III.2

The role of river dynamics in the conservation of dry river grasslands

Kris Van Looy

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Abstract

Question

In what way and to what extent do river dynamics determine the development, conservation and restoration of dry river grasslands?

Location

The River Meuse is one of the larger Northwest European streams with nature protection that places emphasis on river corridor plants in dry river grasslands. The Common Meuse reach is a 30km unregulated river stretch at the border between Belgium and the Netherlands.

Methods

The grasslands of the alluvial plain were mapped and sampled with vegetation relevees and soil sampling. Spatial information gathered using GIS was added to this data matrix, and a hydraulic model added river variables of flood frequency and flow velocity. Ordination and diversity analysis was carried out to link composition and diversity aspects to soil conditions and river dynamics, the results of which were used to build a community distribution model. As the dry river grassland is a threatened vegetation type, an analysis of species at risk was performed to find key constraints and define effective restoration measures.

Results

Flood dynamics, soil conditions and management proved to be determining aspects for the composition and diversity of river grassland. The different dry river grassland communities were clearly distinguished by soil pH and salt concentration – soil variables that were significantly correlated to the flood regime. The group of river corridor plant species studied were good indicators of well developed dry river grassland patches. The significant isolation aspect of the dry river grassland relicts was found to be due to recruitment limitation, as a consequence of habitat fragmentation linked to land use intensification and river regulation. As the habitat creation process is the trigger for sustainable conservation, a spatial model based on hydraulic modelling using GIS allowed the prediction of potential dry river grassland development and gave insight into spatial and management requirements for conservation strategies.

Conclusions

Knowledge of habitat conditions and dynamics is essential when forming conservation strategies for dry river grasslands. The river corridor plants proved to be a good flagship species group for the protection and restoration effort.

Introduction

Conservation and restoration of river landscapes receives much attention today, especially hot spots for diversity within the river corridor, such as the dry river grasslands (Jongman 1992, Stroh et al. 2005). In Northwest Europe's large river valleys, characteristic landscape features are levees and dikes in the floodplain, which can lead to the development of dry river grasslands. A group of river corridor plants reached these habitats by moving along the large floodplain corridors of these rivers. The natural or artificial levees are exposed to the sun and warm up quickly, creating favourable conditions for species that would normally occupy a distribution range more to the southwest; the species of the calcareous upstream regions in particular take advantage of these opportunities. River regulation, intensification of agricultural practices and disconnection of parts of the floodplain area are the main pressures for the river forelands of the large Northwest European rivers. These factors pose a huge threat for river corridor plants through increased habitat fragmentation (Burkart 2001, Donath et al. 2003, Wolfert et al. 2002).

A main focus for this research was the role that river dynamics could play in the potential rehabilitation of dry river grasslands. This central theme could be further divided into the following questions:

1. What physical variables are the most important for determining the composition and diversity aspects of these grasslands?
2. What parameters are of importance for the conservation and regeneration of habitat in space and time?
3. How can these variables be governed/controlled?

For the first question, we sampled grasslands over the Common Meuse valley and tried to identify, using ordination techniques, the determining factors for composition and richness of the vegetation, bearing in mind the special emphasis that must be placed on soil characteristics related to geomorphological processes when developing spatial predictive models for riparian vegetation (Toner & Keddy 1997, Richards et al. 2002). For delineating and choosing conservation and restoration options, we selected the rare species and the habitat at risk, the dry river grasslands being rich in river corridor species; and carried out a diversity analysis to address whether the river corridor species are a good indicator group, and so whether they can function as flagship species.

Regarding the second and third questions, river concepts and modelling approaches can be useful for defining and solving the problem. When searching for effective conservation strategies, river concepts such as the 'shifting mosaics' and 'patch dynamics concept' provide useful frameworks for the definition of spatial and management guidelines (Pickett & White 1985, Petts & Bradley 1997), and river dynamics play a central role in shaping the river landscape according to these concepts. Many authors have described flooding as the driving force behind the composition and diversity of floodplain vegetation (Heiler et al. 1995, Tabacchi et al. 1996, Tockner et al. 1999), and yet several other authors have stressed that the flood intolerance of dry river grasslands is a central conservation aspect (Jongman 1992, Vervuren et al. 2003, Eck et al. 2005). By analysing the determining factors, this study attempts to develop a model to predict the potential recovery of these threatened communities, and to derive guidelines from present distribution patterns for their conservation and restoration. These guidelines will then be useful for further planning of the restoration programme for the river's floodplain.

Study area

The site used for this study was the alluvial plain of the middle course section of the River Meuse between Maastricht and Maaseik on the border between Belgium and the Netherlands (reach of 30 km), known as the Common Meuse. The Meuse is a rain-fed river, originating at an altitude of 400 m above sea level at the Plateau of Langres in the North of France and discharging into the North Sea some 900 km further downstream. The discharge of the Meuse shows great fluctuations due to its rain-fed character and the rocky soils of the Ardennes upstream catchment (Pedroli & De Leeuw 1997), ranging from 10 m?/s during dry periods to 3,000 m?/s during periods of heavy rainfall within the catchment area. The unregulated Common Meuse stretch is a typical gravel river with a strong longitudinal gradient (0.45 m/km), the valley consisting of a gravel underground with a loamy alluvial cover. Local irregularities of levees and dikes are covered with more sandy sediments, as are the dynamic overbank sedimentation zones. The floodplain has been traditionally used as meadows for agriculture. Large parts of the alluvial plain have been excavated for gravel mining, leaving large gravel pits or lowered floodplain zones. The degradation of the floodplain natural heritage was the reason for developing a river restoration programme and to start local pilot areas, mostly in abandoned gravel mining locations. The project is defined within a larger master plan for the whole alluvial plain (Pedroli et al. 2002).

Survey and sampling

Valley and dry river grassland sampling

The vegetation survey for the Flemish side of the Meuse alluvial plain consisted of vegetation mapping with sampling for every recorded patch (Figure 3.4). For delineating homogeneous vegetation patches in the field, a minimum of 500 m? was chosen, and the basis for mapping was topographic. The patches of intensive agricultural land use were mostly uniform in terms of vegetation composition, but for the naturally managed areas more irregular patch forms were present. The 196 patches of grassland under natural or extensive management were sampled in 1999 using 1 x 1m relevees, and all species within the sample plots were recorded using the Tansley scale (Tansley, 1935). The grasslands cover a range of types, from open pioneer to dense, tall vegetation. They were classified into nine types according to river dynamics, elevation and management (Table 3.4), and were then assigned to a corresponding phytosociological association or order according to Weeda et al. (1998).

Table 3.4 Classification of grassland patch types in the Meuse alluvial plain, with annotated phytosociological communities (Schaminée et al. 1998).

Agricultural practice		
	B1 hayfields	*Arrhenatherion elatioris*
	B2 pastures	*Cynosurion cristatus*
	B3 fertilised meadows	*Poö-lolietum perenne*
Natural management		
Lower floodplain meadows	F7 long inundated meadows	*Lolio-potentillion anserinae*
	F9 floodplain meadows	*Alopecurion pratensis*
Higher floodplain meadows	L1 dry river grasslands	*Medicagini-avenetum pubescens*
	L4 xeric grasslands of open sand	*Thero-airion caryophyllea*
Overbank sedimentation zones	A1 gravel overbank sedimentation	*Alysso-sedion albi*
	A2 sand overbank sedimentation	*Sedo-thymetum pulegioides*

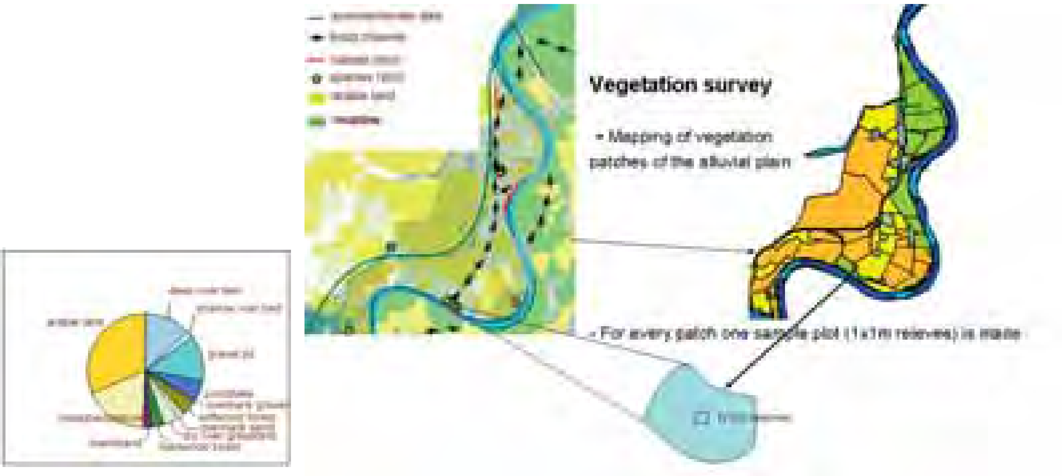


Figure 3.4 Illustration of the alluvial plain survey with an inset of results in a pie chart.

Environmental variables were gathered in the field, or derived from available digital flooding data, and also through GIS mapping. Flooding frequency of the samples ranged from more then once a year to less than once a decade, and was derived from a two-dimensional hydraulic model, developed for the restoration model, and based on a high resolution DEM of the alluvial plain. The frequencies were divided into flood frequency classes (0: >1/year; 1: 1/year; 2: 1/2–5 years; 3: 1/5–10 years; 4: < 1/10 years), and flow velocity (m/s) was also derived from this model, retrieved from the grid cells during a decennial flood episode. In addition, the distance to the river's main channel (m) was determined. Isolation data were ranked into categories, measured as the distance to the nearest same patch type (1: <50m; 2: 50–500m; 3: 500–2000m; 4: >2000m). Management was classified as: extensive meadows with haying and/or pastures (2); natural grazing (1); or no management (0). Soil humidity was classified as: wet (3); periodically wet with high fluctuation (2); moderately dry (1); or extremely dry (0). The organic matter in the topsoil layer was categorized as: a thick humus layer (2); present (1); or absent (0). Soil texture in each sample plot was manually analysed and recorded into nine categories: clay (1); silt (2); loam (3); sandy loam (4); loamy sand (5); clayey sand (6); sand (7); gravel–sand (8); or coarse gravel (9).

A set of 50 topsoil (20cm) samples was taken from the grassland sampling plots, uniformly distributed over the Meuse valley gradients of distance to river and elevation, to specifically look at the soil conditions for grassland species in their root zone. As several authors (Grévilliot et al. 1999, Wolfert et al. 2002, Donath et al. 2003) have identified soil conditions as critical for these communities, emphasis in this study was placed upon these factors in relation to the flooding regime, and relevant soil parameters such as texture, pH, conductivity and organic matter content were measured in the laboratory. Analysis of soil texture was carried out by laser diffraction; pH by Metrohm (titration, pH-carrousel); organic matter by Moffeloven destruction analysis; and conductivity by measuring EC with a conductance meter and translating the readings to soil salt concentration. The surveyed abiotic conditions were screened for correlations using the Pearson correlation test.

Dry river grassland communities and habitat conditions

For the dry river grasslands of the Common Meuse, four vegetation types can be distinguished within the habitat type classification of the European Natura2000 habitat network (EC/92/43, 1992) (Table 3.5). The communities of dry river grasslands can be defined by specific types of pioneer associations of Alysso-Sedion albi (gravel substrates) and the Sedo-Thymetum pulegioides or Thero-Airion caryophyllea of sandy overbank deposits. Succession leads to the dry river grasslands of the Medicagini-Avenetum pubescens or other Koelerio-Corynephoretea communities.

The species of these communities are mostly small and uncompetitive, and for colonization of the habitat to take place, open pioneer conditions are needed. In the xeric Thero-Airion grasslands, two directions of development can be identified: the development of river dune communities, with a richer initial phase; and the continued dynamics of wind and grazing preventing the stabilisation of the stands. Here, the more nutrient-dependent species such as Geranium columbinum and Medicago species indicate an initial phase of development to xeric river dune communities of Thero-airion closer to the Sedo-Cerastion, with the presence of Vulpia bromoides, V. myuros, Carex arenaria and C. hirta. The stands further from the river develop into communities of more acid xeric soils, with the presence of Filago minima and Corynephorus canescens. The most common grasslands of this group are examples under pasture, with a mixture of Thero-airion and Galio-trifolietum grassland, and were classified as an extended Thero-Airion+ community.

Riverine Habitat	Habitat type (EU Habitat Directive)	Characteristic River Meuse corridor species
Overbank gravel deposition A1	6110 pioneer vegetation of calcareous stony substrates Alysso-sedion albi	*Sedum album, S. acre, Poa compressa, Saxifraga tridactylites, Sedum sexangulare, Erophila verna, Galeopsis angustifolia, Geranium pusillum, Kickxia elatine, K. spuria, Lepidium campestre, Verbascum blattaria, Torilis arvensis, Picris echioides*
Overbank sand deposition A2	6120 pioneer grassland of calcareous sandy soils Sedo-thymetum pulegioides	*Sedum reflexum, Avenula pubescens, Carex caryophyllea, Herniaria glabra, Sedum sexangulare, Thymus pulegioides, Potentilla neumannia, Cerastium pumilum, Ononis repens, Potentilla argentea, Valerionella locusta*
Dry river grassland L1	6120 Dry river grasslands of calcareous soils Medicagini-avenetum pubescens	*Medicago falcata, Salvia pratensis, Sanguisorba minor, Plantago media, Scabiosa columbaria, Eryngium campestre, Trifolium striatum, Trifolium scabrum, Anthyllis vulneraria, Rhinanthus alectorolophus, Rhinanthus minor, Vulpia myuros, Trifolium campestre, Leontodon hispidus, Malva mosschata, Tragopogon pratensis*
Xeric grasslands L4	2330 open grasslands of xeric sandy soils and river dunes Thero-airion caryophyllea	*Aira caryophyllea, Carex arenaria, Myosotis ramossisima, Corynephorus canescens, Teesdalia nudicaulis, Ornithopus perpusillus, Filago minima, Medicago arabica, Arenaria serpylifolia, Cerastium glomeratum, Hieracium pilosella, Luzula campestris, Vulpia myuros, Geranium columbinum, Koeleria macrantha.*

Table 3.5 Habitat types of dry river grasslands (including European Natura2000 habitat code) and the associated River Meuse corridor species (italics: diagnostic species following Jansen & Schaminée 2003).

The four types of dry river grasslands (L1, L4, A1, A2) in the valley survey correspond to these vegetation types, and the sampled set of dry river grasslands in our survey were attributed to one of these communities owing to the presence of characteristic species. Thirty-nine well developed dry river grasslands were selected (defined as having > 1 diagnostic species), and for each of these plots sampling of the topsoil was carried out.

Ordination and diversity analysis

A data exploratory Detrended Correspondence Analysis (DCA) using the CANOCO 4.0 software (Gauch 1982; ter Braak & Smilauer 1997) was performed, with only species occurring in more than one plot used for the analysis. A direct gradient analysis for the whole set of environmental variables was run with CCA to reveal relationships between species and the environment. In order to identify the specific contribution of the abiotic drivers of the species composition gradients, the DCA sample scores of the 196 sample plots were related – using a one way Analysis of Variance (ANOVA) – to: flood frequency classes, river channel connectivity, isolation, humidity and vegetation type; and – using a Spearman rank correlation coefficient – to distance to the river and soil texture. This analysis of individual environmental variables was carried out in order to derive relationships useful for a modelling approach.

Guisan et al. (1999) showed that spatial models give better predictions when explanatory variables can be selected, while in CCA-based models and responses, a set of composite environmental variables is applied.

Finally, with the aim of revealing the ecological mechanism behind differences in species diversity, species richness of the plots was related to the environmental parameters using a one way ANOVA, with rare species in the plots being selected and the process repeated. All statistical analyses were performed using the Statistica software package (StatSoft Inc. 2001).

Spatial modelling of dry river grassland community distribution based on hydraulic modelling

A two-dimensional hydraulic model of the Common Meuse reach was developed as part of the river restoration project, using a very detailed DEM basis (1x1m grid, resolution 5cm), and also provided the parameters of flood frequency and peak flow velocity for our mapping units. The stream velocity and shear stress calculated for each grid cell at a given discharge give a reliable measure of the occurrence and delineation of erosion and deposition of gravel and sand (Van Looy et al. 2005). As we determined spatial and flow regime variables for the dry river grasslands, the aim was to integrate these into an expert model to predict the development of these communities over the present and future floodplain, after river restoration. To validate the model results, a field survey was carried out to determine the presence of characteristic species of the Meuse dry river grasslands, and compared to the model predictions.

Results

Alluvial plain grassland survey

Mapping and sampling

The mapping shows that over 50% of the alluvial plain is under intensive agricultural use (Figure 3.4). The dry river grasslands, together with their pioneer stage of overbank gravel and sand depositions, cover only 4% of the alluvial plain, which consists mainly of larger patches of agricultural use (mean area of arable land patches = 4,2ha). Nature reserves and riverbanks account for small vegetation patches.

Analysis of composition and abiotic conditions

The vegetation survey yielded 329 species, of which 226 were present in more than one, and were therefore used for the ordination analysis. For the rare species analysis, 46 species occurring in 2–5 plots (Table S3 in annex) were used. Species richness and patch area were plotted for the grassland types (Figure 3.5), and indicate that the dry river grasslands (types A1, A2, L1 and L4) are the richest communities over the alluvial plain, but with the smallest patches. This indication is even stronger in the species–area plot (Figure 4.10), which shows there is a strong concentration of rare species in the smallest and most species-rich patches. More than half (27 out of 46) of the rare species are river corridor species of the dry river grasslands (Table in annex) of the northern Central European streams (Burkart 2001). Together with the 10 diagnostic species of the dry river grassland associations mentioned above, over two-thirds of the rare species are dry river grassland specialists.

Soil analysis

The measurements taken demonstrate the extremes in soil conditions over the floodplain (Figure 3.6), the conductivity providing an indication of the available salts in the soil, and so the available nutrient content. The extremes over the valley were low pH values (down as far as pH 3.5) for leached higher soils disconnected from the river, and high salt concentration values (up to 316) for frequently flooded silty soils and recent depositions. Most samples yielded high pH values (median of pH 7.25) and low conductivity and salt concentrations (median of 74) due to frequent flooding of, and dry summer conditions for, the floodplain soils respectively.

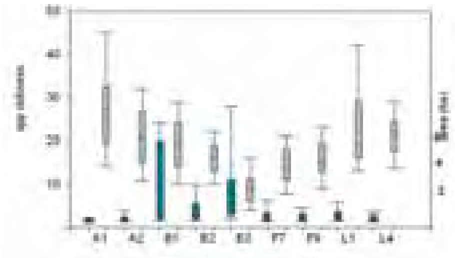


Figure 3.5 Spread of surface and species richness for the grassland patches of the Meuse alluvial plain. Areas in dashed boxes; species richness in grey filled boxes. Bars denote medians and 95th percentiles; boxes denote the 75% confidence intervals.

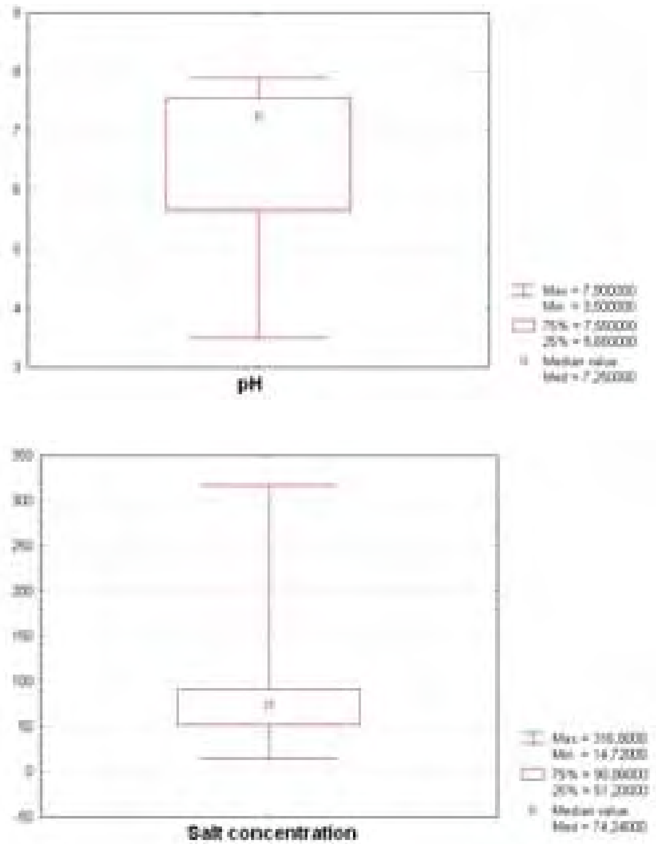


Figure 3.6 pH and salt concentration, as a function of conductivity of the soil (salt concentration=EC (◄S/cm) x 0.64), of topsoils in the Meuse valley (based on a random soil sampling campaign of 80 samples).

Pearson correlation testing revealed significant correlations for conductivity with flood frequency and soil texture; and for pH with flood contact and distance to the river (Table 3.6). Flooding frequency and soil texture also shows a correlation.

Table 3.6 Pearson correlation testing of sampling results for conductivity and pH with spatial variables.

Variable	Conduct.	pH (KCl)	Distance	Frequency
PH (KCl)	-.05			
Distance	.28	-.43*		
Frequency	.46*	.16	.01	
Texture	-.37*	.14	-.17	-.49*

(significant at $p<0.05$)*

The pH of the soil becomes enriched with each flooding event, providing a buffer capacity to soils of the floodplain. Zones further from the river are less buffered because the flood water gradually loses its material and interference with groundwater occurs. Soils are also enriched by salts when flooding occurs – measured by their conductivity – and is particularly pronounced in humid soils and silty sediments. Nutrient availability is therefore related to flood frequency and soil texture and is highest in lower floodplain zones. Higher pH values, however, are more common in higher elevated sandy depositions, closer to the river.

Ordination results

The first three axes of the DCA explained a cumulative percentage of the variance of the species data of 19%, with gradient lengths > 5, expressing the heterogeneous character of the vegetation in the sample plots. For the CCA, the cumulative percentage of explained variance was only 4.9% for the three canonical axes; nevertheless in the Monte Carlo test, eigenvalues and species–environment correlations for the dataset were significant at p:0.005. Inter-set correlations for the seven abiotic conditions showed correlations between soil texture, humidity and flood frequency with the first axis; management and flow velocity with the second axis; and isolation with the third. Dry river grasslands and their diagnostic species are situated in the upper left quarter of the CCA biplot (Figure

3.7) and are strongly correlated to axis 2, indicating a link to river dynamics and management to be a crucial factor for the habitat. Correlation to axis 1 – linked with soil conditions and flooding frequency – is less significant.

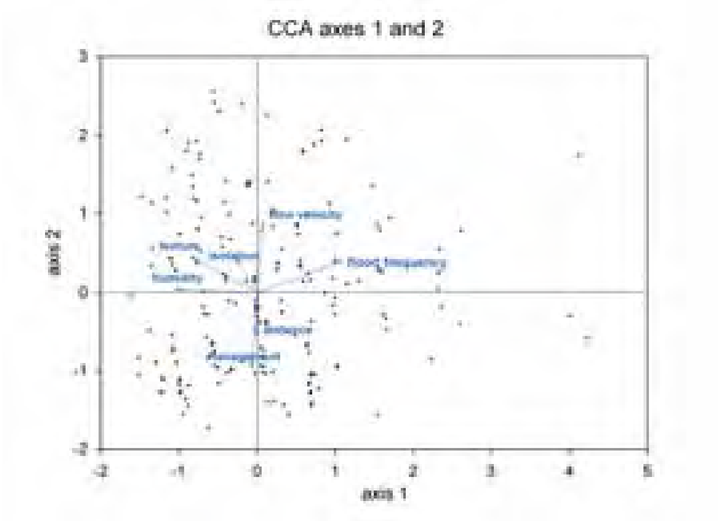


Figure 3.7 Joint plot of the first two CCA axes with plots and environmental parameters.

To reveal further relationships between the abiotic drivers of species composition, the DCA sample scores were analysed against environmental variables. The first DCA axis shows a wet–dry gradient. There are only a few wet meadow patches present and, for the most part, the summer groundwater levels in the alluvial plain are around 3–5 meters below the surface as a consequence of river bed incision during the last century, a process that has been identified for most large European gravel rivers (Bravard et al. 1986, Girel et al. 1997, Piégay et al. 2005). The significant relationship between DCA1 sample scores and flooding frequency, as well as soil characteristics such as texture, soil humidity and organic matter content demonstrates the influence of the river on floodplain environmental conditions. DCA2 sample scores showed significant covariance with soil parameters and management conditions, as well as with isolation and distance to the river (Table 3.7). For this axis, management and soil texture are the most influential abiotic characteristics, showing a gradient of densely vegetated floodplain meadows to open, sandy pioneer grasslands. Hayfield species and nutriphilous species have low values, whereas species preferring sand and calcareous, xerophilic conditions have high DCA2 values. For the third axis, flooding frequency and distance to the river show strong covariance; there is no significant correlation between the dry river grasslands and this axis due to some being close, and others being far, from the river.

Table 3.7 Covariances for environmental variables with ordination axes and species richness.

	distance river	texture	flood freq	contact	isolation	humidity	organic matter	flood class	management
DCA1	0,18*	0,33**	-0,4**	2,95	1,11	37,5**	32,9**	32,6**	4,9*
DCA2	-0,27**	0,45**	0,04	2,15	8,3**	6,7**	17,5**	0,5	10,1**
DCA3	0,38**	0,02	-0,38**	3,12	0,42	0,81	0,74	6,7**	1,2
DCA4	0,2*	0,089	0,07	10,8**	2,3	2,5	0,8	1,2	0,99
Spp richness	0,14	0,16	-0,22*	0,02	2,1	3	5,22*	3,08*	0,9

***red: significant correlation (p< 0,001),*

**green: little significant correlation (0,001< p < 0,01)*

Diversity and rare species analysis

Overall species richness of the samples only shows marginally significant relationships with flooding frequency and organic matter (Table 3.7). For aspects relating to diversity, a clear pattern arises when the rare species are selected; the strong covariance detected between the number of rare species in a plot and the species richness of the plots (F: 3.6, p<0.001) shows that these rare species are good indicators for well developed grassland patches. A greater level of rare species is significantly linked to the higher gravel-sandy soils (F:4.6, p<0.001), which are the stand conditions of the dry river grasslands.

As the DCA explained most of the variance in species composition, in the diversity analysis covariances between environmental variables and species richness of plots with DCA scores were derived. The rare species were also projected over the two-dimensional space in the DCA biplots.

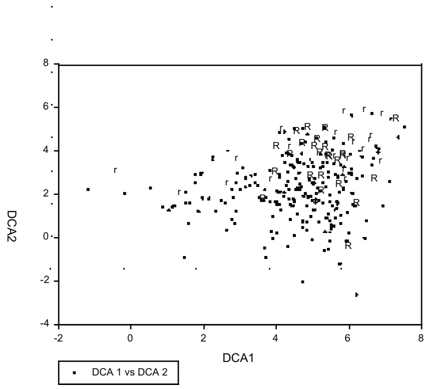


Figure 3.8 Species biplot of the first two DCA axes (r: rare species; R: rare river corridor species).

The rare river corridor plants are clearly grouped together with the dry river grasslands (Figure 3.8). The rare species of the dry river grasslands show a strong correlation with the third axis (Rare species-DCA3 z:5.74, p<0.001), indicating the isolated position of many river corridor plant relicts, situated far from the river and seldom flooded. Also, when considering environmental variables, the strongest covariance was observed between the number of rare species and the degree of isolation (Figure 3.9), which indicates that there is a group of highly isolated relicts harbouring a list of specific rare species. The well developed dry river grasslands are currently under great threat, and this is therefore particularly pertinent for the rare species of these communities. The problem of isolation is caused by an interruption of flood contact and habitat fragmentation due to changing land use conditions.

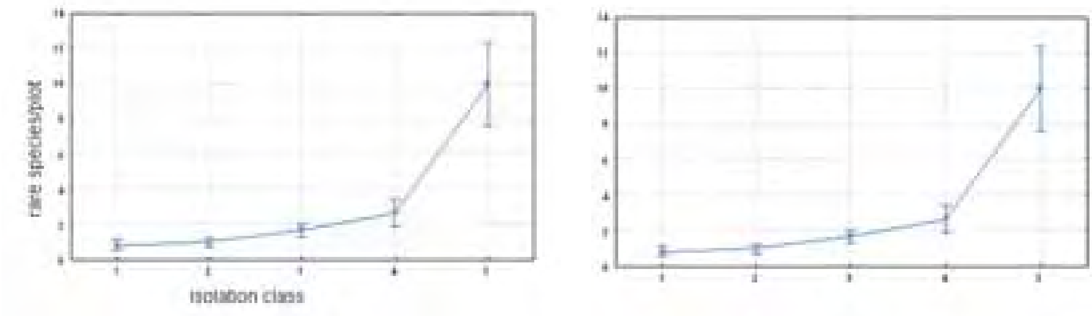


Figure 3.9 Numbers of rare species in the different isolation classes. This graph shows the significant covariance (ANOVA-result F=20,563, p<0,001) between isolation classes 1–5 and the number of rare species of the plots (182 plots with rare species).

Dry river grassland habitat conditions and modelling

Habitat conditions for dry river grasslands

The measured soil conditions for the 39 sampled dry river grasslands show that there is a distinct difference in these conditions depending on the community type. For example, high pH values (Figure 3.10) distinguish Sedo-Thymetum and Alysso-Sedion from Thero-Airion communities, and conductivity differentiates between the Sedo-thymetum and the Alysso-Sedion communities, as well as between the true Thero-Airion and the extended Thero-Airion+ group. For both pH and conductivity, the Medicagini-Avenetum grasslands take an intermediate position and have a broader range, which is obviously due to these grasslands occurring as a later succession stage in these pioneer communities.

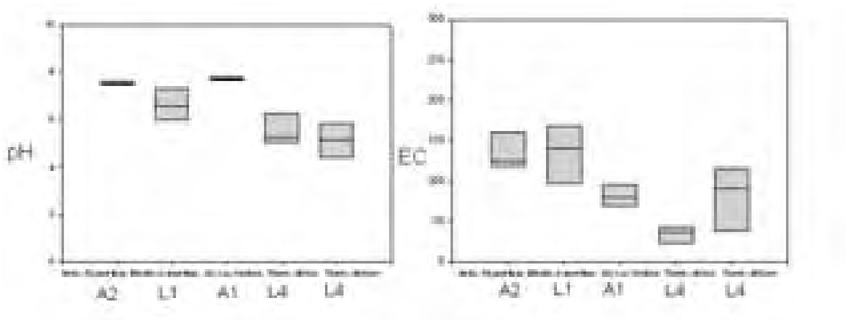
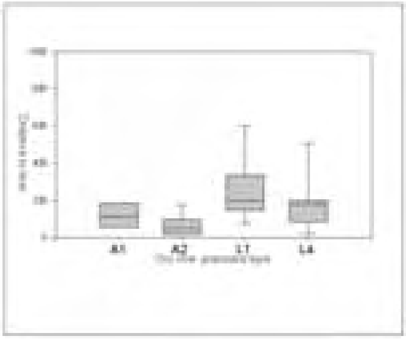
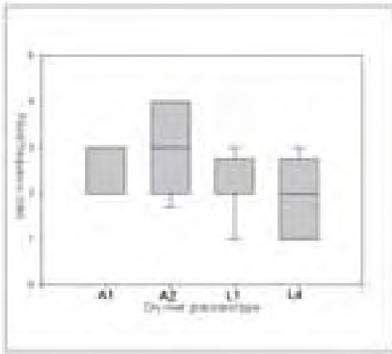


Figure 3.10 PH and conductivity of the dry river grassland communities sampled (Sedo-Thymetum, n= 7; Medicago-Avenetum, n=15; Alysso-Sedion, n=6; Thero-Airion, n=3; Thero-Air/Galio-Trifolietum, n=8). Boxes delineate 25th–75th percentiles; lines denote median values.

As correlations between these influential soil conditions (pH and conductivity) with flow regime and spatial patterns (flood frequency and distance to the river) were detected, sufficient predictive power was assumed present in the hydraulic modelling (flood frequency and flow velocity) to use these responses in a plant community prediction model. With the flow velocity determined as the strongest predictor variable for dry river grasslands in the CCA, and the flood frequency and distance to the river as important parameters with regard to soil conditions, we tried to parameterize these variables based on our dataset.

Using the observed relationships (Figures 3.11a-c), a dry river grassland model application was developed, in a stepwise integration of flood frequency, flow velocity and distance to the river as determining parameters. The combination of these three variables in a decision tree results in a higher predictive power than suggested in the charts.





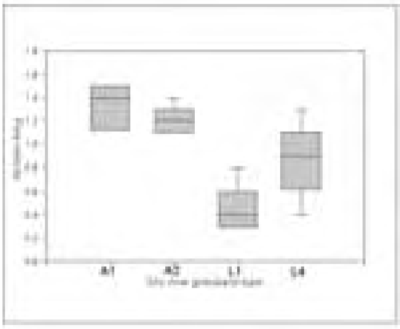


Figure 3.11 Box plots for the distance to the river (a), flood frequency class (b) and flow velocity (c) for the samples/plots of the dry river grassland types (boxes denote 25th–75th percentiles; bars denote the 95th percentile; median values are shown as lines).

The overbank gravel and sand depositions (A1, A2) are characteristic features of extreme flooding events and are restricted to less frequently flooded zones (flood frequency classes > 2; Figure 3.11b). So, they are retrieved from the model runs for extreme flood events (recurrence period 50 years) and determined in flow velocity classes (A1 Alysso-Sedion: >1.3 m/s; A2 Sedo-Thymetum: 0.9–1.3 m/s). The L1 and L4 types are divided in the modelling of the decennial flood (cfr. Fig. 9c), with flow velocity ranges of L1 Medicagini-Avenetum: 0.2–0.6; and L4 Thero-Airion: 0.6-1.1. Possible overlap is excluded with the third criterion (Figure 3.11a); the distance to the river discriminates between the A2 Sedo-Thymetum (< 80m) and the L4 Thero-Airion communities (> 80m).

The power of the model to predict the presence and potential development of dry river grasslands over the alluvial plain was verified by field testing, and this yielded good results (Figure 3.12). The modelling shows a potential of 158 ha of pioneer habitat creation, but only 19 ha was located in the field during vegetation mapping of the study area (Table 3.8). Yet, for the 56 patches predicted in the model, the inventory showed that nearly half of them (27) contained diagnostic species of these communities, mostly restricted to patch edges, road verges, etc. The intensive agricultural use of most of the valley explains this low correspondence.

Table 3.8 Modelling result and field survey validation of dry river grassland habitat.

Pioneer Patches	Potential modelled (ha)	Field mapping 2000 (ha)	Patches modelled (#)	Patches with diagnostic species
Overbank gravel deposition (A1)	44	11	23	10
Overbank sand deposition (A2, L4)	114	8	33	17

Figure 3.12 View of the model outcome for a part of the Common Meuse reach, with the predicted dry river grassland communities' potential distribution.

Discussion

Flood dynamics determine dry river grassland composition and diversity

Disturbance regime and flood contact are documented as playing a determining role in fluvial riparian vegetation (Bornette & Amoros 1996, Andersson et al. 2000). Direct relationships between community composition and flood regime and river contact were identified, as were indirect relationships through soil conditions. The development of communities is in the first place linked to aspects of flood regime, but further soil development and succession governs the community composition. The pioneer communities of Alysso-Sedion and Sedo-Thymetum are in a few years turned into Medicagini-Avenetum by the enrichment of the soil and the emergence of strong perennials. The Medicagini-Avenetum is the best known community for hosting river corridor plants. It can be described as a community in its optimum range because it covers such a broad range of soil and floodplain conditions of the dry river grasslands and it is only slowly replaced by other communities, a process that is sometimes quickened by grazing or fertilization practices.

Several authors have indicated flood intolerance (Jongman 1992, Grévilliot & Muller 2002, Eck et al. 2004, Vervuren et al. 2004, Leyer, 2005) and inadequate dispersal abilities (Hegland et al. 2001, Bischoff 2002, Vécrin et al. 2002, Donath et al. 2003, Stroh et al. 2005) as limiting factors for the restoration potential of dry river grasslands rich in river corridor species in the floodplains of larger Northwest European rivers. Our results do not conflict with these observations of distribution patterns and limitations with regard to flooding, but they do add another dimension in so far as flood events have also been proven as a crucial element in generating appropriate habitat conditions and dispersion potential.

The dry river grasslands have a strong preference for overbank depositions with a deep groundwater level, coarser texture and low organic matter content of the topsoil. Specific soil conditions govern the distribution pattern of dry river grassland communities; extremely high pH characterizes the Alysso-Sedion and Sedo-Thymetum pioneer communities of young river sediments, whereas the extremely low salt concentration of leached sediment soils characterizes the Thero-Airion communities in the valley. The correlation between pH, conductivity and flood contact indicates the important role of river flooding for these communities.

Rare species analysis and modelling result

The rare species analysis reveals important aspects of the threatened status of the dry river grassland communities and necessary measures for their conservation/restoration. There is a clear segregation of rare (river corridor) species of the dry river grasslands indicated by the ordination analysis. The significant covariance of diversity and the isolation of plots with richness in rare river corridor species is proof of their threatened status and a need for restoration. River corridor plants make up the majority of rare species and hence are good indicators of diversity and fragmentation at the river reach scale. The validation of the model revealed recruitment limitation as the main problem for the diagnostic species of these communities and their habitat. Therefore, a prerequisite when dealing with their isolation–fragmentation threats is habitat creation, linked to the periodic process of overbank deposition of sand–gravel sediments.

The flow variables proved the best predictors in the direct gradient analysis, useful in the elaboration of a model to predict the potential plant community distribution over the floodplain. The use of this kind of model application based on direct gradient analysis results works quite satisfactorily in this study, thanks largely to the restricted river reach scale level, and the basis of a validated two-dimensional river hydraulic model. Individual analysis of the influential variables adds strength to the relationships and predictions that were determined and allows a stepwise hierarchical modelling approach. Selection of predictors allows for a more accurate fit to the specific ecological niche of a community because the explained variance is much clearer in this way (Guisan et al. 1999).

Restoration potentials

Restoration projects in general aim at mitigating the effects of regulation works by rehabilitating geomorphologic processes to promote the recovery of degraded biota and the floodplain benefits from the river (Tockner & Schiemer 1997). However, the hydrological, geomorphologic and biological heterogeneity and variability of river floodplain systems, both temporally and spatially, sometimes complicate the restoration schemes (Amoros et al. 1987). Isolation in the river system has a spatial but, particularly, a temporal dimension, important for conclusions on conservation and restoration. The spatial and temporal habitat requirements of these communities can be seen in perspective of patch dynamics and shifting mosaic concepts (Petts & Bradley 1997, Barrat-Segretain & Amoros 1996). The shifting aspect of habitat is clearly linked to, and shows the intrinsic need for, river dynamics, as was also illustrated for these communities by Boedeltje et al. (2004) and Wolfert et al. (2002). If this study succeeds to recognize and parameterize this link between the physical and biological processes at temporal scales determined from flow variability, an effective restoration programme can evolve (Biggs et al. 2005).

The modelling approach – that integrated a set of combined rules of spatial and temporal prerequisites – provides a useful tool for identifying potential restoration sites and also an insight into the requirements for viable restoration of dry river grassland habitat and the characteristic river corridor plants. As the process of habitat creation does not occur annually, the spatial conclusions of the modelling also requires a temporal interpretation.

The potential for restoration – expressed in area for a characteristic unit of river length – could be defined as modelled area/recurrence period. For the studied Meuse reach, the 1/50 year peak discharge gives 158 ha of newly generated habitat of overbank sedimentation zones, with of course the restriction that existing habitat will be put back in succession as local stands will be over-deposited or eroded, allowing for seed and propagule dispersal but also provoking local extinctions. A 1/5 year peak generates 12ha. From these observations, a resulting restoration potential can be quantified as around 3 ha/year. This measure gives an idea of the necessary dynamics in conservation and management strategy.

Conservation strategy

Restrictions in land use or specific management strategies can allow the creation of new habitat but cannot stop gradual succession from pioneer to grassland communities, as these are governed by soil processes. Therefore, the pioneer communities only survive under the benefit of flooding events that generate the deposition of new sediments. Thus, the rehabilitation of fluvial processes is necessary to develop new habitat on the sites we determined through modelling. The rehabilitation of fluvial processes does not only mean that land use practices need to be changed, it also means that the river must transport enough coarse sediment. For this morphological criterion, sediment supply from eroding banks and larger gravel and sand bars in the river bed is necessary (Piégay et al. 2005). As these processes operate on a larger scale in space and time, a restoration approach at the reach scale is necessary to ensure the generation of new habitat for the future conservation of these vegetation types. In this way, from the present 19 ha, the realisation of 158 ha means a significant growth for an otherwise highly threatened habitat, and therefore a benefit for the river corridor species it contains.

Conclusion

Knowledge of the habitat creation process, together with the spatial and temporal requirements of the communities, allows for the design of effective restoration measures. The river corridor plants are a good flagship species group for the protection and restoration effort, as they cover a broad range of information on the characteristic habitats, and provide the best developed stands and richest vegetation. A modelling approach based on the analysis of community–environment relationships (CCA output) yielded management guidelines and demonstrated restoration potential for the dry river grasslands over the river reach.