Oikos

O18525

Violle, C., Bonis, A., Plantegenest, M., Cudennec, C., Damgaard, C., Marion, B., Le Cœur, D. and Bouzillé, J.-B. 2011. Plant functional traits capture species richness variations along a flooding gradient. – Oikos 120: 389–398.

Appendix 1

Description of the hydrological modelling

Study area

Data were collected in an experimental site in the Marais Poitevin (46°28′N, 01°13′W), situated in the western part of France (Loucougaray et al. 2004). Observations were carried out in a 4-ha wet meadow, which is characterized by a large depression. Topography is irregular with many low-lying seasonally flooded depressions and high level flats with intermediate gentle slopes with up to 50 cm elevation difference.

Hydrological modelling

A hydrological model (Violle et al. 2006) with a daily time step, based on meteorological data and on a sampling of 3000 topographic points, has been implemented to precisely assess: the number of flood periods, water depth$_{max}$ and the mean annual flooding duration at any location of the study area and for a 6-year time period (from 1 August 1996 to 31 July 2002).

Overall model structure

Evaluation of the change in water storage

The general time-discretized water balance equation is:

$$\Delta V(t) = V(t+\Delta t) - V(t) = I(t) - O(t) \qquad \text{(A1)}$$

where $\Delta V(t)$ is the change of water storage (in m^3) during the time interval $[t,t+\Delta t]$;
$V(t)$ is the volume of water (in m^3) in the depression at time t;
$I(t)$ and $O(t)$ are respectively the total inflows and outflows of water (in m^3) during the time interval $[t,t+\Delta t]$.

The studied depression is not connected to the surrounding canal. It is also the highest depression of the neighbourhood, thus, it cannot receive overflow from other depressions. The inflows during the time interval $[t,t+\Delta t]$, $I(t)$, are, then, only the accumulated precipitation, $P(t)$ (in m), that falls over the total area of the depression basin, S_{tot} (in m²):

$$I(t) = P(t)\, S_{tot} \qquad \text{(A2)}$$

Percolation is, firstly, assumed to be negligible in the studied system, as soils are rich in clay (Violle et al. 2006). Then the outflows during the time interval $[t,t+\Delta t]$, $O(t)$ are only caused by evapotranspiration, $ETP(t)$ (in m), depending on $S(t)$, the free water surface at time t (in m²). In addition, when the water content exceeds the total volume (V_{max}) of the depression, the excess water, $V_{overflow}(t)$ (in m^3), is lost by overflowing.

$$O(t) = ETP(t) \cdot S(t) + V_{overflow}(t) \qquad \text{(A3)}$$

Relationships between the volume, the surface and the elevation

To implement Eq. 2 and 3, the evaporating free water surface, S, corresponding to any volume, value V, had to be assessed. For this purpose, a precise topographic mapping of the studied area has been carried out using a theodolite (Wild T1000) providing a precision lower than one centimetre on the Z-axe and based on a sampling of 3000 topographic points. A digital elevation model (DEM) was then built using the program AUTOMAP 14 of the AUTOCAD package. The resulting DEM was used to associate the corresponding water volume V, surface S and elevation Z. Finally, the set of (Z, S, V) values was used to fit two phenomenological models (second-degree polynomial functions) using a least-square method.

$$S = f(V) \qquad \text{(A4)}$$

$$Z = g(V) \qquad \text{(A5)}$$

Equation 1, 4 and 5 allowed to express $Z(t)$, the temporal evolution of the free water elevation in terms of rainfall $P(t)$ and evapotranspiration $ETP(t)$.

Calculation of flooding parameters

At any point, A characterized by its 3D Cartesian coordinates (Xa, Ya, Za) and any time step t, the comparison of $Z(t)$ and Za informed whether the point was flooded or not, and provided the water depth over the soil. The model was initialized on the 1 August, 1996, and iterated every day. As the depression is always empty in summer, the model was further re-initialized ($V(0) = 0$) each year on the 1 August in order to correct for infiltration, which may not be negligible in summer. The mean annual flooding duration, the water depth$_{max}$ and the flooding frequency were then assessed between 1 August, 1996, and 31 July, 2002, for each of the 222 quadrats of the depression. The model was validated on an independent dataset consisting of water-table depths measured on a close flood meadow (Violle et al. 2006).

Input data

Meteorological data were obtained from the Météo France weather station of St-Gemme-La-Plaine, located ten kilometres from the studied site, with no difference of climatic context due to orographic effects. The station provided the daily precipitation and evapotranspiration (Penman-Monteith's ETP) for the 6-year period.

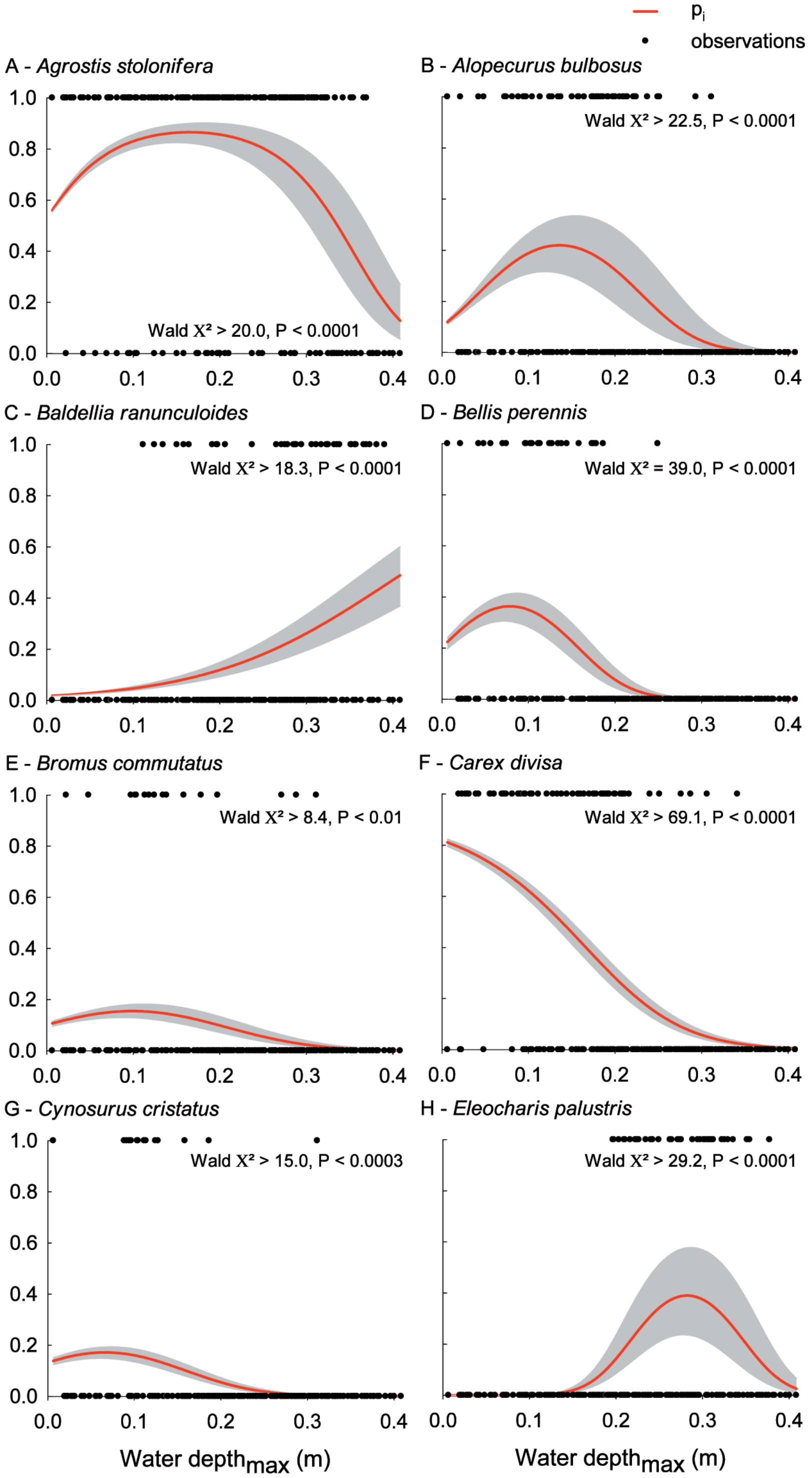
Supplementary references

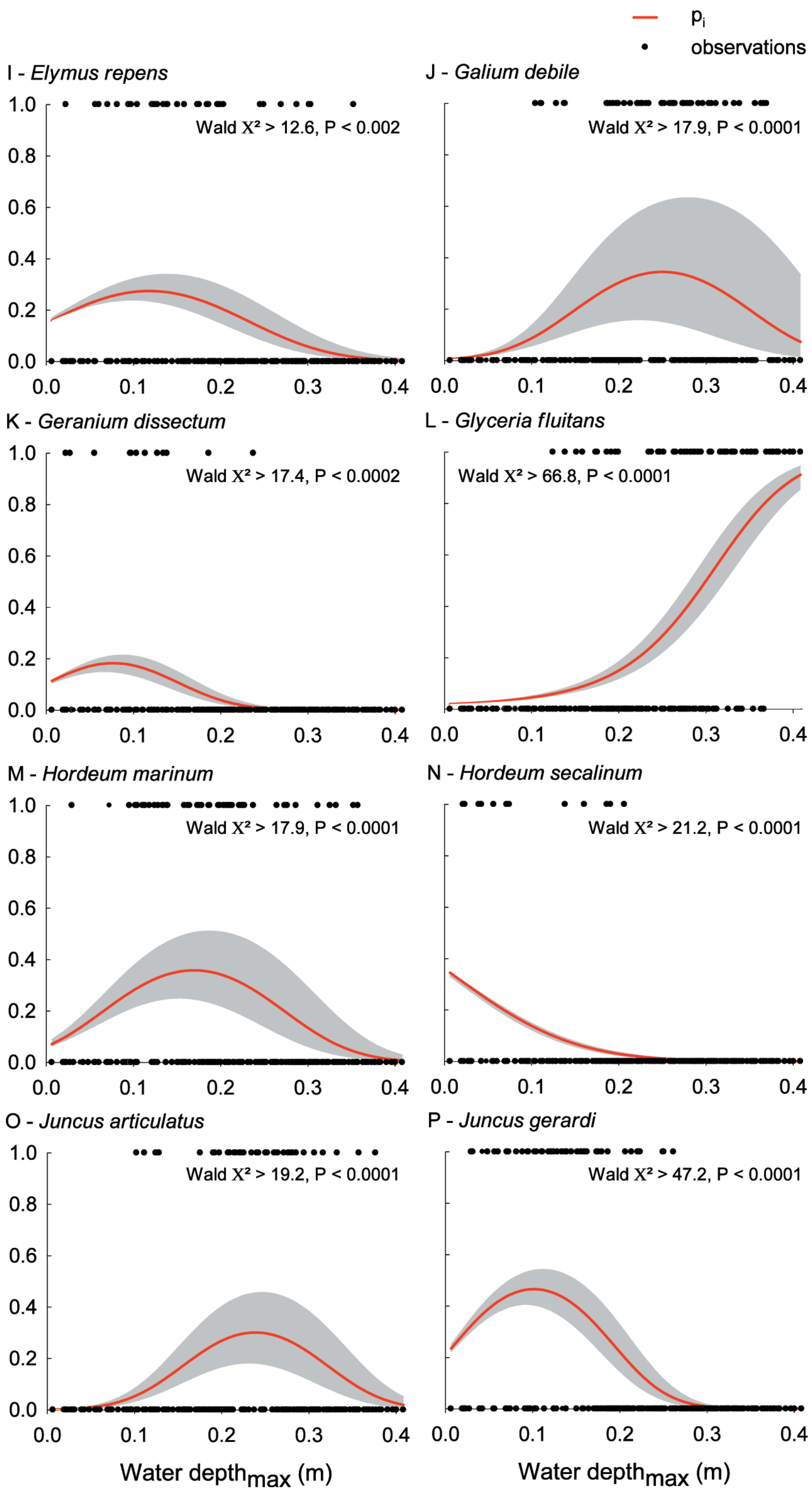
Loucougaray, G. et al. 2004. Effects of grazing by horses and/or cattle on the diversity of coastal grasslands in western France. – Biol. Conserv. 116: 59–71.

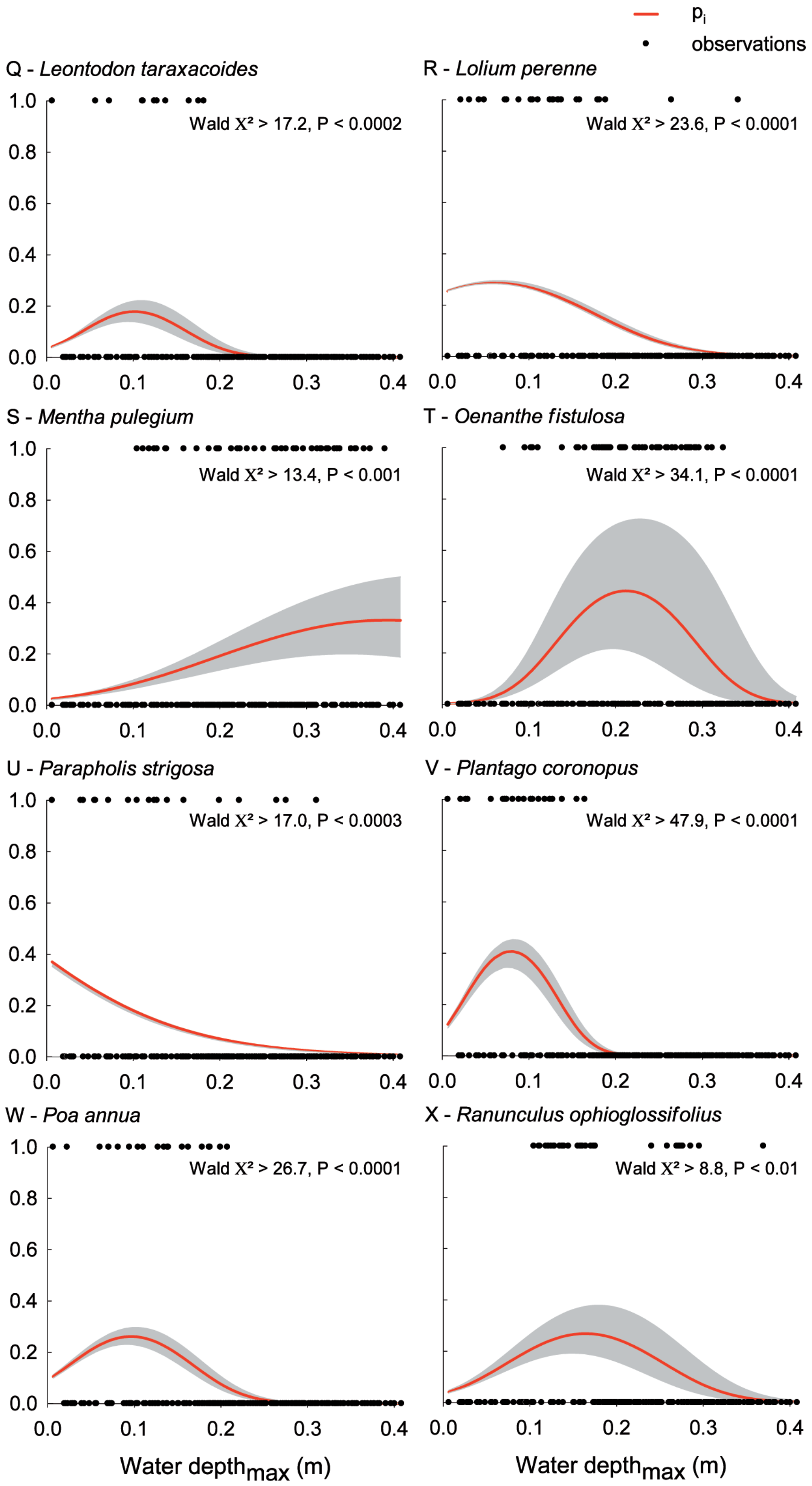
Violle, C. et al. 2006. Indirect assessment of flooding duration as a driving factor of plant diversity in wet grasslands. – IAHS Publ. 303: 334–341.

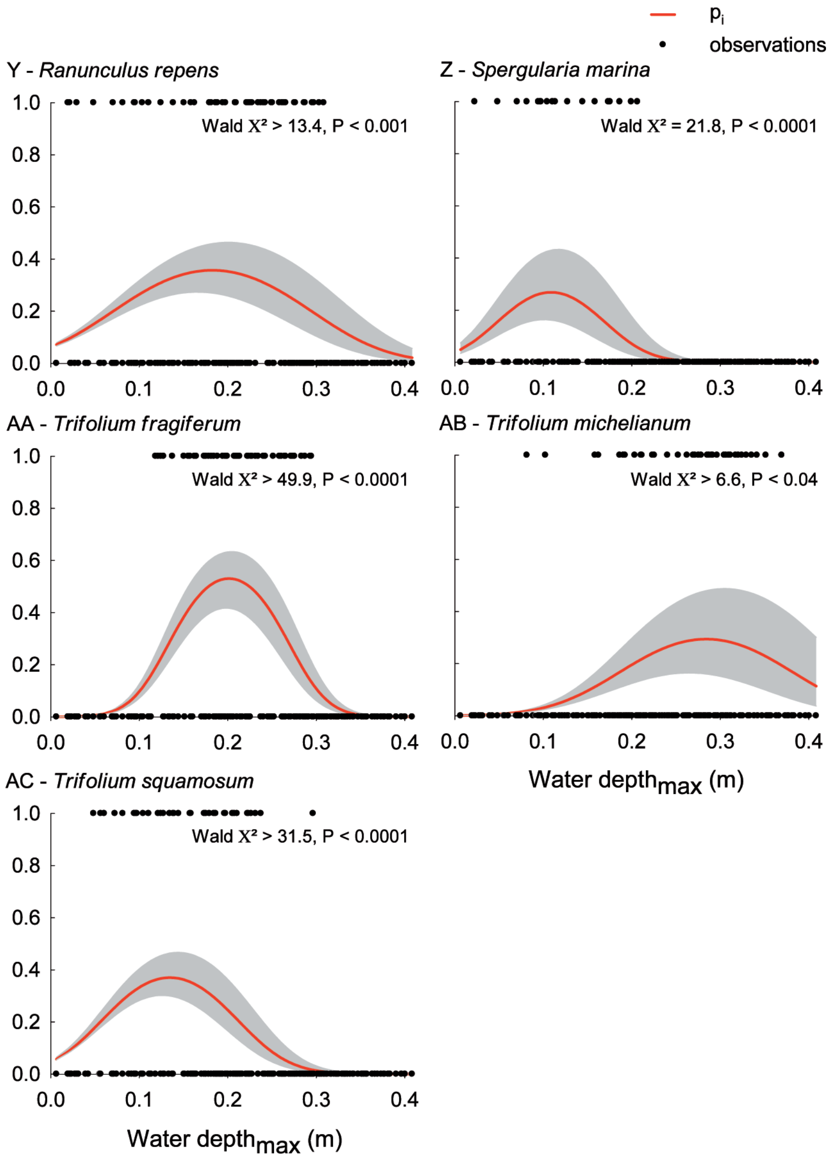
Appendix 2

Results of the niche-based models. Only the species whose distribution significantly varies with water depth$_{max}$ are presented (A – AC). The probability of occurrence was modelled thanks to logistic regressions (the red line is the regression line for all 222 quadrats, the grey zone is the 95% confidence interval obtained from the 100 simulations; coefficients of the logistic regressions are given in Appendix 3). The minimum Wald χ^2-values (and related p-values) are given. The dots are the 222 field-observed data (in presence/absence).




p_i
observations
I - Elymus repens
Wald X² > 12.6, P < 0.002
J - Galium debile
Wald X² > 17.9, P < 0.0001
K - Geranium dissectum
Wald X² > 17.4, P < 0.0002
L - Glyceria fluitans
Wald X² > 66.8, P < 0.0001
M - Hordeum marinum
Wald X² > 17.9, P < 0.0001
N - Hordeum secalinum
Wald X² > 21.2, P < 0.0001
O - Juncus articulatus
Wald X² > 19.2, P < 0.0001
P - Juncus gerardi
Wald X² > 47.2, P < 0.0001
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.1
0.2
0.3
0.4
Water depth$_{max}$ (m)
Water depth$_{max}$ (m)


pi
observations
Q - Leontodon taraxacoides
Wald X² > 17.2, P < 0.0002
R - Lolium perenne
Wald X² > 23.6, P < 0.0001
S - Mentha pulegium
Wald X² > 13.4, P < 0.001
T - Oenanthe fistulosa
Wald X² > 34.1, P < 0.0001
U - Parapholis strigosa
Wald X² > 17.0, P < 0.0003
V - Plantago coronopus
Wald X² > 47.9, P < 0.0001
W - Poa annua
Wald X² > 26.7, P < 0.0001
X - Ranunculus ophioglossifolius
Wald X² > 8.8, P < 0.01
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.1
0.2
0.3
0.4
Water depthmax (m)
Water depthmax (m)


pi
observations
Y - Ranunculus repens
Wald X² > 13.4, P < 0.001
Z - Spergularia marina
Wald X² = 21.8, P < 0.0001
AA - Trifolium fragiferum
Wald X² > 49.9, P < 0.0001
AB - Trifolium michelianum
Wald X² > 6.6, P < 0.04
AC - Trifolium squamosum
Wald X² > 31.5, P < 0.0001
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.1
0.2
0.3
0.4
Water depthmax (m)
Water depthmax (m)

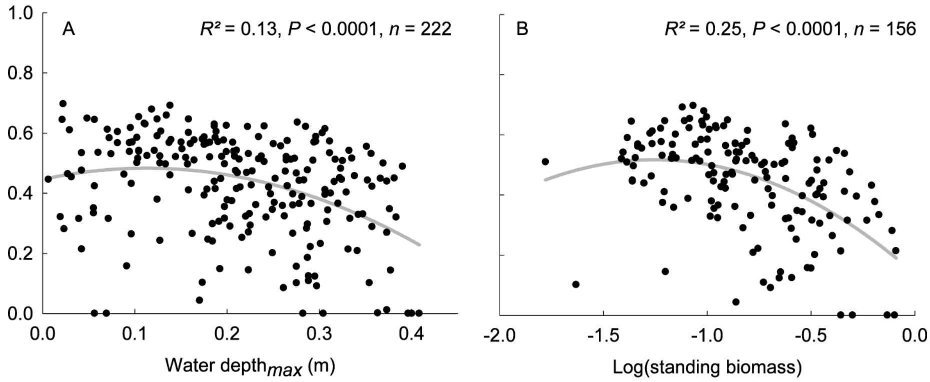
Appendix 3

Coefficients of the logistic regressions (mean +/– SE; results of repeated species distribution models: see text for more detail) where the logit of the probability of occurrence of the ith species was assumed to be a quadratic function of water depth_{max} as: $\ln\left[\frac{p_i(x)}{1 - p_i(x)}\right] = b_{i0} + b_{i1}..x + b_{i2}.x^2$, where $p_i(x)$ is the conditional probability of species i being present at water depth_{max} x, and b_{ij} is the jth regression coefficient for the species i. Values of b_{ij} were estimated with the GENMOD procedure of SAS Software (SAS Inst.)

Species *i*	b_{i0} (SE)	b_{i1} (SE)	b_{i2} (SE)
Agrostis stolonifera	0.11 (0.02)	21.2 (1.7)	–64.0 (1.2)
Alopecurus bulbosus	–2.2 (0.08)	27.2 (2.2)	–100.1 (4.5)
Baldellia ranunculoides	–4.1 (0.09)	10.9 (0.9)	–2.5 (0.09)
Bellis perennis	–1.4 (0.12)	20.6 (1.1)	–130.9 (5.2)
Bromus commutatus	–2.2 (0.1)	9.9 (0.8)	–50.0 (2.3)
Carex divisa	1.5 (0.09)	–8.0 (0.4)	–21.2 (1.1)
Cynosurus cristatus	–1.9 (0.11)	9.4 (0.6)	–70.9 (2.2)
Eleocharis palustratis	–16.3 (0.31)	112.5 (1.4)	–199.4 (0.6)
Elymus repens	–1.7 (0.03)	12.9 (1.6)	–54.8 (2.4)
Galium debile	–5.4 (0.15)	38.1 (3.4)	–76.1 (1.8)
Geranium dissectum	–2.2 (0.06)	17.2 (2.0)	–111.9 (2.0)
Glyceria fluitans	–4.0 (0.07)	7.1 (0.9)	20.4 (0.7)
Hordeum marinum	–2.7 (0.2)	25.3 (1.9)	–74.8 (2.1)
Hordeum secalinum	–0.6 (0.03)	–10.5 (0.7)	–20.5 (1.2)
Juncus articulatus	–6.9 (0.4)	50.8 (0.6)	–106.5 (2.1)
Juncus gerardi	–1.3 (0.08)	23.5 (1.7)	–115.7 (2.9)
Leontodon taraxacoides	–3.4 (0.03)	36.5 (2.1)	–179.8 (3.4)
Lolium perenne	–1.1 (0.01)	6.5 (0.2)	–52.9 (1.7)
Mentha pulegium	–3.8 (0.1)	15.6 (1.1)	–19.8 (1.1)
Oenanthe fistulosa	–6.5 (0.32)	59.4 (3.1)	–140.0 (3.1)
Parapholis strigosa	–0.5 (0.04)	–10.3 (0.2)	–1.4 (0.06)
Plantago coronopus	–2.3 (0.09)	47.4 (1.3)	–298.5 (5.2)
Poa annua	–2.3 (0.06)	26.2 (0.8)	–135.9 (3.5)
Ranunculus ophioglossifolius	–3.3 (0.11)	28.3 (1.8)	–86.4 (2.4)
Ranunculus repens	–2.7 (0.08)	23.2 (1.5)	–63.5 (1.9)
Spergularia marina	–3.2 (0.4)	41.1 (2.2)	–188.9 (3.7)
Trifolium fragiferum	–9.2 (0.2)	92.4 (1.0)	–229.4 (1.0)
Trifolium michelianum	–7.0 (0.1)	43.3 (1.8)	–76.2 (2.2)
Trifolium squamosum	–3.0 (0.08)	37.2 (1.6)	–138.2 (3.2)

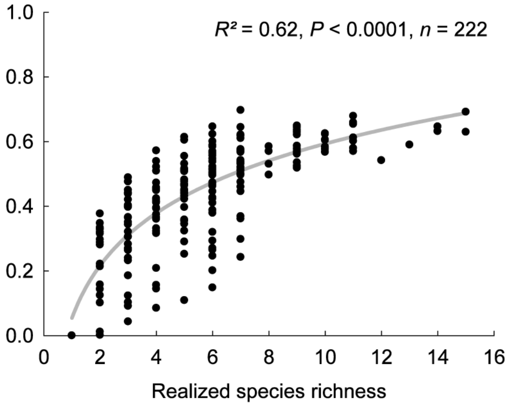
Appendix 4

Changes in functional diversity (calculated based on Rao's Q averaged for the three LHS-related traits) with water depth$_{max}$ and standing biomass (kg m^{-2}; log-transformed).



Appendix 5

Changes in functional diversity (calculated based on Rao's Q averaged for the three LHS-related traits) with realized species richness.



Appendix 6

Changes in functional diversity (calculated based on Rao's Q for each LHS-related trait) with mean community traits.