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1 **Disentangling and ranking the influences of multiple environmental**
2 **factors on plant and soil-dwelling arthropod assemblages in a river**
3 **Rhine floodplain area**

4
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10
11 **Abstract**

12 Floodplains of large rivers are among the most dynamic and diverse, yet most threatened
13 ecosystems on earth. For a solid underpinning of river conservation and rehabilitation
14 measures, it is critical to unravel the influences of the multiple stressors affecting floodplain
15 ecosystems. Using canonical correspondence analysis (CCA) with variance partitioning, we
16 disentangled and ranked the influences of three floodplain ecosystem stressors (land use,
17 flooding and soil contamination) on terrestrial plant and soil-dwelling arthropod assemblages
18 in a floodplain area along the river Rhine in The Netherlands. We included five biotic
19 assemblages: plant species (73 taxa), ground beetle species (57 taxa), ground beetle genera (29
20 taxa), beetle families (32 taxa), and arthropod groups at taxonomic levels from family to class
21 (10 taxa). Plant as well as arthropod assemblages were primarily related to land use, which
22 explained 19% to 30% of the variation in taxonomic composition. For plant species
23 composition, flooding characteristics were nearly as important as land use. Soil metal
24 contamination constituted a subordinate explanatory factor for the plant assemblages only (3%
25 of variation explained). We conclude that the taxonomic composition of terrestrial plant and

1 arthropod assemblages in our study area is related to land use and flooding rather than soil
2 metal contamination.

3

4 **Key words**

5 Carabidae; Coleoptera; canonical correspondence analysis (CCA); flooding; land use; metal
6 contamination; variance partitioning; vegetation

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8

1 **Introduction**

2 Floodplains of large rivers are among the most dynamic and diverse ecosystems on earth
3 (Tockner et al. 2010; Tockner and Stanford 2002). However, being located in low-lying areas,
4 where human population densities are disproportionately high (Cohen and Small 1998),
5 floodplains are also among the most threatened ecosystems (Tockner and Stanford 2002).
6 Particularly in Europe and North America, vast floodplain areas have been reclaimed for
7 agricultural, industrial and urban activities, resulting in the modification and eradication of
8 natural floodplain habitats (Nienhuis et al. 2002; Tockner and Stanford 2002). Along with the
9 reclamation of riverine land, natural river flow regimes have been substantially distorted by the
10 construction of dams, embankments, groynes and diversions (Jansson et al. 2000; Stanford et al.
11 1996). This has reduced the hydrological connectivity between the river channels and adjacent
12 floodplains, leading to reduced floodplain rejuvenation, less pioneer habitats, and decreased
13 heterogeneity and biodiversity (Cabezas et al. 2009; Stanford et al. 1996; Ward et al. 1999).
14 Particularly in lowland river reaches, chemical pollution may pose an additional threat to
15 floodplain ecosystems, due to the downstream transport and subsequent overbank deposition
16 of sediment-bound contaminants originating from the upstream catchment (Hendriks et al.
17 1995; Leuven et al. 2005; Schipper et al. 2012; Van den Brink et al. 2003).

18 For a solid underpinning of floodplain conservation and rehabilitation measures, it is critical
19 to quantify the influences of the multiple stressors that affect floodplain ecosystems. This is
20 particularly relevant because a focus on single stressors may lead to erroneous management
21 priorities and failing rehabilitation efforts, for example when effects observed are ascribed to
22 the wrong stressor or more important stressors are overlooked (Klok et al. 2007; Tockner et al.
23 2010). A simultaneous analysis of the multiple stressors that affect floodplain ecosystems may
24 help to attribute effects to particular stressors and place the impact of each stressor in a
25 realistic perspective (Loos et al. 2010; Tockner et al. 2010). For example, it has been shown that
26 macro-invertebrate communities in river Rhine floodplain lakes in The Netherlands were
27 related to the oxygen content of the water rather than the metal contaminations in the sediment

1 (Van Griethuysen et al. 2004). Yet, many studies regarding floodplain ecosystem stressors focus
2 on one type of stressor at a time, for example interference with the hydrological regime (Bayley
3 and Guimond 2008) or chemical pollution (Rozema et al. 2008).

4 The goal of the present study was to disentangle and rank the influences of multiple
5 floodplain ecosystem stressors on terrestrial plant and soil-dwelling arthropod assemblages in
6 a river Rhine floodplain area in The Netherlands. The river Rhine is one of the longest rivers in
7 Europe, flowing from the Swiss Alps to the North Sea via Germany and The Netherlands. Just
8 downstream of the border between Germany and The Netherlands, the river Rhine splits into
9 three main channels i.e., Waal, Nederrijn and IJssel (Fig. 1). The channels have been regulated by
10 weirs, sluices and groynes for flow regulation and flood defence and the majority of the
11 floodplains have been embanked and cultivated (Nienhuis et al. 2002). During the past century,
12 particularly during the 1930s and the 1950s, the deposition of sediments contaminated with
13 metals has resulted in elevated metal concentrations in the floodplain soil (Middelkoop 2000).
14 Hence, the lowland river Rhine floodplain areas are subject to at least three anthropogenic
15 floodplain ecosystem stressors: land use, interference with the hydrological regime, and
16 floodplain soil contamination.

17 We sampled terrestrial plant and soil-dwelling arthropod assemblages as well as
18 environmental conditions pertaining to land use, flooding and contamination in a floodplain
19 area along the river Nederrijn (Fig. 1). We analysed the relationships between the biotic
20 assemblages and environmental conditions with canonical correspondence analysis (CCA) using
21 the variance partitioning approach. With variance partitioning, variation in taxonomic
22 composition can be ascribed to particular environmental variables by 'factoring out' the effects
23 of other environmental variables (Borcard et al. 1992; Peeters et al. 2004; Volis et al. 2011).
24 Thus, effects of multiple environmental factors on biotic communities can be disentangled and
25 ranked.

26 27 **Methods**

1 *Study area and sampling sites*

2 Data collection took place in the 'Wolfswaard' floodplain area, which is located along the north
3 side of the Nederrijn channel (Fig. 1). The major part of the study area is in use as pasture for
4 cattle. A relatively small part of the area is used for sheep grazing and contains some scattered
5 fruit trees. The sheep grazing area is separated from the cattle by a hedgerow consisting mainly
6 of common hawthorn (*Crataegus monogyna*). A minor embankment parallel to the river, at a
7 distance of approximately 200 m from the middle of the channel, protects a part of the study
8 area against minor floods. Data collection took place at 30 sampling sites, which were selected
9 to cover differences in land use (sheep grazing, cattle grazing, hedgerow) and hydro-
10 topographic setting (distance to the river, elevation, position with respect to the embankment).

11

12 *Biotic assemblages*

13 At each of the 30 sampling sites, terrestrial plant species composition was recorded in a 3x3 m
14 plot in May 2008 (Schipper et al. 2010; 2011). In total, 73 species were recorded (Table S1 in
15 Supplementary Material). The abundance of each plant species was estimated according to a
16 modified Braun-Blanquet scale (Barkman et al. 1964). A pitfall trap was placed at the centre of
17 each sampling site to collect soil-dwelling arthropods (Schipper et al. 2010). The traps were
18 filled with ~ 3.7% formalin and a drop of detergent lotion to reduce surface tension. Traps were
19 sampled monthly from May through October 2007 and were opened two weeks prior to each
20 sampling event, i.e., the trap duration was 14 days. Arthropods were identified to order level
21 (Aranea, Coleoptera, Dermaptera, Hemiptera, Isopoda, Opiliones), except for the mites and ticks
22 (subclass of Acari), myriapods (classes of Chilopoda and Diplopoda) and ants (family of
23 Formicidae). The beetles (order of Coleoptera) were further indentified to the taxonomic level
24 of family, and the ground beetles (family of Carabidae) were identified to genus and species
25 level. Thus, we distinguished four arthropod assemblages, comprising ground beetle species (57
26 taxa), ground beetle genera (29 taxa), beetle families (32 taxa), and groups of arthropods at
27 taxonomic levels ranging from family to class (10 taxa). Per arthropod assemblage, we

1 calculated the average abundance based on the six monthly pitfall trap samples (Table S2-S5 in
2 Supplementary Material).

3

4 *Environmental characteristics*

5 At each of the 30 sampling sites we quantified flooding characteristics, land use, vegetation
6 structure, physical-chemical soil properties, and soil metal contamination levels (Table 1). The
7 distance to the river (m) was calculated per sampling site as the Euclidian distance to the
8 middle of the channel. The surface elevation of each sampling site (m amsl) was derived from
9 The Netherlands' 5x5 m digital elevation model (www.ahn.nl). The average yearly flooding
10 duration (days/year) was derived from the frequency distribution of daily river water level data
11 covering the period 1999–2008 (Schipper et al. 2010; 2011). Land use was quantified as a
12 categorical variable with three levels: sheep grazing, cattle grazing, or hedgerow. Vegetation
13 structure was described by the total cover (%) and height (m) of the vegetation (herb layer).
14 Soil samples were collected in August 2007. Three soil samples collected within 1 m from the
15 centre of each sampling site were pooled, mixed and air-dried for 48 h at ambient room
16 temperature. The soil pH was measured in a suspension of 10 g air-dried soil in 25 ml deionized
17 water (<10 $\mu\text{S}/\text{cm}$), mixed 24 h before the measurements. Soil organic matter content (%) was
18 determined from the weight loss upon ignition (4 h at 550 °C) of 10 g oven-dried (i.e., 24 h at
19 105 °C) samples. The particle size distribution of the soil was analyzed with laser diffraction
20 (Malvern Master Sizer 2000 with Hydro 2000 G) performed on oven-dried samples sieved over
21 2000 μm . Prior to this analysis, samples were treated with 30% H_2O_2 and 10% HCl for detaching
22 coagulating particles and dissolving organic matter. To determine the soil metal concentrations,
23 0.2 g dw of each sample was weighed on a Sartorius LA310S mass balance and digested in a
24 mixture of 4 ml 65% HNO_3 and 1 ml 30% H_2O_2 using a Milestone Ethos-D microwave. Total
25 concentrations of arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), nickel (Ni), lead (Pb)
26 and zinc (Zn) were determined with ICP-MS (X Series; Thermo Electron Cooperation). Dissolved
27 concentrations of Cd, Cu, Pb and Zn were calculated based on their total soil concentrations

1 combined with soil pH and soil organic carbon (SOC) content (Sauvé et al. 2000), whereby SOC
2 was derived from SOM based on a conversion factor of 2 (Pribyl 2010). The mean and range of
3 all but the categorical land use variable are provided in Table 1.

4

5 *Data analysis*

6 We investigated the relationships between the biotic assemblages and the environmental
7 characteristics with canonical correspondence analysis (CCA) using Canoco for Windows 4.56
8 (Ter Braak and Šmilauer 2002). Braun-Blanquet units used to describe plant species abundance
9 (r, +, 1, 2a, 2b, 3, 4, 5) were converted to ordinal values ranging from 1 to 8 (Ter Braak 1987).
10 The arthropod abundance data were square-root transformed, which is considered the most
11 appropriate for count data (Lepš and Šmilauer 2003). Vegetation cover and height were
12 included as potential explanatory factors for both plant and arthropod assemblages, as
13 vegetation not only responds to the environment but also modifies it (Økland and Eilertsen
14 1994; Volis et al. 2011; Wisser and Buxton 2008).

15 First, we conducted exploratory CCA analyses for each of the five biotic assemblages in
16 order to identify and rank significant ($p < 0.05$) explanatory environmental characteristics. This
17 was done with the manual forward selection procedure as available in Canoco. The significance
18 of each explanatory variable was evaluated with Monte Carlo permutation tests (1000
19 permutations). Once the significant environmental variables were identified, we quantified their
20 relative influence on the biotic assemblages with the variance partitioning method. With this
21 approach, variation in taxonomic composition is attributed to specific environmental variables
22 by including other potentially relevant environmental variables as covariables (Borcard et al.
23 1992). For each of the five biotic assemblages, we first performed a CCA including all significant
24 environmental characteristics as explanatory variables. This yielded the amount of variation in
25 the biotic data explained by all significant environmental variables of concern. Then, the
26 environmental variables belonging to a specific category (land use, flooding, soil metal
27 contamination, vegetation structure, or physical-chemical soil properties; Table 1) were used as

1 explanatory variables while all other environmental variables were included as co-variables.
2 This was done for each category of environmental variables. Thus, we isolated the effect of each
3 category of environmental variables by 'factoring out' the effects of the others. Finally, we
4 assessed how much of the variation in the biotic assemblages was due to joint effects of
5 environmental variables belonging to different categories. This so-called 'shared variation' was
6 assessed by summing the variation attributed to the various categories and subtracting this sum
7 from the total variation explained as assessed with the first CCA, i.e., the analysis based on all
8 significant environmental variables together. The significance of each category of explanatory
9 variables was evaluated with Monte Carlo permutation tests (1000 permutations).

10

11 **Results**

12 The forward selection procedure yielded two to seven significant ($p < 0.05$) explanatory
13 variables per biotic assemblage (Fig. 2, Table 2). Variance inflation factors (VIFs) of these
14 variables were all well below 10 (Table 2), indicating limited collinearity and hence little
15 redundancy between the selected variables (Field 2005). The total variation in the biotic
16 assemblages explained by the significant explanatory variables ranged between 31% and 55%
17 (Fig. 2, Table 3).

18 For the terrestrial plant assemblages, significant explanatory variables were land use,
19 flooding characteristics (distance to the river, flooding duration, elevation), vegetation height
20 and the total soil concentration of As (Table 2). Land use and flooding characteristics were
21 clearly more important than vegetation height and contamination (Fig. 2; Table 3). Arthropod
22 assemblages were primarily related to land use variables (Table 2), which accounted for 22% to
23 30% of the taxonomic variation (Fig. 2, Table 3). In addition, vegetation structure was selected
24 as a significant explanatory factor for all four arthropod assemblages, accounting for 4% to 13%
25 of the variation. Flooding duration was selected as significant but subordinate explanatory
26 factor for the ground beetle assemblages. None of the arthropod assemblages was significantly
27 related to physical-chemical soil properties or soil metal concentrations.

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Discussion

Methodological issues

Using canonical correspondence analysis (CCA) with variance partitioning, we disentangled and ranked the influences of multiple environmental factors on terrestrial plant and soil-dwelling arthropod assemblages in a river Rhine floodplain area. Before interpreting the results, a few methodological aspects are to be addressed. First, we used a large number of potential explanatory variables relative to the number of sampling sites included in our study. This increases the probability of chance correlation, i.e., it inflates the Type I error (Blanchet et al. 2008; Freedman et al. 1992). On the other hand, the correlations between our potential explanatory variables probably reduced the risk of false inclusion: if multiple highly correlated variables are included in a stepwise selection procedure, they compete with each other for inclusion, and if one is selected, the others will be left out. If correlations are very high (> 0.9), as were observed among the soil metal concentrations or among the grain size distribution parameters (Supplementary Material, Table S6), this may even result in the explanatory variables being less likely to be selected than can be expected based on the chosen level of significance (Freedman et al. 1992). Thus, in an exploratory forward variable selection procedure like we applied here, the p -values levels do not provide rigorous levels for rejecting or including an explanatory factor as significant. In addition, it should be noted that in CCA the total variation explained is affected by the number of explanatory factors (Blanchet et al. 2008) as well as the total variation within the biotic dataset, represented by the total inertia (Økland 1999). This implies, for example, that we cannot conclude that vegetation structure is more important for the arthropod groups than for the ground beetles in our study area, as the arthropod group dataset was characterized by smaller total inertia (Table 3). Despite these limitations, however, the variation explained by the various environmental characteristics can be compared within one dataset to assess the relative importance of the environmental factors (Økland 1999). Further, the stepwise forward selection procedure selects the 'best' variable at

1 each consecutive step, and hence the order in which the explanatory variables are selected also
2 provides a ranking of their relative importance within one dataset (Ter Braak and Verdonschot
3 1995).

4

5 *Ranking of environmental factors for plant assemblages*

6 The results of our analyses suggest that plant species composition in our study area depends
7 mainly on land use, closely followed by flooding characteristics (Table 3). The hedgerow
8 included 10 plant species absent from the sheep and cattle grazing fields (Supplementary
9 Material, Table S1), such as common hawthorn (*Crataegus monogyna*), oak (*Quercus robur*),
10 common ash (*Fraxinus excelsior*) and elder (*Sambucus nigra*), which may explain why the
11 hedgerow ranked first among the explanatory variables for plant species composition. Sheep
12 grazing was also selected as significant explanatory factor (Table 2), indicating distinct
13 differences in plant species composition between sheep and cattle grazing sites. This may result
14 from a difference in animal density and hence grazing intensity, but also from a difference in
15 grazing behaviour, as sheep are more selective than cattle (Sýkora et al. 1990). Sheep control
16 the dominant grasses, thus allowing lower growing herbs to thrive (Sýkora et al. 1990). This
17 may explain why species like common daisy (*Bellis perennis*) and white clover (*Trifolium repens*)
18 were present almost exclusively in the sheep grazing fields (Supplementary Material, Table S1).

19 Despite the human interference with the hydrological regime of the river Nederrijn,
20 flooding characteristics were nearly as important as land use for plant species composition.
21 Segregation of plant species along a hydrologically defined gradient is a well-described
22 phenomenon (Silvertown et al. 1999; Sýkora et al. 1988; Van Eck et al. 2004). Tolerance to
23 flooding strongly differs between plant species and has been shown to range from 6 to over 60
24 days of total submersion for a selection of 20 grassland species commonly occurring in lowland
25 river Rhine floodplains (Van Eck et al. 2004). Due to such differences in flooding tolerance,
26 spatial variation in flooding duration is generally well reflected by differences in species
27 composition. Our observations agreed well with flooding tolerance differences as observed by

1 Van Eck et al. (2004). Species identified as flood-tolerant, like *Elytrigia repens*, *Potentilla*
2 *anserina*, *Potentilla reptans* and *Rumex crispus*, tended to occur mainly on the most flood-prone
3 sites, whereas more sensitive species, like *Festuca rubra* and *Rumex acetosa*, occurred on less
4 flood-prone sites (Supplementary Material, Table S1).

5 The forward selection procedure resulted in the total soil concentrations of As being
6 selected as subordinate explanatory factor for the plant assemblages (Table 2). This does not
7 necessarily imply that As has larger explanatory power than the other metals, as the soil metal
8 concentrations were highly mutually correlated (Supplementary Material, Table S6). Moreover,
9 the significant correlation between plant species composition and As could be a spurious one,
10 given the relatively large number of potential explanatory variables relative to the number of
11 sampling sites (see above). This would match the observation that the As soil concentrations
12 measured in our study area (Table 1) are below the no-observed effect concentrations (NOECs)
13 for plants that have been established for various European soils (Song et al. 2006). In order to
14 be conclusive on the potential effects of metal contamination on plant species composition in
15 river Rhine floodplain areas, a follow-up study would be needed.

16

17 *Ranking of environmental factors for soil-dwelling arthropod assemblages*

18

19 The terrestrial arthropod assemblages in our study area responded primarily to land use (Fig.
20 2). This is probably the result of indirect effects, i.e., via vegetation characteristics, as was shown
21 in several previous studies (Garcia et al. 2010; Stoner and Joern 2004). As vegetation structure
22 characteristics were included as separate explanatory variables in our analyses, the land use
23 effect in our study may have been mediated by plant species composition. This hypothesis
24 matches with a recent study showing that plant species composition consistently outperformed
25 abiotic conditions as well as vegetation structure in explaining the taxonomic composition of
26 arthropod assemblages (Schaffers et al. 2008).

1 Flooding explained a subordinate part of the variation in the ground beetle assemblages.
2 This seems in contrast with other studies showing clear responses of ground beetle
3 assemblages to flooding regimes (Bonn et al. 2002; Moran et al. 2012). However, these other
4 studies covered considerable gradients in flooding influence, ranging from occasional to
5 prolonged inundation. In the river Nederrijn, river dynamics are strongly reduced due to the
6 sluices and groynes. Hence, clear flooding influence in our study area was present at the river
7 margin only, and the majority of our study sites were hardly inundated (Supplementary
8 Material, Table S1).

9 None of the arthropod assemblages was significantly related to soil metal contamination
10 (Table 2, Fig. 2). Limited impacts of metal contamination on invertebrate fauna in river Rhine
11 floodplains have been found before, for ground-dwelling organisms as well as burrowing
12 invertebrates like earthworms (Ma et al. 2004; Rozema et al. 2008). Metal exposure
13 concentrations for terrestrial invertebrates were generally below or close to (tentative) toxicity
14 thresholds (Hobbelen et al. 2004; Notten et al. 2005; Schipper et al. 2008). This indicates that
15 current bio-available metal concentrations in the floodplain top-soil are too low to induce
16 detectable toxic effects in the organisms exposed. Flooding lowers the redox potential and
17 increases the pH of the soil, notably through the deposition of carbonate-rich sediments
18 (Kashem and Singh 2001). This reduces the bioavailability of sediment-bound heavy metals,
19 thus limiting accumulation in biota and diminishing toxicological effects (De Jonge et al. 1999;
20 Hobbelen et al. 2004; Hobbelen et al. 2006; Kashem and Singh 2001).

21

22 **Concluding remarks**

23 Summarizing, we used canonical correspondence analysis (CCA) and variance partitioning to
24 disentangle and rank the influences of multiple environmental factors on terrestrial plant and
25 soil-dwelling arthropod assemblages in a lowland floodplain area of the river Rhine in The
26 Netherlands. Plant as well as arthropod assemblages were primarily related to land use, which
27 explained 19% to 30% of the variation in taxonomic composition. For plant species

1 composition, flooding characteristics were nearly as important as land use. Soil metal
2 contamination was selected as explanatory factor for the plant assemblages only (3% of
3 variation explained). We conclude that the taxonomic composition of terrestrial plant and
4 arthropod assemblages in our study area is related to land use and flooding rather than soil
5 metal contamination.

6

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12

13 **References**

14

15 Barkman, J. J., H. Doing & S. Segal, 1964. Kritische Bemerkungen und Vorschläge zur
16 quantitativen Vegetationsanalyse. *Acta Botanica Neerlandica* 13:394-419.

17 Bayley, S. E. & J. K. Guimond, 2008. Effects of river connectivity on marsh vegetation community
18 structure and species richness in montane floodplain wetlands in Jasper National Park,
19 Alberta, Canada. *Ecoscience* 15:377-388.

20 Blanchet, F. G., P. Legendre & D. Borcard, 2008. Forward selection of explanatory variables.
21 *Ecology* 89:2623-2632.

22 Bonn, A., K. Hagen & D. Wohlgemuth-von Reiche, 2002. The significance of flood regimes for
23 carabid beetle and spider communities in riparian habitats - a comparison of three
24 major rivers in Germany. *River Research and Applications* 18:43-64.

25 Borcard, D., P. Legendre & P. Drapeau, 1992. Partialling out the spatial component of ecological
26 variation. *Ecology* 73:1045-1055.

- 1 Cabezas, A., F. A. Comín, S. Beguería & M. Trabucchi, 2009. Hydrologic and landscape changes in
2 the Middle Ebro River (NE Spain): implications for restoration and management.
3 *Hydrology and Earth System Sciences* 13:273-284.
- 4 Cohen, J. E. & C. Small, 1998. Hypsographic demography: the distribution of human population
5 by altitude. *Proceedings of the National Academy of Sciences of the United States of*
6 *America* 95:14009-14014.
- 7 De Jonge, J., J. M. Brils, A. J. Hendriks & W. C. Ma, 1999. Ecological and ecotoxicological surveys of
8 moderately contaminated floodplain ecosystems in the Netherlands. *Aquatic Ecosystem*
9 *Health and Management* 2:9-18.
- 10 Freedman, L. S., D. Pee & D. N. Midthune, 1992. The problem of underestimating the residual
11 error variance in forward stepwise regression. *Statistician* 41:405-412.
- 12 Garcia, R. R., F. J. Ocharan, B. M. Jauregui, U. Garcia, K. Osoro & R. Celaya, 2010. Ground-dwelling
13 arthropod communities present in three types of Cantabrian (NW Spain) heathland
14 grazed by sheep or goats. *European Journal of Entomology* 107:219-227.
- 15 Hendriks, A. J., W. C. Ma, J. J. Brouns, E. M. De Ruiter-Dijkman & R. Gast, 1995. Modeling and
16 monitoring organochlorine and heavy metal accumulation in soils, earthworms, and
17 shrews in Rhine-delta floodplains. *Archives of Environmental Contamination and*
18 *Toxicology* 29:115-127.
- 19 Hobbelen, P. H. F., J. E. Koolhaas & C. A. M. Van Gestel, 2004. Risk assessment of heavy metal
20 pollution for detritivores in floodplain soils in the Biesbosch, the Netherlands, taking
21 bioavailability into account. *Environmental Pollution* 129:409-419.
- 22 Hobbelen, P. H. F., P. J. Van den Brink, J. F. Hobbelen & C. A. M. Van Gestel, 2006. Effects of heavy
23 metals on the structure and functioning of detritivore communities in a contaminated
24 floodplain area. *Soil Biology & Biochemistry* 38:1596-1607.
- 25 Jansson, R., C. Nilsson & B. Renöfält, 2000. Fragmentation of riparian floras in rivers with
26 multiple dams. *Ecology* 81:899-903.

- 1 Kashem, M. A. & B. R. Singh, 2001. Metal availability in contaminated soils: I. Effects of flooding
2 and organic matter on changes in Eh, pH and solubility of Cd, Ni and Zn. *Nutrient Cycling*
3 *in Agroecosystems* 61:247-255.
- 4 Klok, C., P. W. Goedhart & B. Vandecasteele, 2007. Field effects of pollutants in dynamic
5 environments. A case study on earthworm populations in river floodplains
6 contaminated with heavy metals. *Environmental Pollution* 147:26-31.
- 7 Lepš, J. & P. Šmilauer, 2003. *Multivariate analysis of ecological data using CANOCO*. Cambridge
8 University Press, Cambridge.
- 9 Leuven, R. S. E. W., S. Wijnhoven, L. Kooistra, R. J. W. De Nooij & M. A. J. Huibregts, 2005.
10 Toxicological constraints for rehabilitation of riverine habitats: a case study for metal
11 contamination of floodplain soils along the Rhine. *Archiv für Hydrobiologie* 155:657-
12 676.
- 13 Loos, M., A. M. J. Ragas, R. Plasmeijer, A. M. Schipper & A. J. Hendriks, 2010. Eco-SpaCE: An
14 object-oriented, spatially explicit model to assess the risk of multiple environmental
15 stressors on terrestrial vertebrate populations. *Science of the Total Environment*
16 408:3908-3917.
- 17 Ma, W. C., P. W. Van Vliet & J. Bodt, 2004. *Multistress van verontreiniging en hydrodynamiek op*
18 *populaties van Oligochaeta in de uiterwaarden*. Alterra, Wageningen.
- 19 Middelkoop, H., 2000. Heavy-metal pollution of the river Rhine and Meuse floodplains in the
20 Netherlands. *Netherlands Journal of Geosciences* 79:411-428.
- 21 Moran, J., M. Gormally & M. S. Skeffington, 2012. Turlough ground beetle communities: the
22 influence of hydrology and grazing in a complex ecological matrix. *Journal of Insect*
23 *Conservation* 16:51-69.
- 24 Nienhuis, P. H., A. D. Buijse, R. Leuven, A. J. M. Smits, R. J. W. De Nooij & E. M. Samborska, 2002.
25 Ecological rehabilitation of the lowland basin of the river Rhine (NW Europe).
26 *Hydrobiologia* 478:53-72.

- 1 Notten, M. J. M., A. J. P. Oosthoek, J. Rozema & R. Aerts, 2005. Heavy metal concentrations in a
2 soil-plant-snail food chain along a terrestrial soil pollution gradient. *Environmental*
3 *Pollution* 138:178-190.
- 4 Økland, R. H., 1999. On the variation explained by ordination and constrained ordination axes.
5 *Journal of Vegetation Science* 10:131-136.
- 6 Økland, R. H. & O. Eilertsen, 1994. Canonical Correspondence Analysis with variation
7 partitioning: some comments and an application. *Journal of Vegetation Science* 5:117-
8 126.
- 9 Peeters, E., R. Gylstra & J. H. Vos, 2004. Benthic macroinvertebrate community structure in
10 relation to food and environmental variables. *Hydrobiologia* 519:103-115.
- 11 Pribyl, D. W., 2010. A critical review of the conventional SOC to SOM conversion factor.
12 *Geoderma* 156:75-83.
- 13 Rozema, J., M. J. M. Notten, R. Aerts, C. A. M. Van Gestel, P. H. F. Hobbelen & T. H. M. Hamers,
14 2008. Do high levels of diffuse and chronic metal pollution in sediments of Rhine and
15 Meuse floodplains affect structure and functioning of terrestrial ecosystems? *Science of*
16 *the Total Environment* 406:443-448.
- 17 Sauvé, S., W. Hendershot & H. E. Allen, 2000. Solid-solution partitioning of metals in
18 contaminated soils: Dependence on pH, total metal burden, and organic matter.
19 *Environmental Science and Technology* 34:1125-1131.
- 20 Schaffers, A. P., I. P. Raemakers, K. V. Sykora & C. J. F. Ter Braak, 2008. Arthropod assemblages
21 are best predicted by plant species composition. *Ecology* 89:782-794.
- 22 Schipper, A. M., K. Lotterman, M. Geertsma, R. S. E. W. Leuven & A. J. Hendriks, 2010. Using
23 datasets of different taxonomic detail to assess the influence of floodplain characteristics
24 on terrestrial arthropod assemblages. *Biodiversity and Conservation* 19:2087-2110.
- 25 Schipper, A. M., K. Lotterman, R. S. E. W. Leuven, A. M. J. Ragas, H. De Kroon & A. J. Hendriks,
26 2011. Plant communities in relation to flooding and soil contamination in a lowland
27 Rhine River floodplain. *Environmental Pollution* 159:182-189.

- 1 Schipper, A. M., S. Wijnhoven, H. Baveco & N. W. Van den Brink, 2012. Contaminant exposure in
2 relation to spatio-temporal variation in diet composition: A case study of the little owl
3 (*Athene noctua*). *Environmental Pollution* 163:109-116.
- 4 Schipper, A. M., S. Wijnhoven, R. S. E. W. Leuven, A. M. J. Ragas & A. J. Hendriks, 2008. Spatial
5 distribution and internal metal concentrations of terrestrial arthropods in a moderately
6 contaminated lowland floodplain along the Rhine River. *Environmental Pollution*
7 151:17-26.
- 8 Silvertown, J., M. E. Dodd, D. J. G. Gowing & J. O. Mountford, 1999. Hydrologically defined niches
9 reveal a basis for species richness in plant communities. *Nature* 400:61-63.
- 10 Song, J. F., J. Zhao, S. P McGrath, & Y. M. Luo, 2006. Influence of soil properties and aging on
11 arsenic phytotoxicity. *Environmental Toxicology and Chemistry* 25:1663-1670.
- 12 Stanford, J. A., J. V. Ward, W. J. Liss, C. A. Frissell, R. N. Williams, J. A. Lichatowich & C. C. Coutant,
13 1996. A general protocol for restoration of regulated rivers. *Regulated Rivers: Research*
14 *& Management* 12:391-413.
- 15 Stoner, K. J. L. & A. Joern, 2004. Landscape vs. local habitat scale influences to insect
16 communities from tallgrass prairie remnants. *Ecological Applications* 14:1306-1320.
- 17 Sýkora, K. V., E. Scheper & F. Van der Zee, 1988. Inundation and the distribution of plant
18 communities on Dutch river dikes. *Acta Botanica Neerlandica* 37:279-290.
- 19 Sýkora, K. V., G. Van der Krogt & J. Rademakers, 1990. Vegetation change on embankments in the
20 south-western part of The Netherlands under the influence of different management
21 practices (in particular sheep grazing). *Biological Conservation* 52:49-81.
- 22 Ter Braak, C. J. F., 1987. The analysis of vegetation-environment relationships by canonical
23 correspondence analysis. *Plant Ecology* 69:69-77.
- 24 Ter Braak, C. J. F. & P. Šmilauer, 2002. CANOCO Reference manual and CanoDraw for Windows
25 user's guide: software for canonical community ordination (version 4.5). Microcomputer
26 Power, Ithaca, NY.

- 1 Ter Braak, C. J. F. & P. F. M. Verdonschot, 1995. Canonical correspondence analysis and related
2 multivariate methods in aquatic ecology. *Aquatic Sciences* 57:255-289.
- 3 Tockner, K., M. Pusch, D. Borchardt & M. S. Lorang, 2010. Multiple stressors in coupled river-
4 floodplain ecosystems. *Freshwater Biology* 55:135-151.
- 5 Tockner, K. & J. A. Stanford, 2002. Riverine flood plains: present state and future trends.
6 *Environmental Conservation* 29:308-330.
- 7 Van den Brink, N. W., N. M. Groen, J. De Jonge & A. T. C. Bosveld, 2003. Ecotoxicological
8 suitability of floodplain habitats in The Netherlands for the little owl (*Athene noctua*
9 *vidalli*). *Environmental Pollution* 122:127-134.
- 10 Van Eck, W. H. J. M., H. M. Van de Steeg, C. W. P. M. Blom & H. De Kroon, 2004. Is tolerance to
11 summer flooding correlated with distribution patterns in river floodplains? A
12 comparative study of 20 terrestrial grassland species. *Oikos* 107:393-405.
- 13 Van Griethuysen, C., J. Van Baren, E. Peeters & A. A. Koelmans, 2004. Trace metal availability and
14 effects on benthic community structure in floodplain lakes. *Environmental Toxicology &*
15 *Chemistry* 23:668-681.
- 16 Volis, S., M. Dorman, M. Blecher, Y. Sapir & L. Burdeniy, 2011. Variation partitioning in canonical
17 ordination reveals no effect of soil but an effect of co-occurring species on translocation
18 success in *Iris atrofusca*. *Journal of Applied Ecology* 48:265-273.
- 19 Ward, J. V., K. Tockner & F. Schiemer, 1999. Biodiversity of floodplain river ecosystems:
20 Ecotones and connectivity. *Regulated Rivers: Research and Management* 15:125-139.
- 21 Wisser, S. K. & R. P. Buxton, 2008. Context matters: Matrix vegetation influences native and exotic
22 species composition on habitat islands. *Ecology* 89:380-391.

23

1 **Tables**

2

3 **Table 1:** Environmental characteristics measured in the ‘Wolfswaard’ river floodplain area (n =
4 30).

Category	Variable	Mean	Min	Max
Flooding characteristics	Distance to river (m)	225	102	347
	Elevation (m amsl)	8.41	7.00	9.64
	Flooding duration (days/year)	10	1	79
Physical-chemical soil properties	Clay content (< 2 µm; %)	6.6	1.8	11.3
	Silt content (2 - 64 µm; %)	59.4	17.3	84.0
	Sand content (> 64 µm; %)	7.9	7.9	80.9
	Median grain size (d50; µm)	54	9	292
	pH	7.6	7.3	8.0
	Soil organic matter (SOM; %)	11.4	5.3	16.1
Vegetation structure ^a	Vegetation cover (%)	91	40	100
	Vegetation height (m)	0.31	0.05	1.10
Soil metal contamination	As (mg/kg dw)	8.17	3.30	14.7
	Cd (mg/kg dw)	1.18	0.30	3.20
	Cr (mg/kg dw)	42.8	12.8	103
	Cu (mg/kg dw)	35.9	12.3	76.8
	Ni (mg/kg dw)	21.8	10.8	35.6
	Pb (mg/kg dw)	77.4	29	148
	Zn (mg/kg dw)	205	66.3	413
	Cd - dissolved (mg/l)	0.189	0.0392	0.481
	Cu - dissolved (mg/l)	11.1	4.66	21.6
	Pb - dissolved (mg/l)	1.09	0.508	1.64
	Zn - dissolved (mg/l)	24.6	7.11	45.8

5 ^aVegetation cover and height refer to the herb layer of the vegetation.

6

1 **Table 2:** Significant explanatory variables ($p < 0.05$) for terrestrial plant and soil-dwelling
 2 arthropod assemblages in the 'Wolfswaard' floodplain area, according to a CCA with manual
 3 forward selection procedure as available in Canoco.

Biotic assemblages	Step	Explanatory variables ^a	F-statistic	p -value ^b	VIF ^c
Plant species	1	Hedgerow	5.77	0.001	2.17
	2	Flooding duration	4.11	0.001	6.26
	3	Sheep grazing	3.65	0.001	3.10
	4	Elevation	2.41	0.001	5.35
	5	Vegetation height	2.29	0.001	1.58
	6	Distance to river	1.73	0.025	4.51
	7	Total As concentration in soil	1.70	0.035	3.69
Ground beetle species	1	Cattle grazing	4.39	0.001	1.95
	2	Sheep grazing	2.94	0.001	1.85
	3	Flooding duration	3.08	0.001	1.22
	4	Vegetation height	1.53	0.043	1.09
Ground beetle genera	1	Cattle grazing	5.88	0.001	1.90
	2	Sheep grazing	3.61	0.001	1.79
	3	Flooding duration	2.47	0.003	1.23
	4	Vegetation height	1.65	0.042	1.09
Beetle families	1	Cattle grazing	5.19	0.001	1.64
	2	Sheep grazing	3.09	0.002	1.71
	3	Vegetation height	2.33	0.005	1.06
Arthropod groups	1	Hedgerow	12.18	0.001	1.32
	2	Vegetation cover	6.30	0.006	1.32

4 ^aVegetation cover and height refer to the herb layer of the vegetation.

5 ^b The significance was evaluated with Monte Carlo permutation tests involving 1000 permutations.

6 ^c VIF = variance inflation factor

7

8

1 **Table 3:** Variance partitioning results for terrestrial plant and arthropod assemblages in the
 2 'Wolfswaard' study area.

3

Biotic assemblage	Explanatory variables ^a	Sum	Sum	Variance	<i>p</i> -value
		canonical	unconstrained	explained	
		eigenvalues	eigenvalues ^b	(%)	
Plant species	all	1.33	2.61	55	0.001
	flooding	0.16	1.75	17	0.001
	land use	0.42	1.78	19	0.001
	vegetation	0.12	1.40	5	0.006
	contamination	0.09	1.27	3	0.035
Ground beetle species	all	0.66	1.92	34	0.001
	flooding	0.16	1.15	8	0.016
	land use	0.42	1.68	22	0.001
	vegetation	0.09	1.34	4	0.043
Ground beetle genera	all	0.43	1.13	38	0.001
	flooding	0.07	0.78	6	0.008
	land use	0.31	1.02	27	0.001
	vegetation	0.05	0.75	4	0.047
Beetle families	all	0.17	0.56	31	0.001
	land use	0.13	0.52	24	0.001
	vegetation	0.04	0.42	6	0.009
Arthropod groups	all	0.05	0.12	43	0.001
	land use	0.04	0.10	30	0.001
	vegetation	0.02	0.08	13	0.005

4 ^a 'All' refers to all explanatory variables that were selected as significant ($p < 0.05$) in the exploratory CCA
 5 analyses (see Table 2).

6 ^b The sum of the unconstrained eigenvalues with all environmental variables included represents the total
 7 inertia.

1 **Figures**

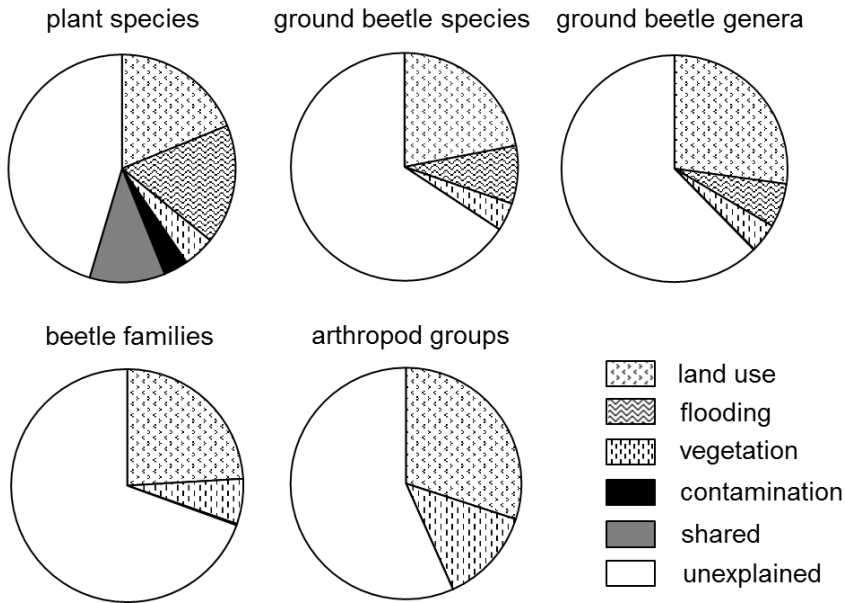
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3

4 **Fig. 1:** Location of the 'Wolfswaard' study area.

5



1

2 **Fig. 2:** Variance partitioning with canonical correspondence analysis (CCA) for terrestrial plant
 3 and soil-dwelling arthropod assemblages in the 'Wolfswaard' study area. 'shared' refers to
 4 variation in taxonomic contribution attributed to joint effects of environmental factors
 5 belonging to different categories.