Effects of consumptive water use on biodiversity in wetlands of international importance

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S1. Inland Ramsar wetlands

According to the Ramsar convention, wetlands are defined as “areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres”.[1] The biological importance of the Ramsar sites, as indicated in the Ramsar Sites Information Service (RIS)[2], is shown in Table S1 and Table S2. Note that each Ramsar site can be named several times within the biological importance category.

Table S1: Biological importance of the Ramsar sites. The number of sites is given for total sites, surface water-fed sites and groundwater-fed sites. The percentages are related to the respective total (i.e. 1184 for total, 1033 for surface water-fed and 151 for groundwater-fed wetlands).

importance for	Total		Surface water-fed		Groundwater-fed	
	Number of sites[-]	Percentage [%]	Number of sites[-]	Percentage [%]	Number of sites[-]	Percentage [%]
amphibians	300	25	261	25	39	26
birds	795	67	703	68	92	61
critical link in major food chain	106	9	97	9	9	6
crocodilians	77	7	76	7	1	1
fish	489	41	447	43	42	28
flora	809	68	720	70	89	59
invertebrates	331	28	289	28	42	28
mammals	579	49	513	50	66	44
marine turtles	11	1	11	1	0	0
reptiles	304	26	259	25	45	30
waterbirds	862	73	762	74	100	66

Table S2: Biological importance of the Ramsar sites per geographical region.

importance for	Africa	Asia	Central America	Europe	Near-East	North America	South America	Oceania
amphibians	42	28	31	154	1	15	21	8
birds	153	124	56	346	4	28	59	25
crocodilians	29	10	12	8	0	1	15	2
fish	104	77	45	190	3	24	28	18
flora	153	98	52	431	3	7	36	29
invertebrates	30	40	11	219	1	13	7	10
mammals	140	73	41	236	1	22	53	13
marine turtles	0	2	0	9	0	0	9	0
reptiles	75	36	40	97	2	16	25	13
waterbirds	140	124	44	459	3	24	42	26
critical link in major food chain	28	22	7	25	0	8	10	6

S2. Overview of species and data sources

We have included different taxa for calculating effect factors of water consumption on biodiversity in wetlands. All species combined can act as a proxy for biodiversity. Table S3 lists all considered taxa.

Table S3: Overview of taxa, data sources and total number of species. The SI section indicates in which section more information and the calculated maps for the respective taxon can be found.

Taxon	total Species number	data source	SI section	comments
Waterbirds	2119	Birdlife/Nature Serve[3]	S3	habitat was according to BirdLife “wetland (inland)” or “artificial landscapes (aquatic)”.
Non-residential birds	1274	Birdlife/Nature Serve[3]	S3	seasonal category "resident" excluded during calculation. Non-residential waterbirds excluded
amphibians	6021	IUCN[4, 5]	S5	all amphibians with map and TL data included
reptiles	268	IUCN[4, 6]	S4	only reptiles included whose habitat is "wetland (inland)" and contain TL and map data
water-dependent mammals	123	Global Mammal Assessment[7]	S6	only mammals included that are directly water-dependent (not only for drinking water)

S3. Bird maps

For each bird species a shape file is available from BirdLife and NatureServe 2011[3], indicating the range of distribution. Additionally, it gives information on Presence, Origin and Season (see Table S4) that is equally valid for amphibians and reptiles.

Table S4: Codes for presence, origin and season of the dataset of BirdLife and NatureServe,[3] that are also valid for amphibians and reptiles.

	Presence	
Code	**Term**	**Explanation**
1	Extant	Occurs presently in area
2	Probably extant	Species presence thought probable
3	Possibly extant	Species may possibly occur
4	Possibly extinct	Species is most likely extirpated from area
5	Extinct	Formerly occurred in area, not recorded since 30 years, almost certainly extinct
6	Presence uncertain	Species formerly there, but now uncertain
	Origin	
Code	**Term**	**Explanation**
1	Native	Native inhabitant
2	Reintroduced	Formerly native range, reintroduced through human activities
3	Introduced	Through human activities to areas outside its natural range
4	Vagrant	Species recorded once or sporadically, not native to area
5	Origin uncertain	May be native, reintroduced or introduced
	Season	
Code	**Term**	**Explanation**
1	Resident	Present throughout the year
2	Breeding season	Occurs regularly during breeding season
3	Non-breeding season	Occurs regularly during non-breeding season, winter
4	Passage	Present during short periods during migration
5	Seasonal occurrence uncertain	Is present but unknown how long/which season

Resulting bird maps for the number of non-residential birds and waterbirds and the respective vulnerability scores are shown in Figure S1 to Figure S8. For the definition of waterbirds, non-residential birds and the calculation of the vulnerability scores, see the main document.

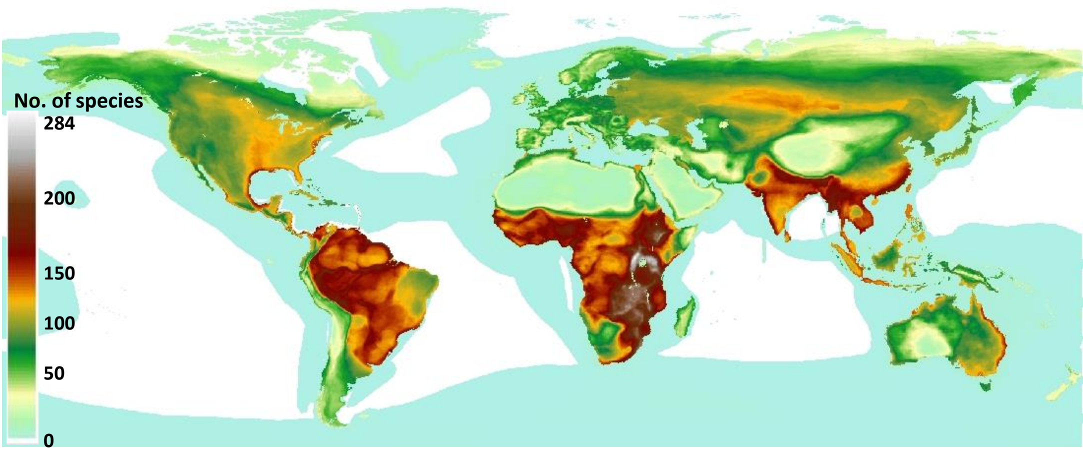


Figure S1: Bird richness map for the waterbird sample based on data from BirdLife and NatureServe.[3] Presence values are chosen from categories 1 to 3, values for season are at 1 to 5 (see Table S4).

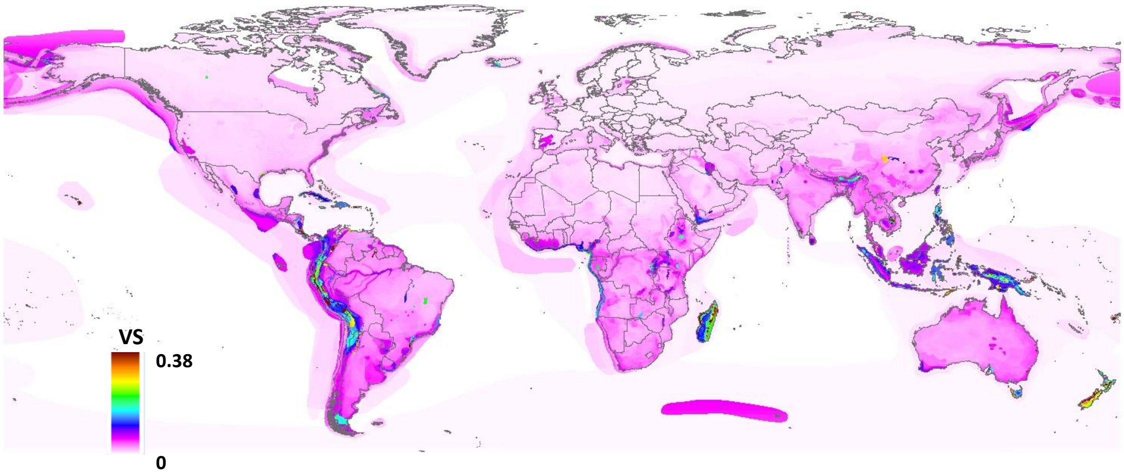


Figure S2: Bird vulnerability score (VS) map for waterbirds. Presence values are chosen from categories 1 to 3, values for season are at 1 to 5 (see Table S4).

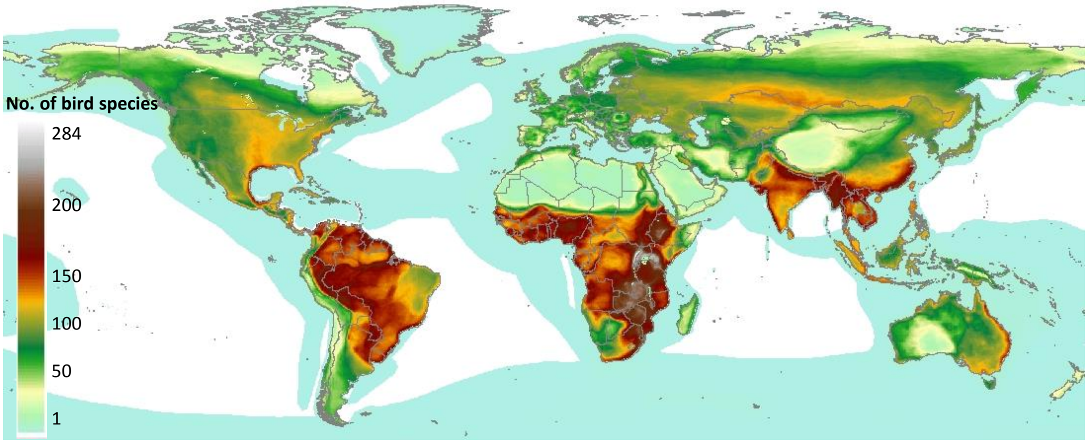


Figure S3: Bird richness map for the waterbird sample based on data from BirdLife and NatureServe.[3] Presence values are chosen from categories 1 to 4 (instead of 1 to 3), values for season remain at 1 to 5 (see Table S4). Base map with country boundaries adapted from ref.[8]

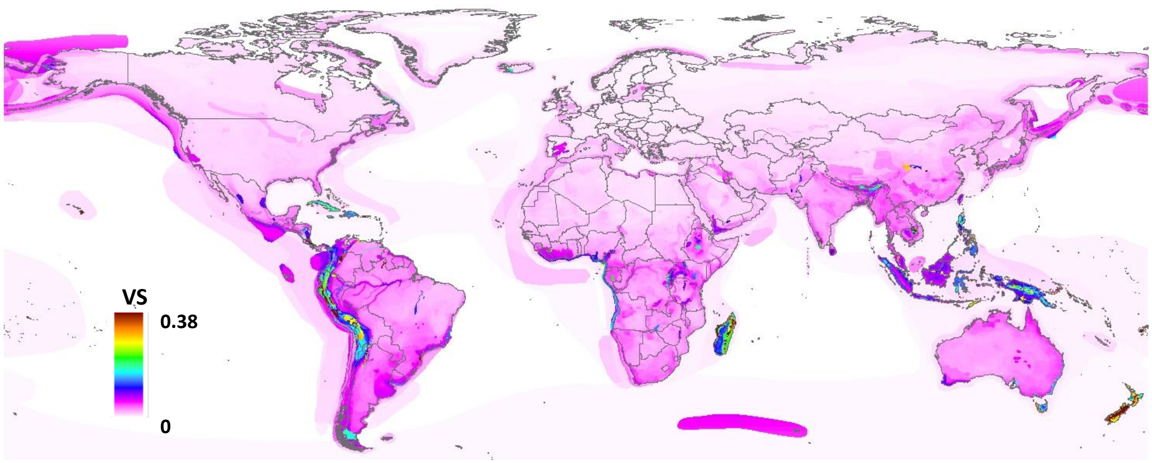


Figure S4: Bird vulnerability score (VS) map for waterbirds. Presence values are chosen from categories 1 to 4 (instead of 1 to 3), values for season remain at 1 to 5 (see Table S4).

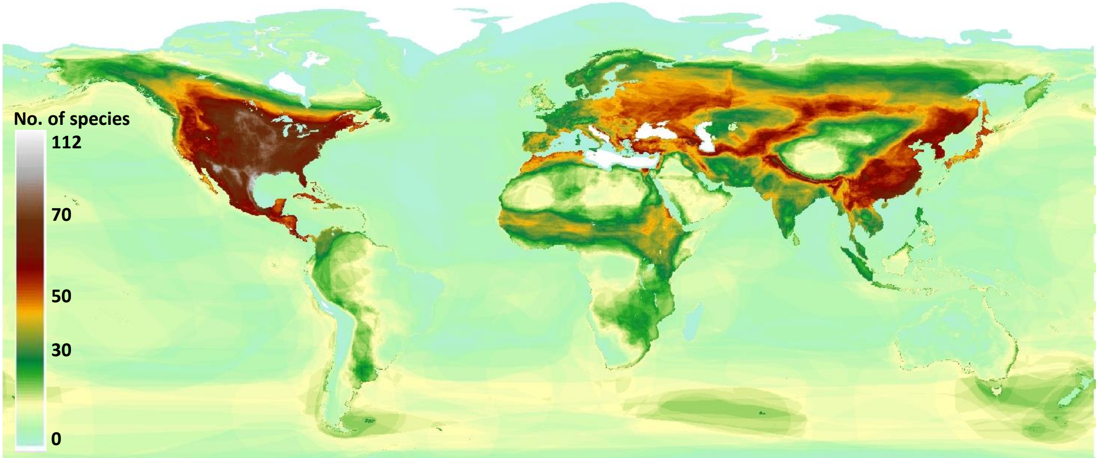


Figure S5: Bird richness map for the non-residential birds based on data from BirdLife and NatureServe.[3] Presence values are chosen from categories 1 to 3, values for season are at 2 to 5 (see Table S4).

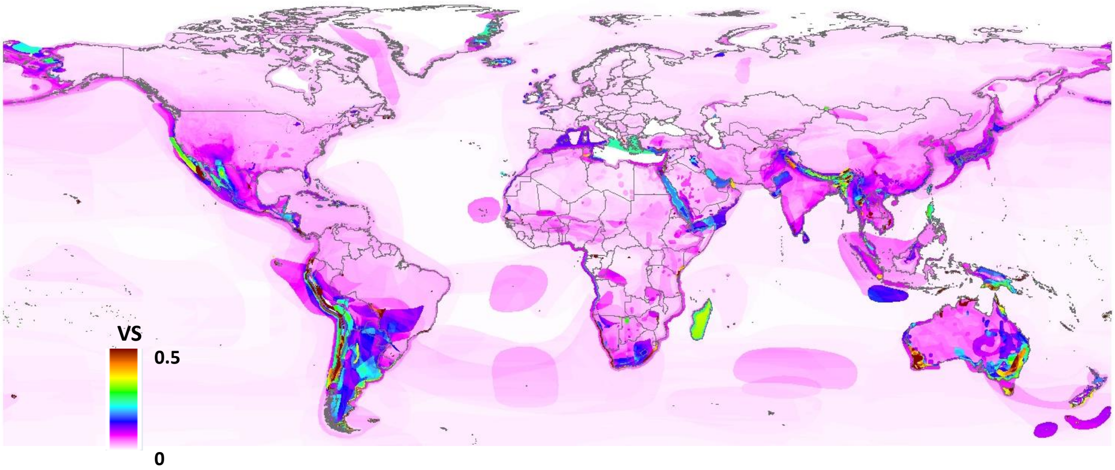


Figure S6: Bird vulnerability score (VS) map for non-residential birds. Presence values are chosen from categories 1 to 3, values for season are at 2 to 5 (see Table S4).

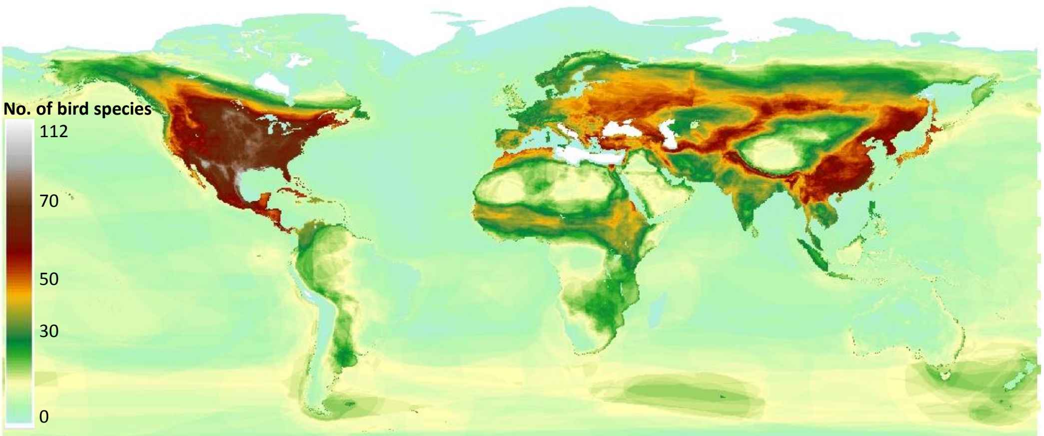


Figure S7: Bird richness map for the non-residential birds based on data from BirdLife and NatureServe.[3] Presence values are chosen from categories 1 to 4 (instead of 1 to 3), values for season remain at 2 to 5 (see Table S4).

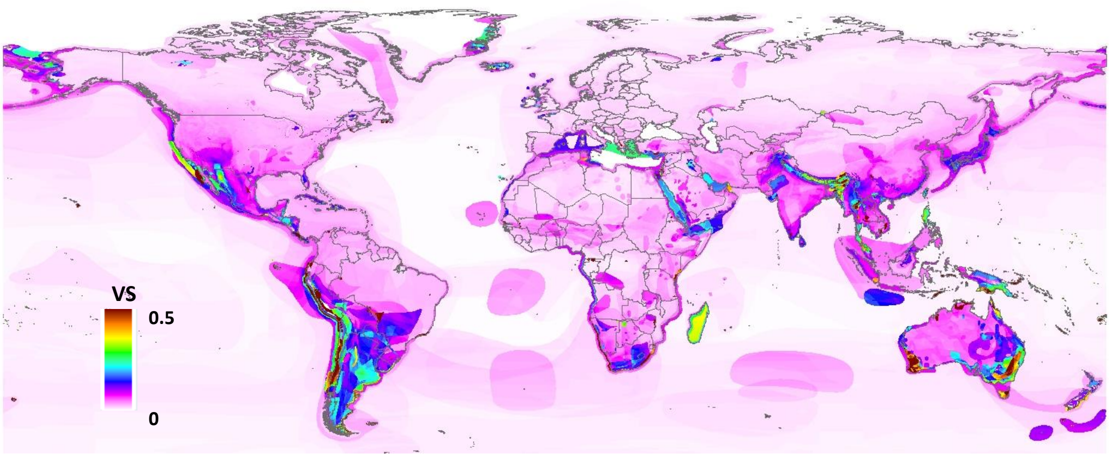


Figure S8: Bird vulnerability score (VS) map for non-residential birds. Presence values are chosen from categories 1 to 4 (instead of 1 to 3), values for season remain at 2 to 5 (see Table S4).

The largest difference between species richness calculated with presence values 1 to 3, or with presence values 1 to 4, was 7 for waterbirds (The Bahamas), and 6 for non-residential birds (St.Helena). None of them were in areas where one of our 1184 Ramsar wetlands was located.

S4. Reptile maps

Reptile maps were derived based on data from IUCN.[4, 6] We only used those species which were classified as having "Wetland (inland)" as habitat. The categories for presence and seasonality from Table S4 are valid for reptiles as well. All seasonality values were used, and for presence categories we changed between 1 to 3 and 1 to 4. The maps and corresponding vulnerability scores (VS) are shown in Figure S9 to Figure S12.

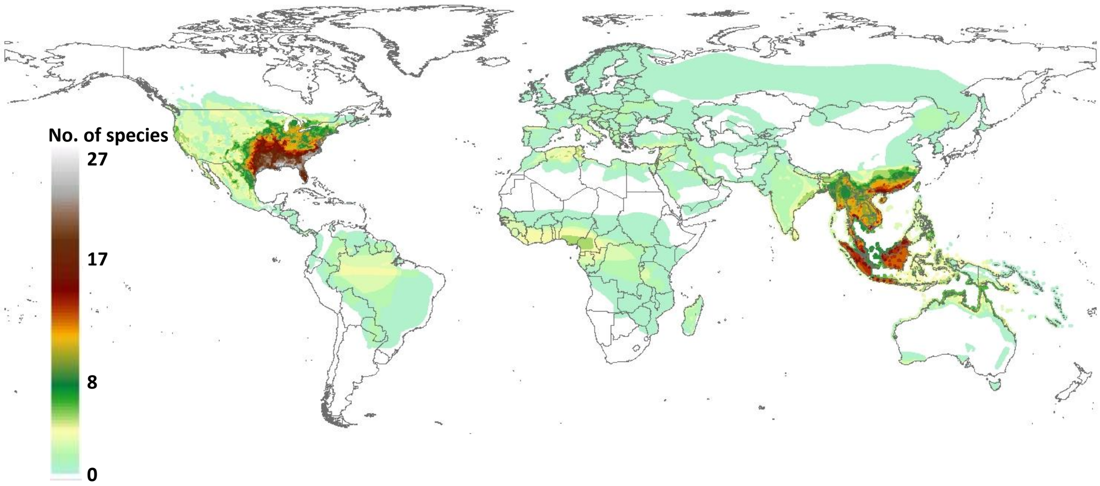


Figure S9: Species richness map of wetland reptiles based on data from IUCN.[4, 6] Presence values are chosen from categories 1 to 3. Base map with country boundaries adapted from ref.[8]

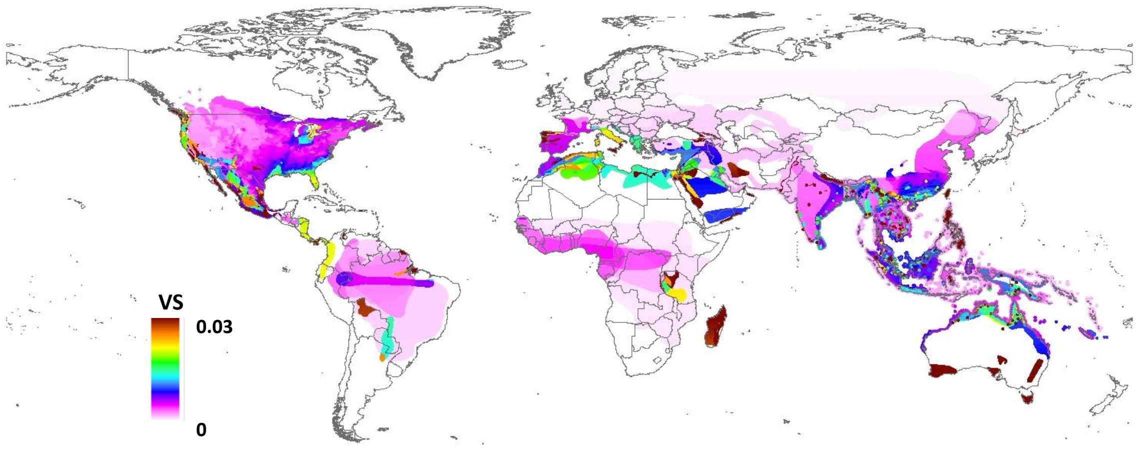


Figure S10: Map of the vulnerability score (VS) of wetland reptiles based on data from IUCN.[4, 6] Presence values are chosen from categories 1 to 3. Base map with country boundaries adapted from ref.[8]

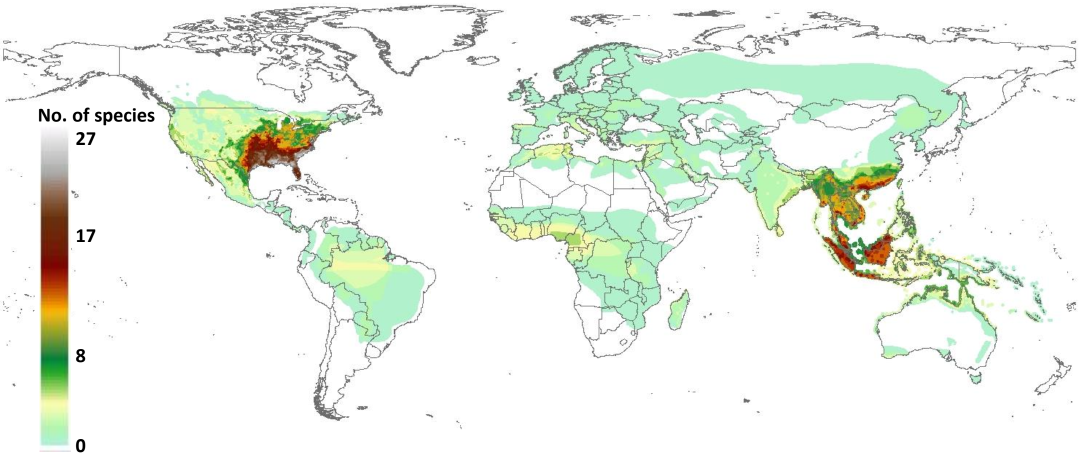


Figure S11: Species richness map of wetland reptiles based on data from IUCN.[4, 6] Presence values are chosen from categories 1 to 4 (instead of 1 to 3). Base map with country boundaries adapted from ref.[8]

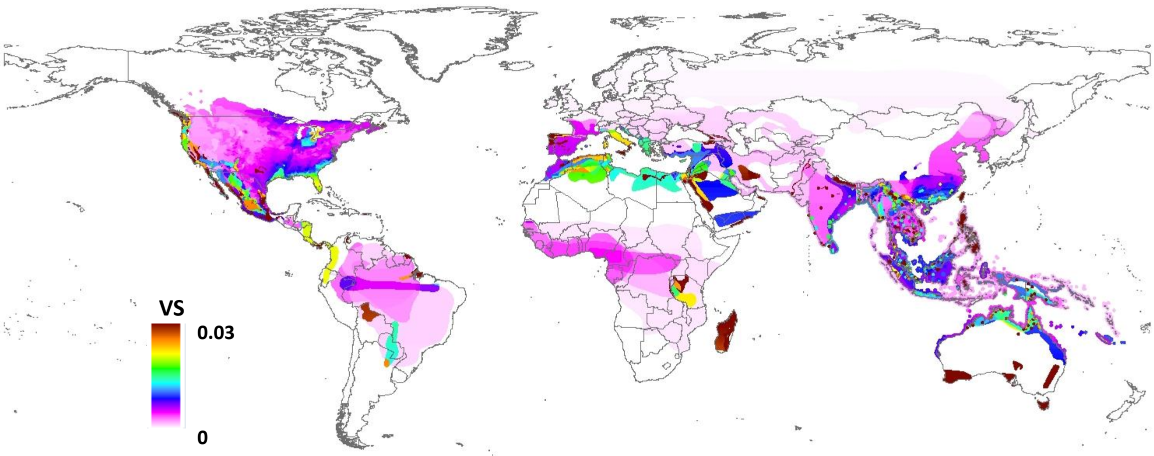


Figure S12: Map of the vulnerability score (VS) of wetland reptiles based on data from IUCN.[4, 6] Presence values are chosen from categories 1 to 4 (instead of 1 to 3). Base map with country boundaries adapted from ref.[8]

S5. Amphibian maps

Amphibian maps were derived based on data from IUCN.[4, 5] All amphibian species were used. The categories for presence and seasonality from Table S4 are valid for reptiles as well. All seasonality values were used, and for presence categories we altered between 1 to 3 and 1 to 4. The maps and corresponding vulnerability scores (VS) are shown in Figure S13 to Figure S16.

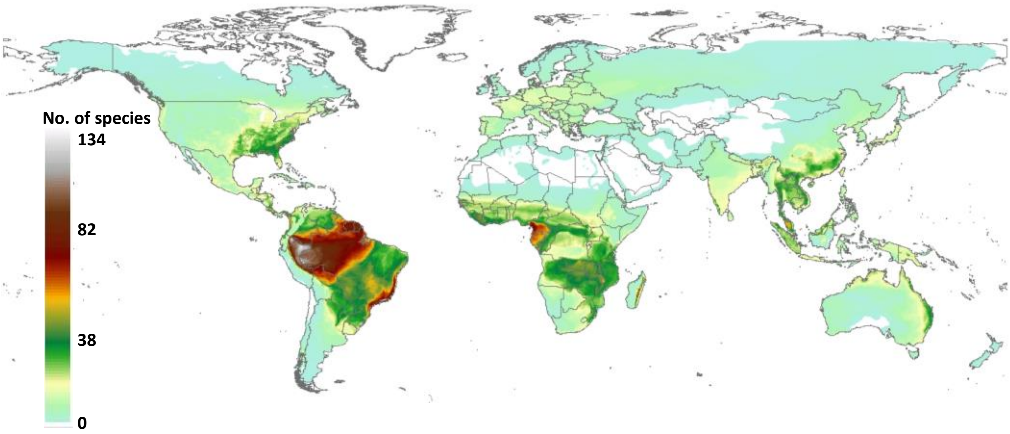


Figure S13: Species richness map of amphibians based on data from IUCN.[4, 5] Presence values are chosen from categories 1 to 3. Base map with country boundaries adapted from ref.[8]

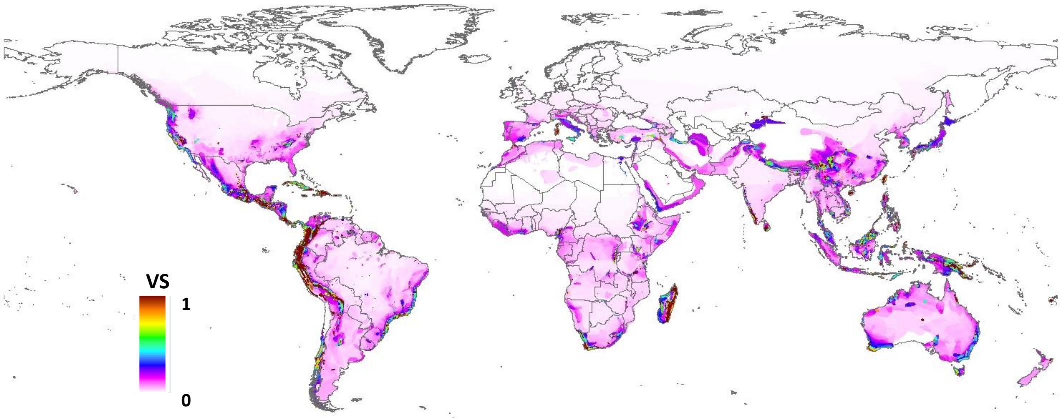


Figure S14: Map of the vulnerability score (VS) of amphibians based on data from IUCN.[4, 5] Presence values are chosen from categories 1 to 3. Base map with country boundaries adapted from ref.[8]

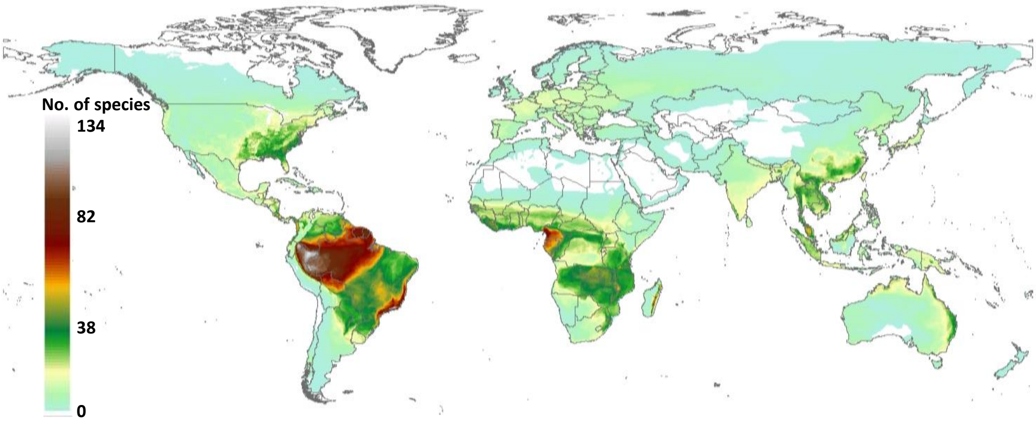


Figure S15: Species richness map of amphibians based on data from IUCN.[4, 5] Presence values are chosen from categories 1 to 4 (instead of 1 to 3). Base map with country boundaries adapted from ref.[8]

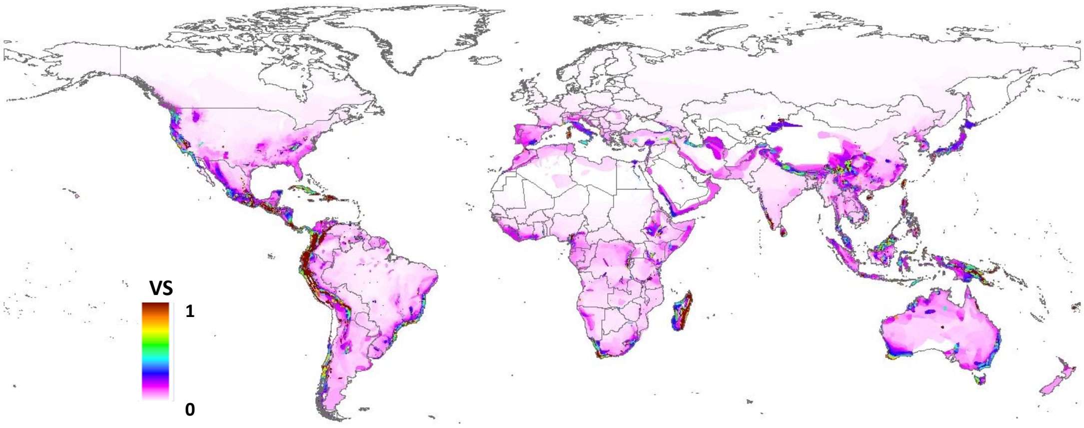


Figure S16: Map of the rarity score of amphibians based on data from IUCN.[4, 5] Presence values are chosen from categories 1 to 4 (instead of 1 to 3). Base map with country boundaries adapted from ref.[8]

S6. Mammal maps

Maps for the number of water-dependent mammals and the respective vulnerability scores are shown in Figure S17 to Figure S20. The mammal suitability model was developed by the Global Mammal Assessment (see e.g. ref[7])

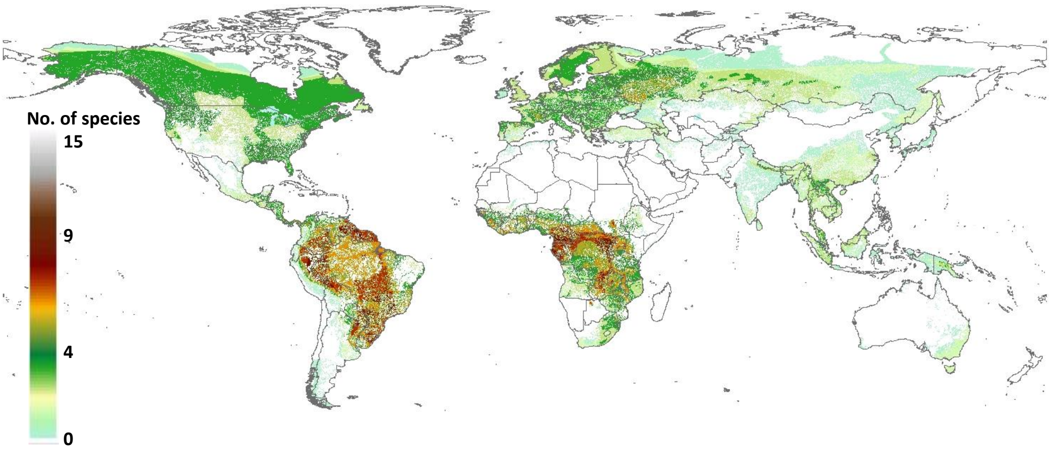


Figure S17: Species richness of water-dependent mammals based on the extent of occurrence of the mammals. Base map with country boundaries adapted from ref.[8]

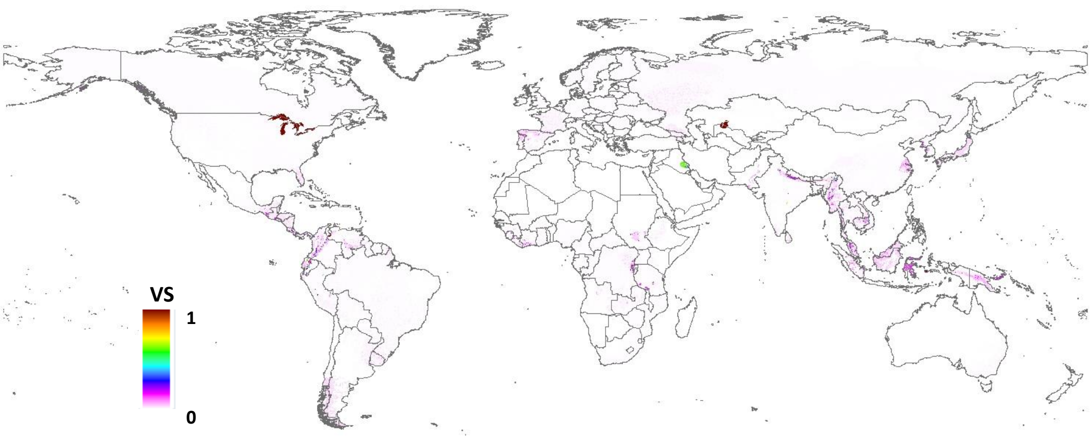


Figure S18: Vulnerability score (VS) of the water-dependent mammals, based on the extent of occurrence of the mammals. Base map with country boundaries adapted from ref.[8]

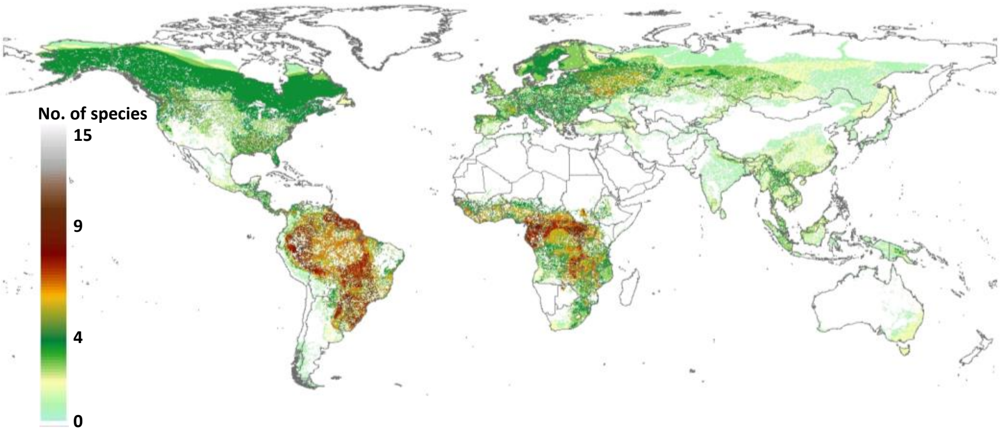


Figure S19: Species richness of water-dependent mammals based on the suitable habitat of the mammals (AOO). Base map with country boundaries adapted from ref.[8]

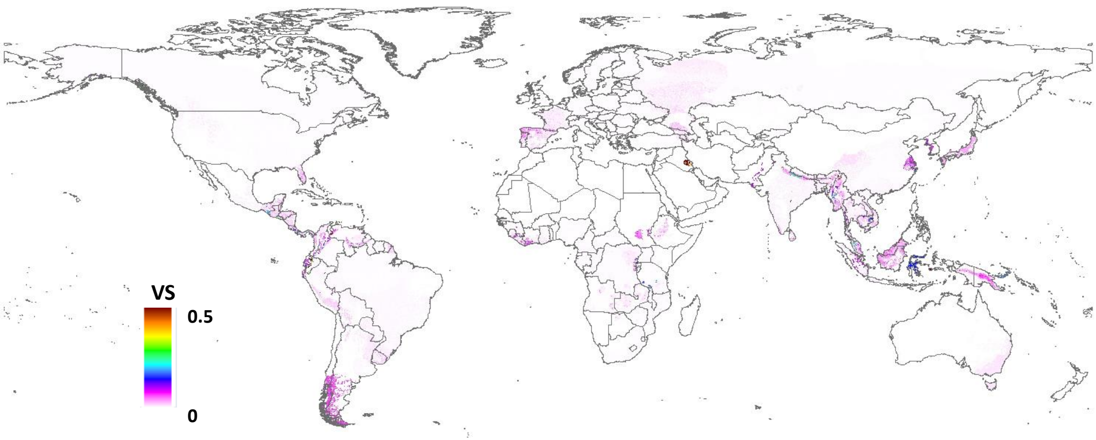


Figure S20: Vulnerability score (VS) of the water-dependent mammals, based on the suitable habitat of the mammals (AOO). Base map with country boundaries adapted from ref.[8]

Difference between species richness map with EOO and AOO is small. The reason is that, as water-dependent mammals are limited to waterbodies, the difference between AOO and EOO is not large, and that AOO represents a nested subset of the EOO data. The geographical outermost boundary can only follow waterbody borders, as in the AOO.

S7. CpA – Waterbody count per area

The waterbody count per area (CpA) data set is derived, as described in the main manuscript, based on the rivers of the world dataset[9] and the global lakes and wetland database[10] by counting how many points (i.e. waterbodies or river sections) fall into each sub-watersheds area (N in Equation S1).[9] Dividing the number of points by the area of the sub-watershed (A in Equation S1) and multiplying with an aridity index (precipitation P[11] divided by potential evapotranspiration PET[12]) leads to a value set that tells us for each pixel i how large the habitat loss risk in the network of waterbodies in each pixel is (taking into account a potential larger density of temporary pools by multiplying with the aridity index). By dividing all values with the maximum value, CpA is scaled between 0 and 1 and becomes unitless. If there is little water, the pixel had higher chances of becoming unsuitable as habitat, thus if the CpA is small, the habitat loss risk is large.

$$CpA_i = \frac{\frac{N_{per\ subwatershed,i}}{A_{subwatershed,i}} \cdot \frac{P_i}{PET_i}}{\max CpA_i}$$

Equation S1

Iceland, Norway, Finland, as well as parts of Sweden and Eastern Russia are not covered in the dataset for the watersheds.[9] The closest available CpA values were thus assumed to be valid in the administrative regions of these countries which were missing for calculating the CpA. As they have a high CpA, they are not relevant and this simplification is acceptable. For remote islands for which no P, PET, rivers and lakes data were available in global databases (e.g. Azores), a CpA of 1 was assumed. Since there was no indication about counts of waterbodies, we decided to set CpA to 1 in these cases, although this was not a conservative assumption and the damage is likely to be underestimated. However, this concerns only very few wetlands on individual islands and these small, data deficient wetlands would need a closer look in future. For islands close to the mainland, the closest mainland value was assigned to the island (e.g. Malta received its value from Sicily).

The resolution of the CpA data set (Figure S21) is 0.167°x0.167° since this was the resolution of the precipitation dataset (coarsest dataset).

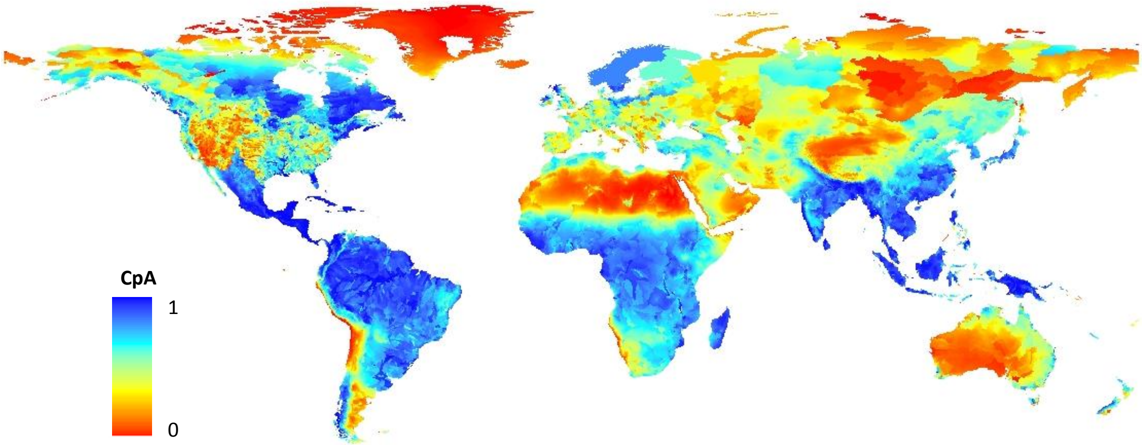


Figure S21: Habitat loss risk index CpA.

CpA=1 are areas with a large density of waterbodies, and as the value approaches zero, wetland habitats get more rare. The smaller the CpA, the rarer the waterbodies and the larger the threat of losing the habitat type “wetland/waterbody” in the region, when water is consumed.

S8. Species-area relationship and z-values

The formula of the species-area relationship is shown in Equation S2. The species richness S can be predicted from a habitat area A, an exponent z indicating the slope of the species richness curve and a constant c. z is often determined for specific curves, but a common value of 0.25 is often applied.[13]

$$S = c \cdot A^z$$

Equation S2

For a known area change a new species richness S_{new} can thus be predicted based on the original area and species richness, as shown in Equation S3.

$$S_{new} = \left(\frac{A_{new}}{A_{original}}\right)^z \cdot S_{original}$$

Equation S3

The number of lost species S_{lost} from the original area is thus (Equation S4).

$$S_{lost} = S_{original} - S_{new} = S_{original} - \left(\frac{A_{new}}{A_{original}}\right)^z \cdot S_{original} = \left(1 - \left(\frac{A_{new}}{A_{original}}\right)^z\right) \cdot S_{original}$$

Equation S4

The range of the z values applied for the different taxa are shown in Table S5. All values are taken from Drakare et al. [14] For birds and mammals, we only used the z-values from nested studies because they best represent pure diversity change over different sampling area sizes, are best suited to the power model employed, and are more suited for extrapolation beyond the range of area sizes used to derive the z-value.[15] For reptiles and amphibians, we used z-values from independent (non-nested) studies from the same data source, since no values for nested studies were available. Values across multiple studies for a single taxon were averaged to derive taxon-specific[14] values. All z-values are close to the commonly used z-value of 0.25.[13, 16, 17]

Table S5: Minimum, maximum and average slopes of the species-area relationship for the different taxa.[14]

Taxon	zmin	zmax	zaverage	No. of studies used
birds	0.15	0.63	0.37	8 (nested)
mammals	-0.24	0.93	0.34	4 (nested)
reptiles	0.08	0.81	0.33	10 (independent)
amphibians	0.04	0.36	0.20	18 (independent)

S9. Characterization factors – determining individual catchments

All characterization factors (CFs) are applicable on a larger scale than just the wetland itself. The reasoning is explained below for surface water-fed and groundwater-fed wetlands separately.

Surface water-fed wetlands

A surface water-fed wetland is fed by inflowing water from the catchment upstream of the wetland. If water is consumed anywhere in the area upstream of the wetland, inflow will be reduced and the wetland will be damaged. Therefore, the CF for this wetland is applicable in the whole watershed of the wetland (e.g. blue watershed in Figure S22). A second wetland, which is for instance situated upstream of the first one, may receive water from partly the same sources. But other rivers, for example, may be completely irrelevant for the second wetland, because they do not flow into this specific wetland. Thus, the CF for the second wetland is applicable in another area, which is the individual catchment of the second wetland (e.g. orange area in Figure S22). However, water which is consumed in the range area does not reach both wetlands and therefore both of them are damaged and the CFs of both are applicable. That means that the CFs are summed in these areas. This procedure is repeated for all 1033 surface water-fed wetlands and leads to the global maps.

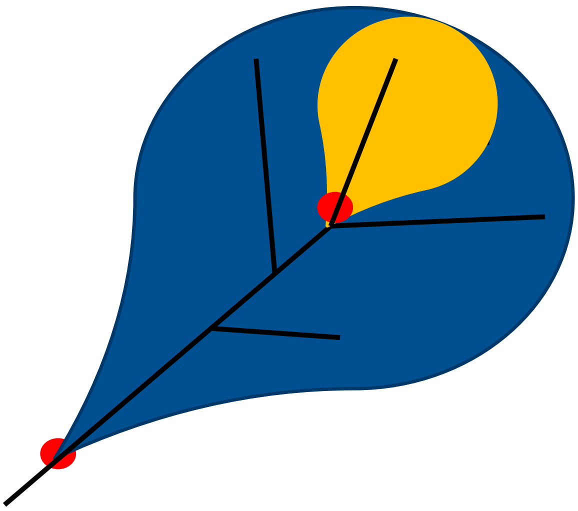


Figure S22: Schematic representation of two surface water-fed wetlands (red dots) in their respective watersheds (blue and orange). The river network is shown in black.

<u>Groundwater-fed wetlands</u>

Here the relevant area is calculated according to the hydrogeological condition surrounding the wetland (not upstream-downstream as in the surface water-fed wetland cases). The Area of Relevance (AoR) has been used for the calculation of the FF before (for details see ref[18]). In principle, we determined circles around the wetlands from which water is being drawn to the wetland (imagining the wetland to act like a pump). The decrease in groundwater level due to pumping anywhere in this Area of Relevance influences the infiltrating amount into the wetland. Thus, any pumping within this area leads to damage and thus the CF is applicable in the whole AoR. If there is a second groundwater-fed wetland and their AoRs overlap, the CFs are summed, because it was assumed that pumping in that region will damage both wetlands.

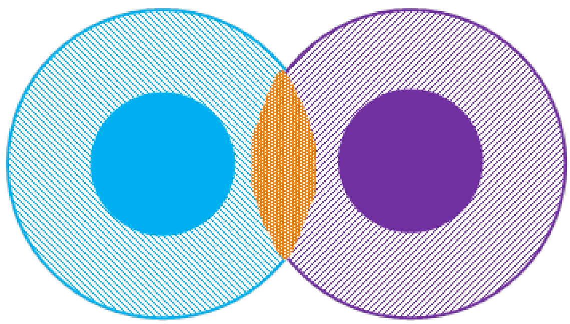


Figure S23: Schematic representation of two Areas of Relevance (AoR, hatched circles) around two groundwater-fed wetlands (blue and violet circle). The orange part is the area where the AoRs overlap and where CFs are thus summed.

S10. EFs and CFs

In Figure S24, an overview of all the necessary parameters and modeling steps for the calculation of the EF is shown. As an example, all the values of the parameters for lake Naivasha and lake Elmenteita (both in Kenya) are given in Table S6. These two wetlands are used in the application example and have individual catchments. For the location Bleiswijk, no example is provided since the used factor at the location consists of a several overlaying catchments of wetlands within the Rhine watershed.

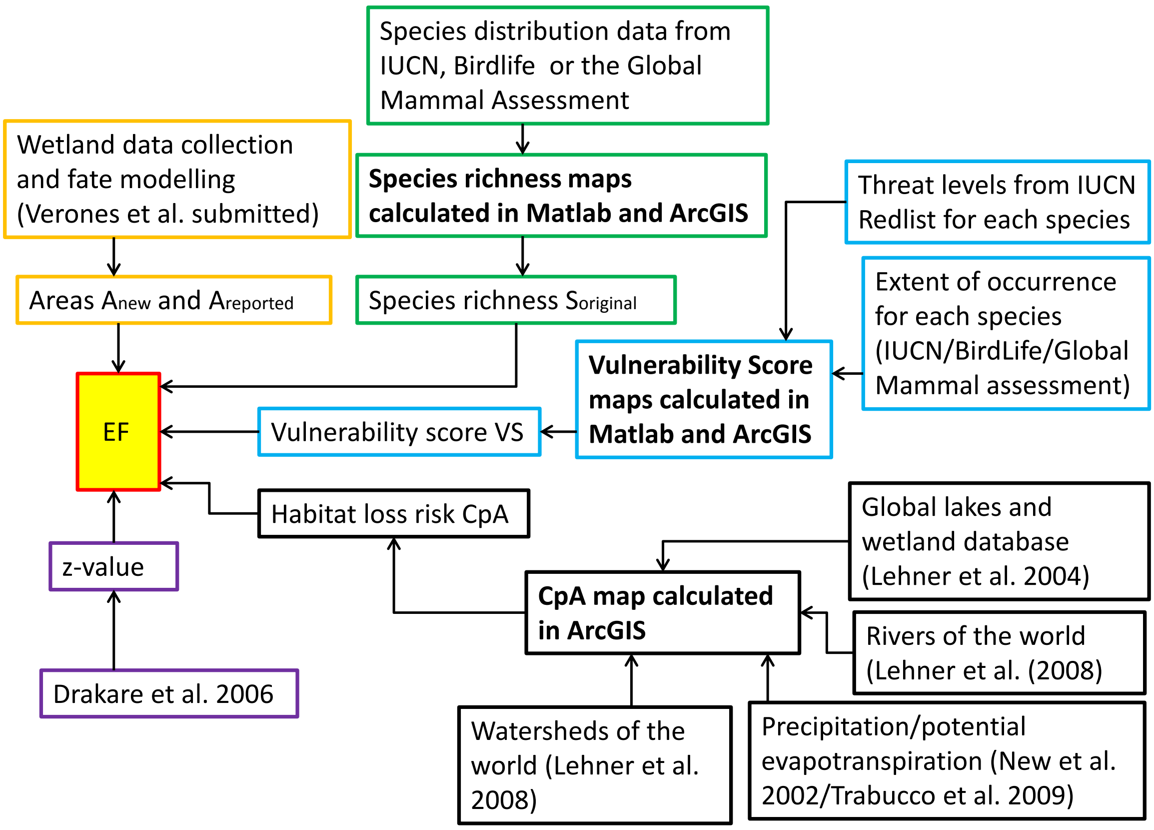


Figure S24: Overview of the parameters and their origin, as well as the modeling steps that are required for calculating the EFs of a wetland. Modeling steps are indicated in bold.

Table S6: Examples for all required parameters for calculating EFs for lake Naivasha (SW-fed, Kenya) and lake Elmenteita (GW-fed, Kenya).

	Lake Naivasha	Lake Elmenteita	References/comments
Area reported [ha]	30000	10880	RIS[2]
Area new [ha]	29999	10879	Calculated, see Verones et al.[18]
CpA [-]	0.064	0.027	Habitat loss risk index (SI, S7)
z-value waterbirds[-]	0.37	0.37	Based on Drakare et al.(2006)[14]
z-value non-residential birds[-]	0.37	0.37	Based on Drakare et al.(2006)[14]
z-value water-dependent mammals[-]	0.34	0.34	Based on Drakare et al.(2006)[14]
z-value reptiles[-]	0.33	0.33	Based on Drakare et al.(2006)[14]
z-value amphibians[-]	0.20	0.20	Based on Drakare et al.(2006)[14]
Species richness waterbirds [no.of species]	250	245	Maps, based on Birdlife/NatureServe data[3] (SI, S3)
Species richness non-residential birds [no.of species]	32	37	Maps, based on Birdlife/NatureServe data[3] (SI, S3)
Species richness water-dependent mammals [no.of species]	6	6	Maps, data from global mammal assessment (SI, S6)
Species richness reptiles [no.of species]	1	1	Maps, based on IUCN data[6] (SI, S4)
Species richness amphibians [no.of species]	29	24	Maps, based on IUCN data[5] (SI, S5)
Vulnerability score waterbirds [-]	8.5E-06	8.5E-06	Maps, based on Birdlife/NatureServe data[3] and IUCN data[4] (SI, S3)
Vulnerability score non-residential birds [-]	4.1E-06	3.8E-06	Maps, based on Birdlife/NatureServe data[3] and IUCN data[4] (SI, S3)
Vulnerability score water-dependent mammals [-]	8.4E-06	6.9E-06	Maps, based on IUCN data[4] (SI, S6)
Vulnerability score reptiles [-]	2.1E-06	2.1E-06	Maps, based on IUCN data[4] (SI, S4)
Vulnerability score amphibians [-]	7.8E-05	1.1E-04	Maps, based on IUCN data[4] (SI, S5)
EF waterbirds [species-eq/m2]	4.74E-11	2.66E-10	Calculated
EF non-residential birds[species-eq/m2]	2.52E-12	1.78E-11	Calculated
EF water-dependent mammals [species-eq/m2]	9.52E-13	4.53E-12	Calculated
EF reptiles [species-eq/m2]	3.58E-14	2.35E-13	Calculated
EF amphibians [species-eq/m2]	2.37E-11	1.90E-10	Calculated

Bird species are present in all wetlands. This does not apply to the other taxa. In Table S7, the number of wetlands is shown that do not harbour mammals, reptiles or amphibians.

Table S7: Number of wetlands that do not contain a certain taxa in absolute numbers and as percentage of wetland type. SW stands for surface water-fed wetlands and GW for groundwater-fed wetlands.

	Number of wetlands zero		Percentage of wetlands zero	
Taxa	**SW [-]**	**GW [-]**	**SW [%]**	**GW [%]**
Waterbird	0	0	0	0
Non-residential birds	0	0	0	0
water-dependent mammals	121	28	12	19
reptiles	168	25	16	17
amphibians	43	6	4	4

Effect and characterization factors calculated on the basis of the waterbody area are presented in Table S8.

Table S8: Effect factors [species-eq/m^2] and characterization factors [species-eq·yr/m^3] for waterbirds, non-residential birds, water-dependent mammals, wetland reptiles, amphibians and all combined based on the area of the waterbodies within the Ramsar sites. Factors are presented summarized for surface-fed wetlands with surface water consumption (SW) and groundwater-fed wetlands with groundwater consumption (GW). Presence categories are 1 to 3 (birds, reptiles, amphibians). CV is the coefficient of variation.

	EF [species-eq/m^2]		CF [species-eq·yr/m^3]	
	SW	**GW**	**SW**	**GW**
waterbirds min	1.7E-13	7.1E-13	1.7E-15	6.8E-15
waterbirds max	2.4E-05	2.0E-06	1.1E-05	1.3E-06
waterbirds mean	5.8E-08	3.0E-08	1.4E-08	1.3E-08
CV	16	6	25	8
non-residents min	1.9E-15	2.1E-13	5.3E-17	1.2E-14
non-residents max	2.0E-05	1.8E-06	7.4E-06	3.7E-06
non-residents mean	5.6E-08	3.2E-08	1.0E-08	2.9E-08
CV	14	5	23	10
water-dep. mammals min	1.6E-15	1.1E-14	3.4E-17	1.7E-16
water-dep. mammals max	2.0E-06	4.7E-07	3.8E-08	8.4E-08
water-dep. mammals mean	3.9E-09	5.0E-09	3.4E-10	7.9E-10
CV	17	8	7	9
wetland reptiles min	1.29E-16	1.38E-14	2.01E-17	7.91E-17
wetland reptiles max	2.58E-05	1.13E-05	1.72E-05	1.11E-06
wetland reptiles mean	3.53E-08	8.19E-08	1.70E-08	1.54E-08
CV	24	11	32	8
amphibians min	5.02E-16	8.24E-15	5.62E-16	6.74E-16
amphibians max	6.47E-05	9.79E-07	4.56E-05	1.88E-06
amphibians mean	1.29E-07	3.14E-08	6.01E-08	1.50E-08
CV	17	4	24	10
combined taxa min	2.5E-13	1.1E-12	2.3E-15	2.7E-14
combined taxa max	8.1E-05	1.1E-05	5.7E-05	4.7E-06
combined taxa mean	2.8E-07	1.8E-07	1.0E-07	7.4E-08
CV	13	6	21	7

Characterization factors (CFs) calculated with the waterbody areas within the Ramsar area are shown in Figure S25 to Figure S36.

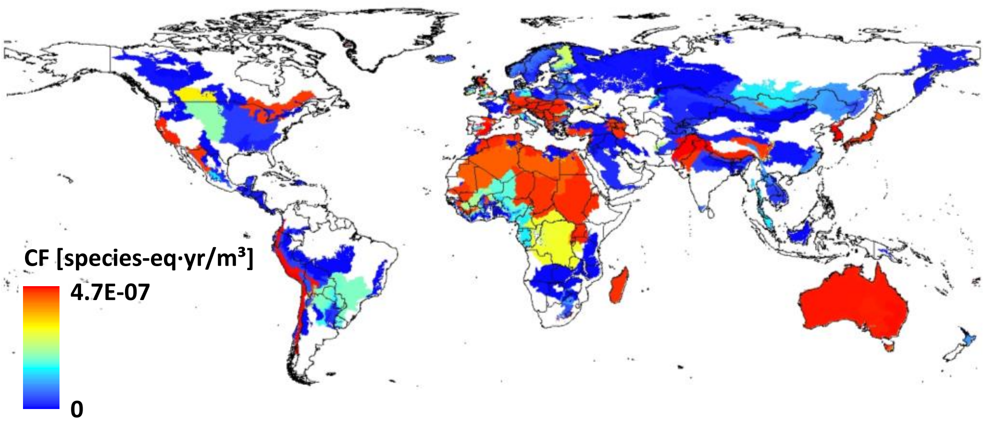


Figure S25: CFs for surface water-fed wetlands with surface water consumption for waterbirds (presence 1 to 3) based on waterbody areas within the Ramsar areas. Base map with country boundaries adapted from ref.[8]

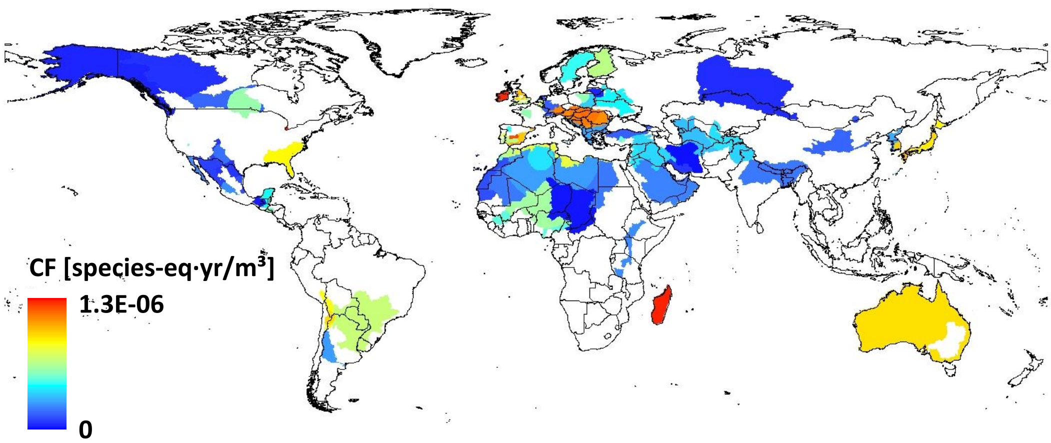


Figure S26: CFs for groundwater-fed wetlands with groundwater consumption for waterbirds (presence 1 to 3) based on waterbody areas within the Ramsar areas. Base map with country boundaries adapted from ref.[8]

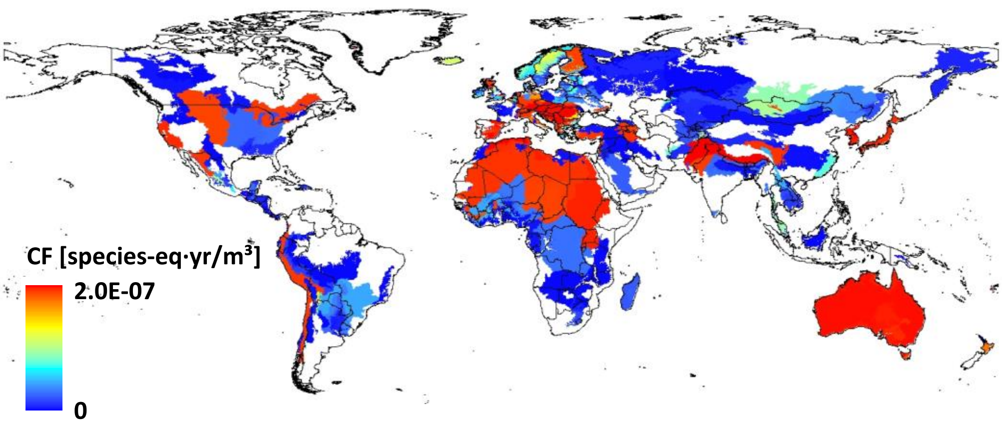


Figure S27: CFs for surface water-fed wetlands with surface water consumption for non-residential birds (presence 1 to 3) based on waterbody areas within the Ramsar areas. Base map with country boundaries adapted from ref.[8]

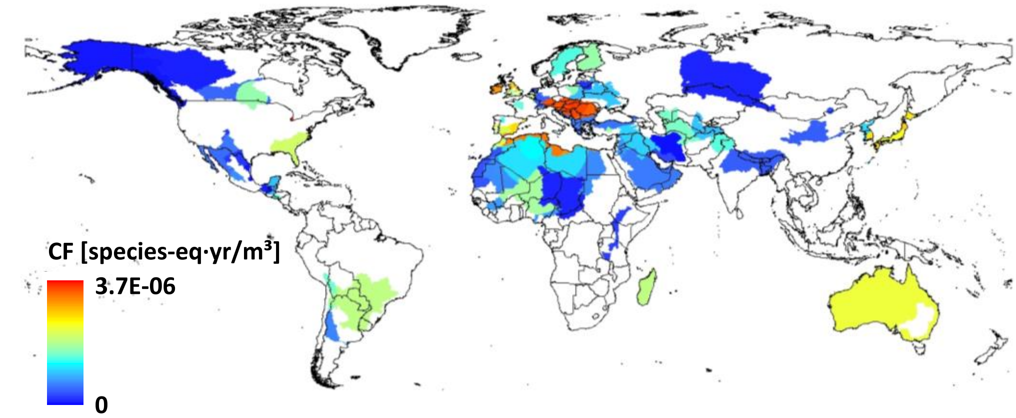


Figure S28: CFs for groundwater-fed wetlands with groundwater consumption for non-residential birds (presence 1 to 3) based on waterbody areas within the Ramsar areas. Base map with country boundaries adapted from ref.[8]

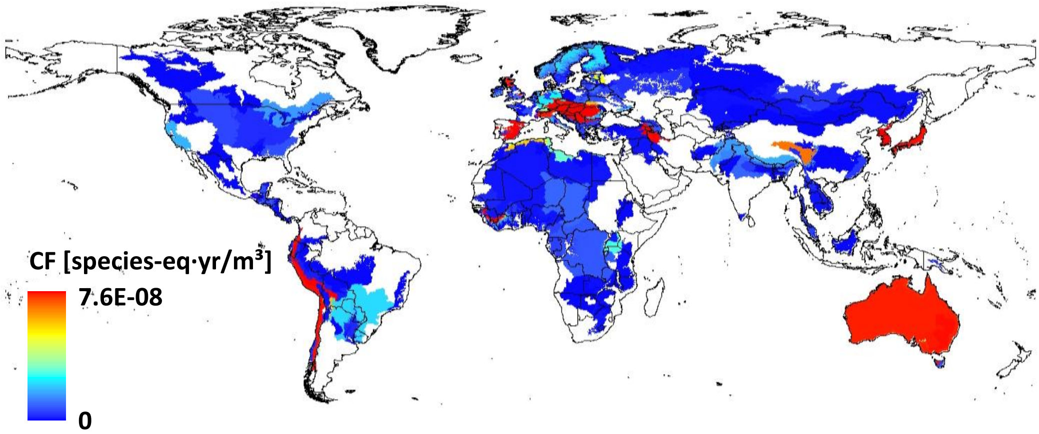


Figure S29: CFs for surface water-fed wetlands with surface water consumption for water-dependent mammals based on waterbody areas within the Ramsar areas. Base map with country boundaries adapted from ref.[8]

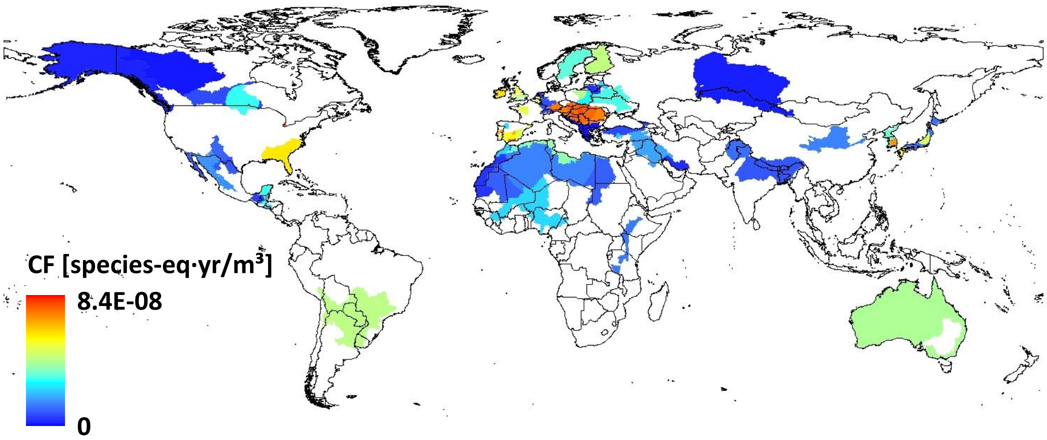


Figure S30: CFs for groundwater-fed wetlands with groundwater consumption for water-dependent mammals based on waterbody areas within the Ramsar areas. Base map with country boundaries adapted from ref.[8]

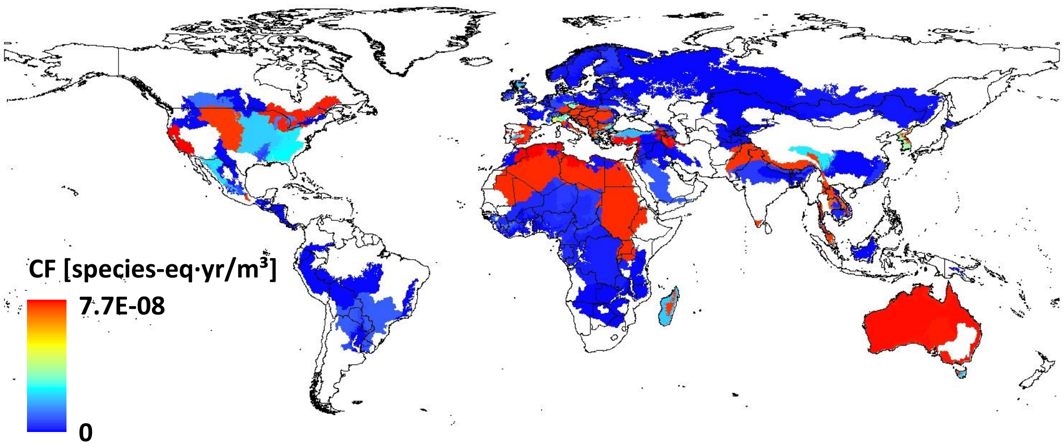


Figure S31: CFs for surface water-fed wetlands with surface water consumption for wetland reptiles based on waterbody areas within the Ramsar areas. Base map with country boundaries adapted from ref.[8]

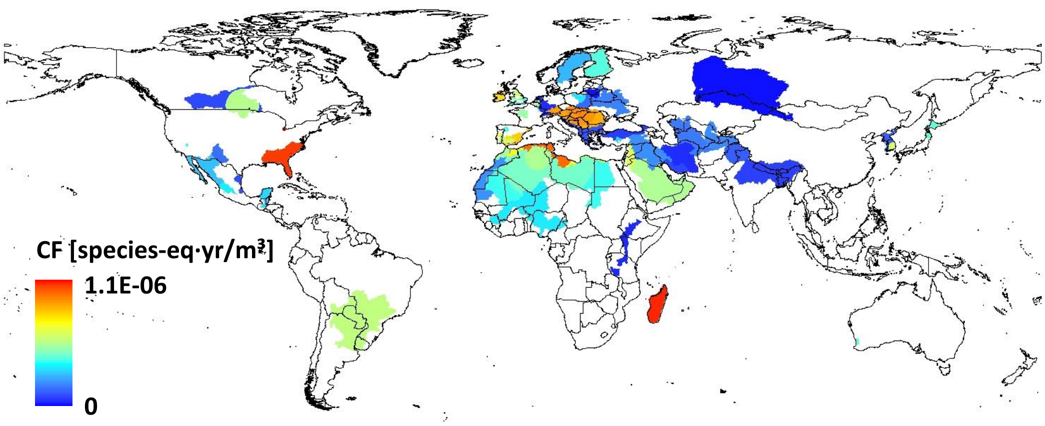


Figure S32: CFs for groundwater-fed wetlands with groundwater consumption for wetland reptiles based on waterbody areas within the Ramsar areas. Base map with country boundaries adapted from ref.[8]

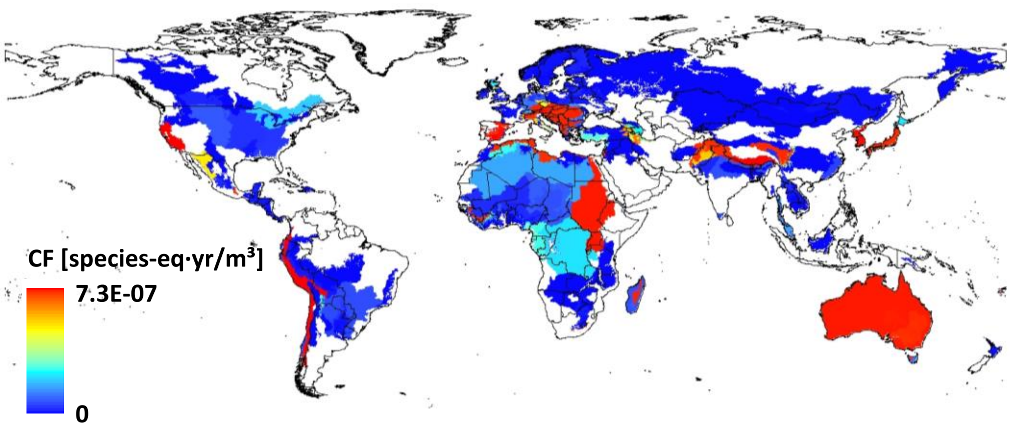


Figure S33: CFs for surface water-fed wetlands with surface water consumption for amphibians based on waterbody areas within the Ramsar areas. Base map with country boundaries adapted from ref.[8]

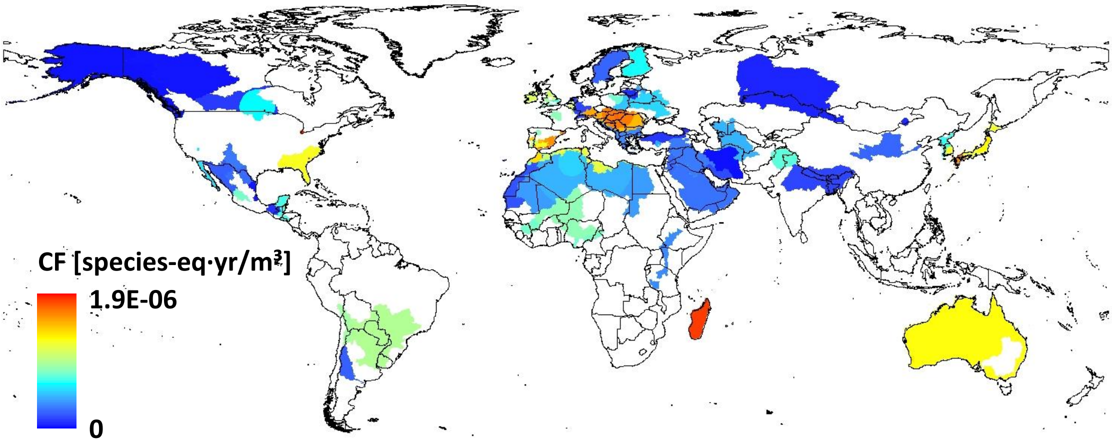


Figure S34: CFs for groundwater-fed wetlands with groundwater consumption for amphibians based on waterbody areas within the Ramsar areas. Base map with country boundaries adapted from ref.[8]

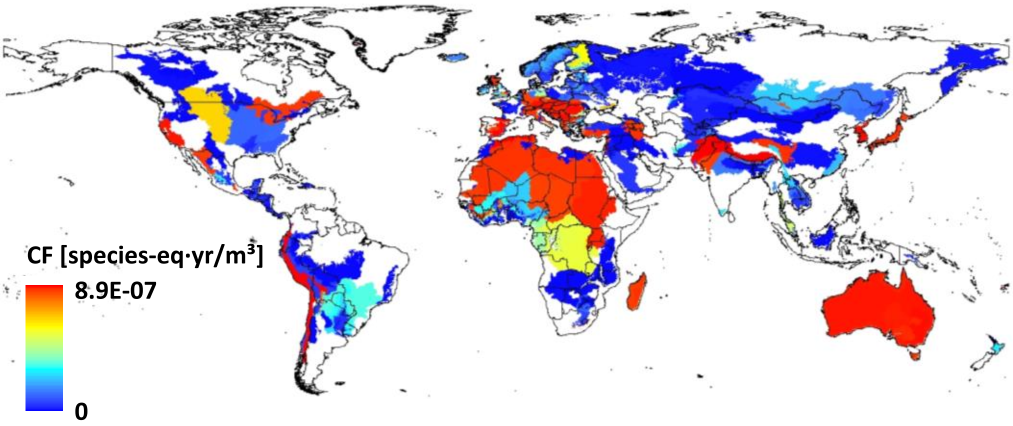


Figure S35: CFs for surface water-fed wetlands with surface water consumption for all taxa combined, based on waterbody areas within the Ramsar areas. Base map with country boundaries adapted from ref.[8]

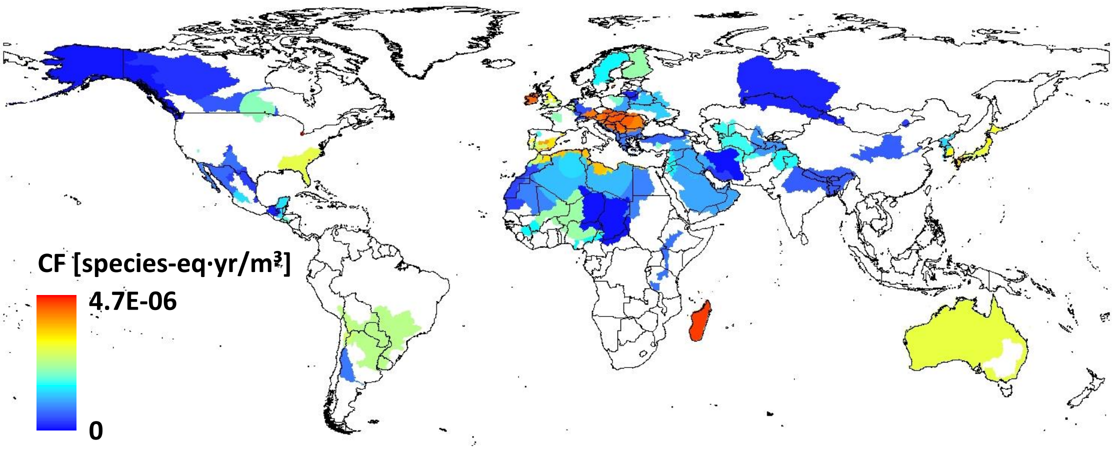


Figure S36: CFs for groundwater-fed wetlands with groundwater consumption for all taxa combined, based on waterbody areas within the Ramsar areas. Base map with country boundaries adapted from ref.[8]

S11. Sensitivities and correlations of EF and CF

The correlation between CFs of different taxa and correlations between different parts of the EF and the EF itself are shown in Table S9 and Table S10.

Table S9: Spearman's rank correlation coefficient ρ between CFs of different taxa and for both surface water- fed (SW) and groundwater-fed (GW) wetlands. The color code indicates whether there is medium (ρ > 0.3, green with green letters) or high correlation (ρ > 0.5, blue with yellow letters).

Water source	Correlation	Spearman ρ [-]
SW	CF waterbirds – CF non-residential birds	0.921
	CF waterbirds – CF mammals	0.653
	CF waterbirds -CF reptiles	0.535
	CF waterbirds – CF amphibians	0.836
	CF non-residential birds – CF mammals	0.606
	CF non-residential birds – CF reptiles	0.569
	CF non-residential birds – CF amphibians	0.801
	CF mammals –CF reptiles	0.490
	CF mammals –CF amphibians	0.689
	CF reptiles –CF amphibians	0.600
GW	CF waterbirds – CF non-residential birds	0.967
	CF waterbirds – CF mammals	0.741
	CF waterbirds – CF reptiles	0.734
	CF waterbirds – CF amphibians	0.907
	CF non-residential birds – CF mammals	0.742
	CF non-residential birds – CF reptiles	0.757
	CF non-residential birds – CF amphibians	0.923
	CF mammals –CF reptiles	0.647
	CF mammals –CF amphibians	0.768
	CF reptiles –CF amphibians	0.711

Table S10: Correlations between components of the effect factor and effect factor itself (EF), as well as the fate factor (FF). Correlations are calculated for each taxa separately, except for the correlation between CpA and FF, which is the same for all taxa and is thus only calculated for SW-fed and GW-fed wetlands. VS is the vulnerability score, S the species number and CpA is the habitat loss risk index.

Water source	Correlation	Spearman ρ [-]
SW	CpA-FF	-0.263
	CpA-VS waterbirds	0.229
	CpA-VS non-residents	0.175
	CpA-VS mammals	0.037
	CpA-VS reptiles	-0.016
	CpA-VS amphibians	0.063
	S-VS waterbirds	0.429
	S-VS non-residents	0.030
	S-VS mammals	0.311
	S-VS reptiles	0.551
	S-VS amphibians	0.367
	S-CpA waterbirds	0.259
	S-CpA non-residents	-0.054
	S-CpA mammals	0.092
	S-CpA reptiles	0.082
	S-CpA amphibians	0.238
GW	CpA-FF	-0.005
	CpA-VS waterbirds	0.305
	CpA-VS non-residents	0.379
	CpA-VS mammals	0.241
	CpA-VS reptiles	0.025
	CpA-VS amphibians	0.250
	S-VS waterbirds	0.275
	S-VS non-residents	0.199
	S-VS mammals	0.418
	S-VS reptiles	0.791
	S-VS amphibians	0.355
	S-CpA waterbirds	0.562
	S-CpA non-residents	0.404
	S-CpA mammals	0.062
	S-CpA reptiles	0.133
	S-CpA amphibians	0.439
SW	S-EF waterbirds	-0.175
	S-EF Nonresidents	0.161
	S-EF mammals	0.193
	S-EF reptiles	0.440
	S-EF amphibians	0.176
	VS-EF waterbirds	0.136
	VS-EF non-residents	0.194
	VS-EF mammals	0.443
	VS-EF reptiles	0.699
	VS-EF amphibians	0.627
	CpA-EF waterbirds	-0.215
	CpA-EF non-residents	-0.268
	CpA-EF mammals	-0.238
	CpA-EF reptiles	-0.183
	CpA-EF amphibians	-0.189
GW	S-EF waterbirds	-0.016
	S-EF non-residents	0.099
	S-EF mammals	0.521
	S-EF reptiles	0.577
	S-EF amphibians	0.423
	VS-EF waterbirds	0.046
	VS-EF non-residents	0.206
	VS-EF mammals	0.623
	VS-EF reptiles	0.703
	VS-EF amphibians	0.487
	CpA-EF waterbirds	-0.073
	CpA-EF non-residents	-0.026
	CpA-EF mammals	0.009
	CpA-EF reptiles	-0.129
	CpA-EF amphibians	0.079

We calculated the histogram of species richness, a dominant factor for the EF, and EFs themselves for all taxa. They are shown for SW-fed and GW-fed wetlands in Figure S37. In Figure S37A, mammals are with 912 wetlands highest in the bin category 10-20 species. Also, reptiles and amphibians are mostly represented by 10-20 species (840 wetlands and 539 wetlands, respectively). The largest number of wetlands for non-residential bird species is 235 in the species richness category 40-50 species. Only waterbirds show their maximum in an even higher category (80-90 species in 128 wetlands). The distribution of species richness is widest for waterbirds. In GW-fed wetlands (Figure S37B), waterbird species are present in 29 wetlands with between 70 and 80 species. Non-residential birds have their maximum with 50-60 species in 35 wetlands, and this is again a bit lower than for SW-fed wetlands. Mammals, reptiles and amphibians are all mostly present with 10-20 species (123, 123 and 83 wetlands, respectively). For the EFs, the most frequent bins for the EFs are those between 10^{-11} species-eq/m^2 and 10^{-8} species-eq/m^2 (Figure S37C and D).

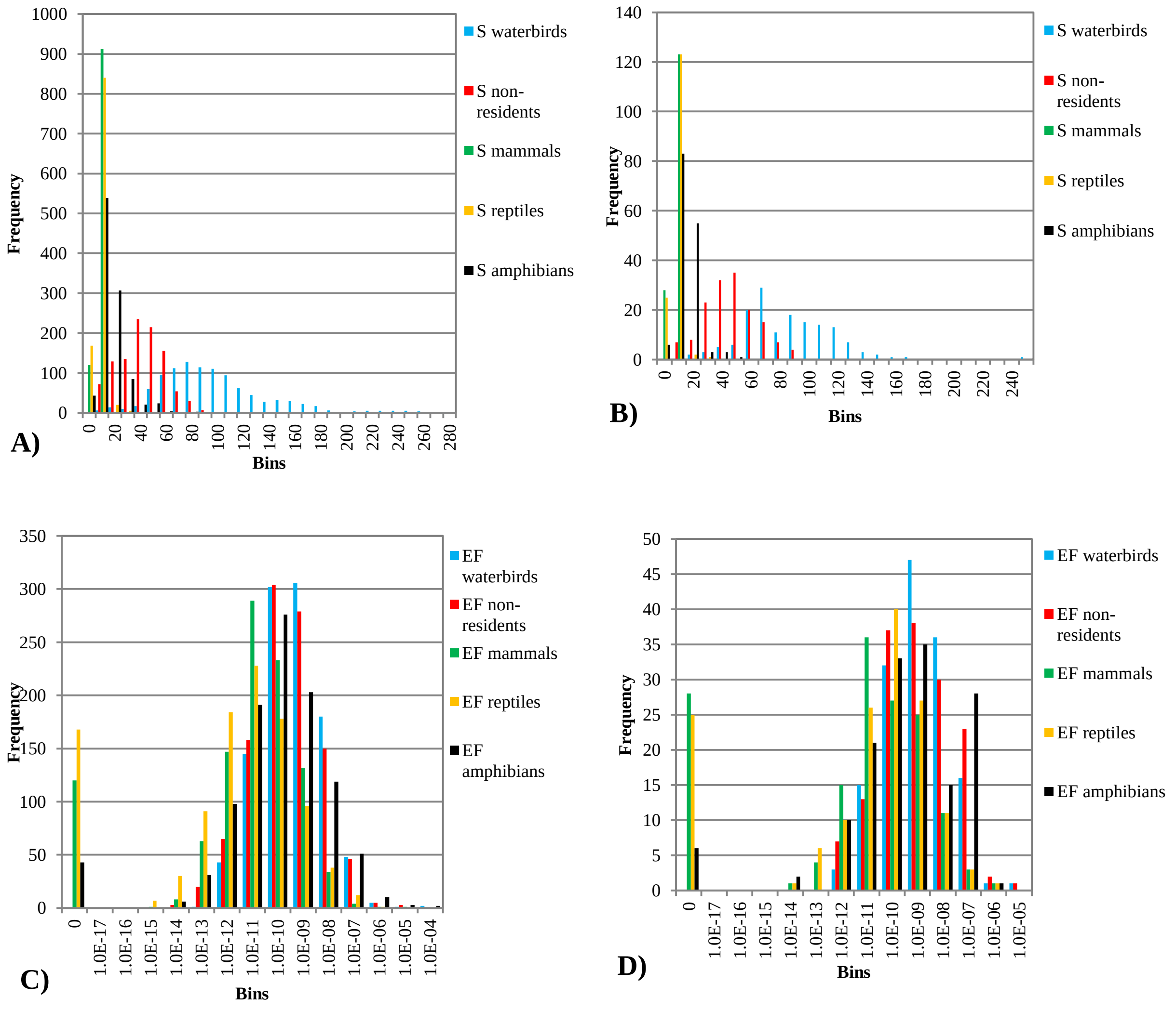


Figure S37: Distribution of the species richness for A) SW-fed wetlands and B) GW-fed wetlands. The distribution for the EF factors is shown in C) for SW-fed wetlands and D) for GW-fed wetlands.

A large part of the sensitivity of the characterization factor comes from the fate factor (FF). The sensitivity of the FF is discussed in detail in ref[18]. In Figure S38, the differences between the FFs for different amounts of water consumption is shown as factor of the FF with 10 m^3/yr consumption divided by the FF with 1’000’000 m^3/yr consumption. For the SW-fed wetlands, the differences are small, since the factor varies over the whole globe only between 1 and 1.167. For the GW-fed wetlands, the non-linearity of the well formula shows in the much larger differences between the FFs, distributed over the world. As stated in ref[18], caution should thus be applied when using the factors for GW-fed wetlands.

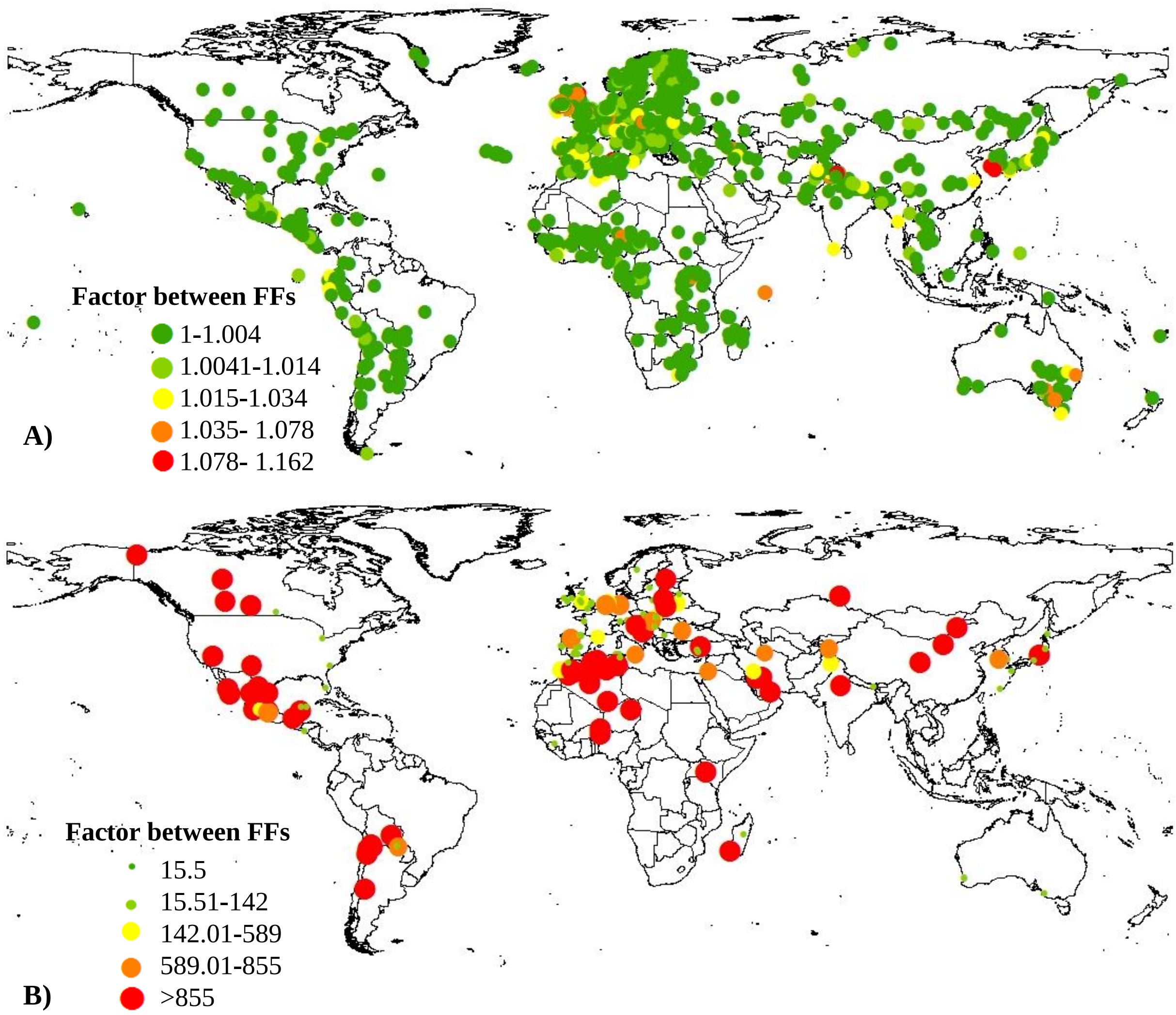


Figure S38: Factor between FFs with different amounts of water consumption. A) for SW-fed wetlands. B) for GW-fed wetlands. Base map with country boundaries adapted from ref.[8]

Whether the CF is calculated with the Ramsar area or the waterbody area can make a substantial difference, as is shown in Table S11 exemplarily for waterbirds (being the most dominant taxon). For the other taxa the trend is similar. The table shows the relation between values that are once calculated (CF, EF, FF) or extracted from maps (S, VS, CpA) based on Ramsar areas and once based on waterbody areas. The median, as well as the 2.5% and 97.5% percentile (between them are 95% of the data), are shown for these factors between Ramsar and waterbody areas based results. The difference between species richness, CpA and the vulnerability score is very low. However, the difference in the EF is larger, which is due to the non-linearity of the species-area relationship. In 95% of the data, the difference of the FF is smaller than for the EF. For the GW-fed wetlands, the difference between the FFs regarding waterbody or Ramsar area is negligible, because differences between the areas are often smaller. This is probably a coincidence. Bear in mind that the sample for the SW-fed wetlands is almost 10 times larger than for the GW-fed wetlands. The differences between CFs and EFs calculated with either Ramsar or wetland areas for the other taxa, are shown in Table S12. Since the differences for the FFs and the underlying area are the same, they are not repeated. The minor differences from S, VS and CpA are not indicated.

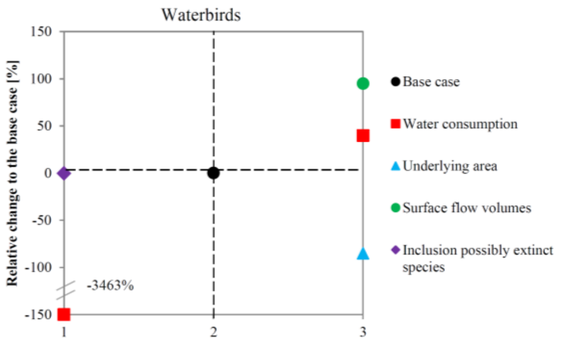
Table S11: Factors between different parameters calculated based on the waterbody and the Ramsar area of each wetland, respectively. Between the 2.5% percentile and 97.5 % percentile 95% of the wetlands are found. These values are for waterbirds, as this is the most dominant taxon and covers all wetlands.

Factor between waterbody and Ramsar value	SW-fed wetlands			GW-fed wetlands		
	median	2.5% percentile	97.5% percentile	median	2.5% percentile	97.5% percentile
CF	1.25	0.92	70.14	1.60	0.64	62.44
EF	1.67	0.97	55.24	1.67	1.00	63.23
FF	0.93	0.12	10.53	1.00	0.19	1.00
Underlying wetland area (A)	0.60	0.02	1.00	0.60	0.02	1.00
Species richness (S)	1.00	0.96	1.04	1.00	0.98	1.02
Habitat loss risk (CpA)	1.00	0.92	1.09	1.00	0.91	1.09
Vulnerability score (VS)	1.00	0.94	1.06	1.00	0.98	1.03

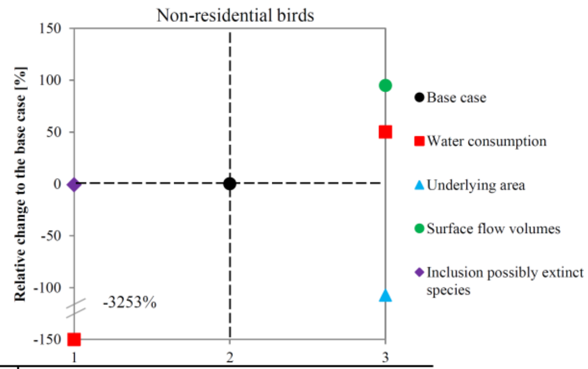
Table S12: Factors for the taxa other than waterbirds between CF and EF calculated based on the waterbody and the Ramsar area of each wetland, respectively. Between the 2.5% percentile and 97.5 % percentile 95% of the wetlands are found. Factors between the FFs or the underlying areas are the same as for waterbirds.

Taxa	Factor between waterbody and Ramsar value	SW-fed wetlands			GW-fed wetlands		
		median	2.5% percentile	97.5% percentile	median	2.5% percentile	97.5% percentile
non-residential birds	CF	1.24	0.88	73.31	1.60	0.64	61.74
	EF	1.67	0.97	58.29	1.67	1.00	63.43
water-dependent mammals	CF	1.22	0.90	53.65	1.50	0.67	32.49
	EF	1.67	0.99	34.12	1.67	1.00	41.31
reptiles	CF	1.20	0.93	55.82	1.58	0.57	23.13
	EF	1.67	1.00	42.12	1.67	1.00	28.27
amphibians	CF	1.24	0.85	57.64	1.57	0.63	44.07
	EF	1.67	0.96	49.39	1.67	1.00	51.32

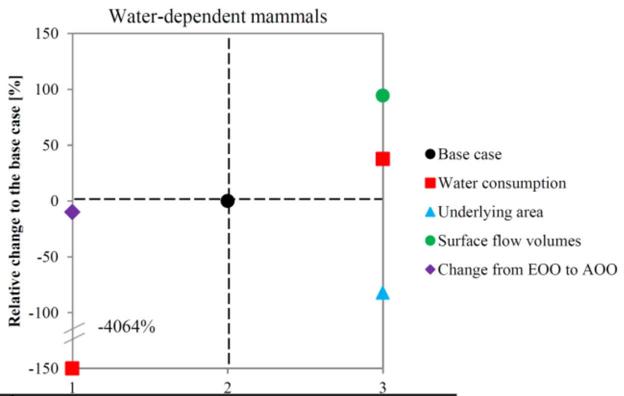
Overviews of the sensitivity analysis for the characterization factors (for each taxon and water source separately) are shown in Figure S39 and Figure S40. The parameters that were important in the sensitivity analyses of the fate factors (FF)[18] were used here again. In addition, the influence of including possibly extinct species (presence category 4, see Table S4) was checked (for mammals: area of occupancy instead of extent of occurrence). As for the FFs, the amount of water consumed, surface water flow volumes, and hydraulic conductivity were most relevant. However, due to the non-linear species-area relationship, the underlying area is now relevant for both SW-fed and GW-fed wetlands, while for the FF it was only relevant for some GW-fed wetlands. The influence of including possibly extinct species is in the majority of cases negligible. For the mammals, the change from the extent of occurrence (EOO) to the actual area of occupancy (AOO) of the species had a slightly larger influence, showing that for future developments the derivation of AOOs is relevant.



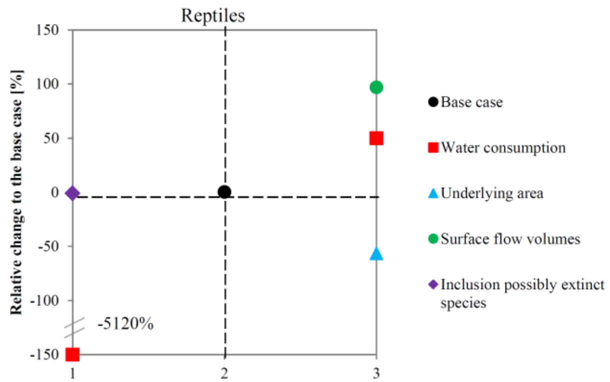
parameter	1	2 (base case)	3
Water consumption [m³/yr]	10	**1000**	1'000'000
underlying area [ha]	-	**Ramsar area**	waterbody area
surface flow volumes [-]	-	**own model**	WaterGap
Inclusion possibly extinc species [-]	Presence 1-4	**Presence 1-3**	-



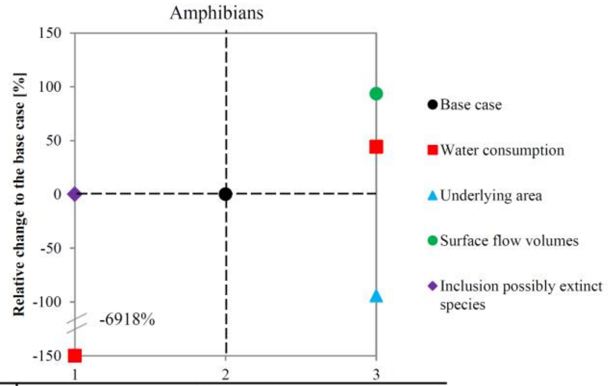
parameter	1	2 (base case)	3
Water consumption [m³/yr]	10	**1000**	1'000'000
underlying area [ha]	-	**Ramsar area**	waterbody area
surface flow volumes [-]	-	**own model**	WaterGap
Inclusion possibly extinc species [-]	Presence 1-4	**Presence 1-3**	-



parameter	1	2 (base case)	3
Water consumption [m³/yr]	10	**1000**	1'000'000
underlying area [ha]	-	**Ramsar area**	waterbody area
surface flow volumes [-]	-	**own model**	WaterGap
Change from EOO to AOO [-]	AOO	**EOO**	-

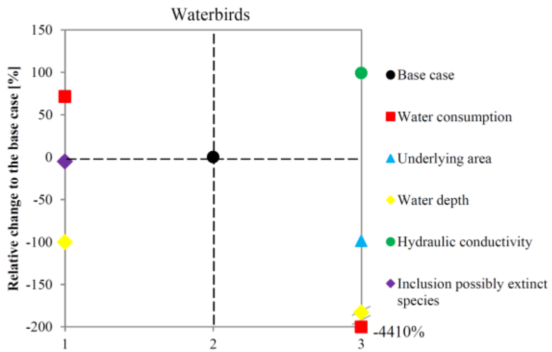


parameter	1	2 (base case)	3
Water consumption [m³/yr]	10	**1000**	1'000'000
underlying area [ha]	-	**Ramsar area**	waterbody area
surface flow volumes [-]	-	**own model**	WaterGap
Inclusion possibly extinc species [-]	Presence 1-4	**Presence 1-3**	-

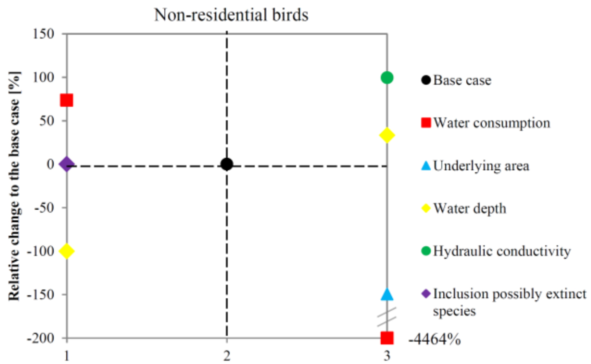


parameter	1	2 (base case)	3
Water consumption [m^3/yr]	10	**1000**	1'000'000
underlying area [ha]	-	**Ramsar area**	waterbody area
surface flow volumes [-]	-	**own model**	WaterGap
Inclusion possibly extinc species [-]	Presence 1-4	**Presence 1-3**	-

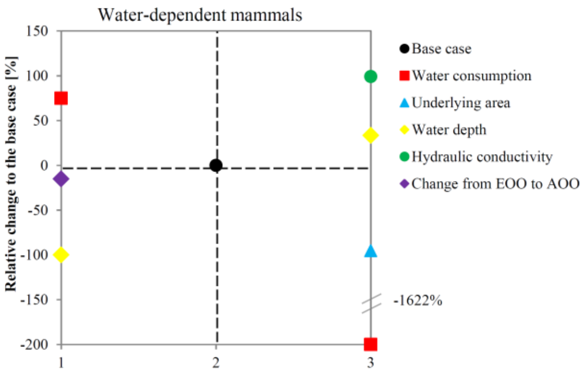
Figure S39: Sensitivity analysis overview for SW-fed wetlands and all taxa separately. The change in each parameter is given for the global median values, parameters are listed below the graphic. Too large changes are indicated next to the marker.



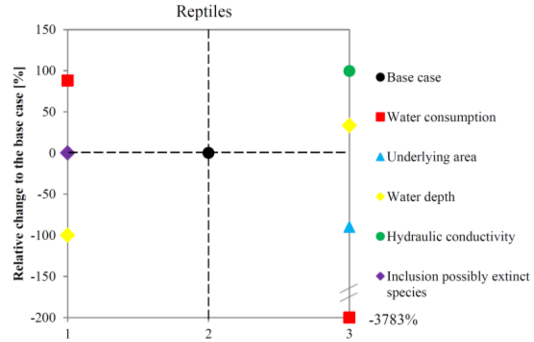
parameter	1	2 (base case)	3
Water consumption [m^3/yr]	10	**1000**	1'000'000
underlying area [ha]	-	**Ramsar area**	waterbody area
water depth [m]	-50%	**data from literature**	+50%
Hydraulic conductivity [m/s]	-	**calculated**	*100
Inclusion possibly extinct species [-]	Presence 1-4	**Presence 1-3**	-



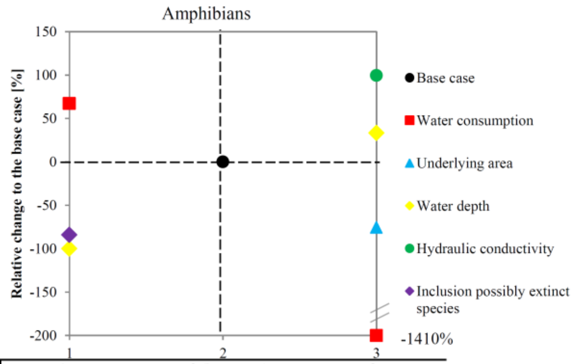
parameter	1	2 (base case)	3
Water consumption [m^3/yr]	10	**1000**	1'000'000
underlying area [ha]	-	**Ramsar area**	waterbody area
water depth [m]	-50%	**data from literature**	+50%
Hydraulic conductivity [m/s]	-	**calculated**	*100
Inclusion possibly extinct species [-]	Presence 1-4	**Presence 1-3**	-



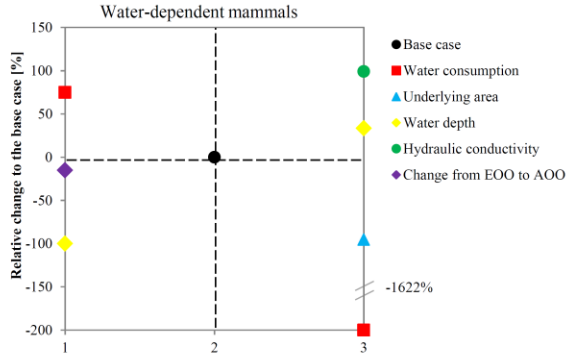
parameter	1	2 (base case)	3
Water consumption [m³/yr]	10	**1000**	1'000'000
underlying area [ha]	-	**Ramsar area**	waterbody area
water depth [m]	-50%	**data from literature**	+50%
Hydraulic conductivity [m/s]	-	**calculated**	*100
Change from EOO to AOO [-]	AOO	**EOO**	-



parameter	1	2 (base case)	3
Water consumption [m³/yr]	10	**1000**	1'000'000
underlying area [ha]	-	**Ramsar area**	waterbody area
water depth [m]	-50%	**data from literature**	+50%
Hydraulic conductivity [m/s]	-	**calculated**	*100
Inclusion possibly extinct species [-]	Presence 1-4	**Presence 1-3**	-



parameter	1	2 (base case)	3
Water consumption [m³/yr]	10	**1000**	1'000'000
underlying area [ha]	-	**Ramsar area**	waterbody area
water depth [m]	-50%	**data from literature**	+50%
Hydraulic conductivity [m/s]	-	**calculated**	*100
Inclusion possibly extinct species [-]	Presence 1-4	**Presence 1-3**	-



parameter	1	2 (base case)	3
Water consumption [m³/yr]	10	**1000**	1'000'000
underlying area [ha]	-	**Ramsar area**	waterbody area
water depth [m]	-50%	**data from literature**	+50%
Hydraulic conductivity [m/s]	-	**calculated**	*100
Inclusion possibly extinct species [-]	Presence 1-4	**Presence 1-3**	-

417 **Figure S40: Sensitivity analysis overview for GW-fed wetlands and all taxa separately. The change in each parameter is given for the global median values, parameters are listed below**
418 **the graphic. Too large changes are indicated next to the marker.**

S12. Example of comparison of CFs calculated with PDFs and species-eq.

The CF in PDF·yr/m^3 of the two SW-fed wetlands “Cheyenne Bottoms” (USA) and “Lake Ånnsjön” (Sweden) is the same ($3.38 \cdot 10^{-9}$ PDF·yr/m^3). However, the number of waterbird species present is very different, being 112 in “Cheyenne Bottoms” and 49 in “Lake Ånnsjön”. Absolute species loss was one order of magnitude smaller in the Swedish wetland. VS is the same order of magnitude in both wetlands ($2.5 \cdot 10^{-6}$ for Cheyenne Bottoms and $1.1 \cdot 10^{-6}$ for Lake Ånnsjön) and CpA one order of magnitude lower in “Cheyenne Bottoms”, showing that the wetland habitat loss risk is larger than in “Lake Ånnsjön”. CFs are consequently different for those two wetlands in the species-eq approach (CF for “Cheyenne Bottoms” $1.83 \cdot 10^{-10}$ species-eq·yr/m^3, for “Lake Ånnsjön” $5.8 \cdot 10^{-12}$ species-eq·yr/m^3).

S13. Agricultural water requirement ratio

The consumptive share of the water use can be used for estimating water consumption amounts from withdrawn water amounts (for agriculture). It is based on data from AQUASTAT[19] for 93 developing countries and on data from Döll and Siebert[20] for other world regions and is shown in Figure S41.

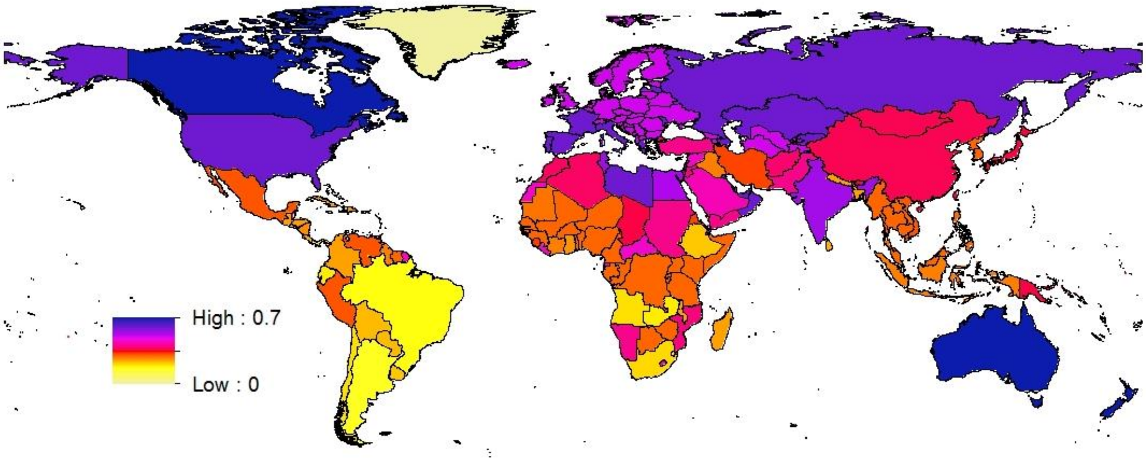


Figure S41: Water requirement ratios based on data from AQUASTAT[19] and Döll and Siebert (2002).[20] Base map with country boundaries adapted from ref.[8]

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