by leaching, the lower parts are enriched by the river water. This is in accordance with the correlation between the first axis and the nitrogen indicator values. No other factors show any clear relation to the altitude.

Because of the facts stated above the assumption that the vertical changes in the floristic composition are mainly influenced by the hydrological conditions and that other soil factors are only of secondary importance is very plausible. This is in accordance with the statement by Balátová-Tuláckovà (1972) that in grassland 'the trophic status of the soil and the moisture conditions are the most important controlling environmental factors. Major changes may occur in the quantitative representation of individual species in habitats characterized by considerable moisture fluctuation in the course of a year'. In years of excessive rainfall Balatová-Tuláckova (1972) observed a marked general reduction in species that cannot survive prolonged inundation, e.g. species of the class Molinio–Arrhenatheretea (see also Stoffers & Knapp 1962; Klapp 1965; Walther 1977). During these years swamp species were on the increase.

The flooding leads to oxygen depletion of the soil which again causes the formation of toxic substances, which can seriously trouble the respiration of the cell. Flood-tolerant species are metabolically adapted to these conditions. While under anaerobic conditions flood-sensitive species produce toxic amounts of ethanol as a result of an increased rate of glycolysis; in flood-tolerant species, a metabolic switch may lead to the accumulation of mainly (non-toxic) malic acid. Various species may also avoid oxygen stress by means of oxygen diffusion through stems, rhizomes and roots. Species selection is probably already taking place in the seed bank. Most seeds will not normally germinate if the oxygen tension is decreased below that of the atmosphere and after some time their viability becomes impaired. Other species can only germinate in a very moist habitat (for references see Sýkora 1983).

Along the second axis of the ordination the relevés of the transect from the river Maas are clearly separated from those of the other transects. The different species combination probably depends on the fact that the soil of the Maas transect differs from that of the other transects in that its soil texture is very sandy. The soil is generally heavier in the other locations. Apart from the lowest quadrats, the Maas Transect is differentiated from all other transects by the presence of: *Sedum acre, Sedum sexangulare, Erophilia verna, Arenaria serpyllifolia, Salvia pratensis, Capsella bursa-pastoris, Tanacetum vulgare, Viola arvensis, Sisymbrium officinale, Medicago lupulina, Veronica arvensis* and *Leontodon saxatilis*. A number of these species clearly indicate dry sandy conditions. Just as in the other transects the relevés made in the Maas transect are clearly arranged according to their vertical position. The lower distribution limits in the Maas transect, when compared with the other transects, is probably due to the sandy soil being water-logged during considerably shorter time after the retreat of the water.

One of the directives for the improvement of the river dikes is the 'normative water-level'. This water-level occurs at a discharge of 16 500 m^3 at Lobith. The total height of the dikes after improvement will be at least 50 cm above 'normative water-level'. On dike slopes facing the river, the Koelerio–Corynephoretea, Festuco–Brometea and Mesobromion species were only found above 2–2·30 m below MHW. Beneath this altitude introduction of these phytosociological elements by special construction methods and management practices are likely to fail.

These communities are very sensitive to summer inundations. Furthermore, the presence of the first three elements is stimulated by the lower fertility of the upper quadrats.

ACKNOWLEDGEMENTS

We thank Professor Dr V. Westhoff for critically reading the text, H. M. Klees for his technical assistance in preparing the figures. The help of N. de Zylva in correcting the English text is also appreciated.

REFERENCES

Balátová-Tuláckova, E. (1972): Dynamics of the plant cover in inundated meadows of southern Moravia. In: M. Rychnovská (ed.): *Ecosystem Study on Grassland Biome in Czechoslovakia* PTPP/IPB Report no. **2:** 5–10.

Barkman, J.J., Doing, H. & Segal, S. (1964): Kritische Bemerkungen und Vorschläge zur quantitativen Vegetationsanalyse. *Acta Bot. Neerl.* **13:** 394–419.

Ellenberg, H. (1978): *Vegetation Mitteleuropas mit den Alpen.* Verlag Eugen Ulmer, Stuttgart.

Heukels, H. & van der Meijden, J. (1983): *Flora van Nederland (20^e druk).* Wolters-Noordhoff, Groningen.

Hill, M.O. (1973): Reciprocal averaging: an eigenvector method of ordination. *J. Ecol.* **61:** 237–249.

— (1979): *DECORANA.* Cornell University, Ithaca.

Hoofddirectie Rijkswaterstaat (1986): *Indicatief uitvoeringsprogramma rivierdijken.* Den Haag.

Houba, V.J.G., van der Lee, J.J., Walinga, I. & Novozamsky, I. (1983): *Soil Analysis, Part 2: Procedures.* Landbouwhogeschool, Wageningen.

Klapp, E. (1965): *Grünlandvegetation und Standort.* Paul Parey, Berlin und Hamburg, 384 pp.

Sloff, J.G. & van Soest, J.L. (1939): Het fluviatiele district in Nederland en zijn flora. *Ned. Kruidk. Arch.* **48:** 199–265.

— & — (1939): Het fluviatiele district in Nederland en zijn flora. *Ned. Kruidk. Arch.* **49:** 268–316.

Stoffers, A.L. & Knapp, R. (1962): Experimentelle Untersuchungen über den Einfluss von Ueberflutungen auf verschiedene Rasengesellschaften. *Ber. Deutsch. Bot. Ges.* **75**(8): 280–294.

Sýkora, K.V. (1983): *The Lolio-Potentillion anserinae R. Tüxen 1947 in the northern part of the Atlantic domain.* PhD thesis, University of Nijmegen.

— (1985): Relatie tussen beheer, vegetatietype en bodembedekking op rivierdijken. *Bladgroen* **6:** 14–21.

— & Liebrand, C. (1986): Behoud, herstel en ontwikkeling van soortenrijke dijkvegetaties. *Waterschapsbelangen* **23/24:** 686–699.

— & Zonderwijk, P. (1986): Kleurrijke dijkbeemden hoe lang nog? *Waterschapsbelangen* **10:** 247–253.

Technische Adviescommissie Waterkeringen (1985): *Leidraad voor het ontwerpen van rivierdijken. Deel 1 Bovenrivieren.* Staatsuitgeverij, Den Haag.

— (1986): *Landbouwkundig en natuurtechnisch beheer van rivierdijkgrasland.* TAW, Den Haag.

Van der Maarel, E. (1979): Transformation of cover-abundance values in phytosociology and its effect on community similarity. *Vegetatio* **39**(2): 97–114.

Walther, K. (1977): Die Flussniederung von Elbe und Seege bei Gartow (Kr. Lüchow-Dannenberg). *Abh. Verh. Naturwiss. Ver. Hamburg* **20,** 123 pp. P. Parey, Hamburg.

Westhoff, V. & den Held, A.J. (1969): *Plantengemeenschappen in Nederland.* W.J. Thieme & Cie, Zutphen.