Methods in Ecology and Evolution

SUPPORTING INFORMATION

Accounting for biotic interaction through alpha-diversity constraints in stacked species distribution models.

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Supplementary Information

Table S1 – species names, acronyms and feeding guilds, along with their prevalence and the performance indices of the original SDM

Table S2 – predictors used in the SDMs and alpha-diversity models

Supporting information S1 – Poisson-binomial distribution approximations of the alpha-adjusted SDM

Supporting information S2 – R codes for applying the alpha-adjusted SDM analysis (ExampleGatherers.R)

Supporting information S3 – Example data set for the 8 gatherer species (GathererRMO.csv)

Supporting information S4 – The background river network (RiverNetwork.csv)

Figure S1 – the total number of occupancies predicted for each community by the original SDM, and the two alpha-adjusted SDMs (based on max TSS PA maps).

Table S1: The 87 freshwater invertebrate species from the 5 feeding guilds, alongside their prevalences in the training data, and various performance indices of the original SDMs. Details on the references used to define the guilds is given below.

Guild	group	Species	Total training sites (presence, absence)	Max TSS	Max TSS threshold	Sensitivity at Max TSS	Specificity at Max TSS	AUC
filterer	Bivalvia	Sphaerium corneum	62 (49 , 13)	0.637	0.869	0.714	0.923	0.878
filterer	Diptera	Simulium cryophilum	50 (27 , 23)	0.615	0.459	0.963	0.652	0.76
filterer	Diptera	Simulium vernum	40 (17 , 23)	0.637	0.368	0.941	0.696	0.877
filterer	Ephemeroptera	Ephemera danica	95 (89 , 6)	0.494	0.985	0.494	1.000	0.751
filterer	Gastropoda	Pisidium amnicum	35 (21 , 14)	0.119	0.631	0.476	0.643	0.537
filterer	Trichoptera	Philopotamus montanus montanus	34 (11 , 23)	0.692	0.355	0.909	0.783	0.838
gatherer	Diptera	Prodiamesa olivacea	91 (88 , 3)	0.602	0.992	0.602	1.000	0.693
gatherer	Ephemeroptera	Habroleptoides confusa	78 (58 , 20)	0.948	0.703	0.948	1.000	0.991
gatherer	Ephemeroptera	Habrophlebia lauta	64 (45 , 19)	0.77	0.754	0.822	0.947	0.96
gatherer	Ephemeroptera	Paraleptophlebia submarginata	46 (24 , 22)	0.636	0.142	1.000	0.636	0.778
gatherer	Oligochaeta	Eiseniella tetraedra	74 (61 , 13)	0.277	0.91	0.508	0.769	0.598
gatherer	Oligochaeta	Haplotaxis gordioides	29 (7 , 22)	0.636	0.07	1.000	0.636	0.721
gatherer	Oligochaeta	Lumbriculus variegatus	64 (50 , 14)	0.526	0.736	0.74	0.786	0.736
gatherer	Oligochaeta	Stylodrilus heringianus	49 (34 , 15)	0.682	0.554	0.882	0.8	0.808
grazer	Coleoptera	Hydraena gracilis Ad.	56 (41 , 15)	0.933	0.103	1.000	0.933	0.969
grazer	Coleoptera	Limnius perrisi Ad.	81 (63 , 18)	0.73	0.564	0.952	0.778	0.913
grazer	Coleoptera	Limnius volckmari Ad.	62 (46 , 16)	0.832	0.361	0.957	0.875	0.933
grazer	Coleoptera	Oulimnius tuberculatus Ad.	55 (38 , 17)	0.797	0.463	0.974	0.824	0.904
grazer	Ephemeroptera	Centroptilum luteolum	62 (44 , 18)	0.508	0.552	0.841	0.667	0.806
grazer	Ephemeroptera	Electrogena affinis	38 (15 , 23)	0.6	0.801	0.6	1.000	0.678
grazer	Ephemeroptera	Epeorus assimilis	70 (54 , 16)	0.794	0.535	0.981	0.813	0.933
grazer	Gastropoda	Ancylus fluviatilis	106 (99 , 7)	0.827	0.742	0.97	0.857	0.952
grazer	Plecoptera	Brachyptera risi	83 (66 , 17)	0.676	0.55	0.97	0.706	0.85
grazer	Plecoptera	Brachyptera seticornis	44 (22 , 22)	0.682	0.397	1.000	0.682	0.806
grazer	Trichoptera	Goera pilosa	32 (11 , 21)	0.727	0.591	0.727	1.000	0.818
grazer	Trichoptera	Silo nigricornis	29 (10 , 19)	0.642	0.512	0.8	0.842	0.905
grazer	Trichoptera	Silo pallipes	38 (17 , 21)	0.714	0.407	1.000	0.714	0.871
grazer	Trichoptera	Silo piceus	33 (9 , 24)	0.889	0.539	0.889	1.000	0.986
predator	Coleoptera	Orectochilus villosus Ad.	30 (9 , 21)	0.508	0.248	0.889	0.619	0.709
predator	Coleoptera	Orectochilus villosus Lv.	76 (62 , 14)	0.776	0.648	0.919	0.857	0.9
predator	Coleoptera	Oreodytes sanmarkii Ad.	29 (11 , 18)	0.778	0.047	1.000	0.778	0.924
predator	Coleoptera	Platambus maculatus Ad.	31 (11 , 20)	0.218	0.115	0.818	0.4	0.568
predator	Coleoptera	Platambus maculatus Lv.	28 (12 , 16)	0.875	0.083	1.000	0.875	0.922
predator	Diptera	Atherix ibis	46 (31 , 15)	0.774	0.725	0.774	1.000	0.806

Guild	group	Species	Total training sites (presence, absence)	Max TSS	Max TSS threshold	Sensitivity at Max TSS	Specificity at Max TSS	AUC
predator	Diptera	Atrichops crassipes	31 (11 , 20)	0.214	0.473	0.364	0.85	0.632
predator	Heteroptera	Aphelocheirus aestivalis	51 (38 , 13)	0.66	0.89	0.737	0.923	0.895
predator	Hirudinae	Erpobdella nigricollis	38 (18 , 20)	0.278	0.869	0.278	1.000	0.533
predator	Hirudinae	Erpobdella octoculata	82 (66 , 16)	0.737	0.693	0.924	0.813	0.844
predator	Hirudinae	Erpobdella vilnensis	40 (23 , 17)	0.854	0.691	0.913	0.941	0.926
predator	Hirudinae	Glossiphonia complanata	51 (39 , 12)	0.41	0.925	0.41	1.000	0.673
predator	Hirudinae	Helobdella stagnalis	41 (26 , 15)	0.513	0.532	0.846	0.667	0.726
predator	Megalloptera	Sialis fuliginosa	51 (34 , 17)	0.824	0.132	1.000	0.824	0.908
predator	Megalloptera	Sialis lutaria	43 (29 , 14)	0.648	0.487	0.862	0.786	0.756
predator	Odonata	Calopteryx splendens	40 (22 , 18)	0.616	0.521	0.727	0.889	0.833
predator	Odonata	Calopteryx virgo	32 (13 , 19)	0.304	0.568	0.462	0.842	0.571
predator	Platyhelminthes	Dendrocoelum lacteum	32 (11 , 21)	0.446	0.34	0.636	0.81	0.602
predator	Platyhelminthes	Dugesia gonocephala	62 (46 , 16)	0.576	0.694	0.826	0.75	0.773
predator	Trichoptera	Cyrnus trimaculatus	40 (17 , 23)	0.56	0.553	0.647	0.913	0.788
predator	Trichoptera	Polycentropus flavomaculatus flavomaculatus	85 (68 , 17)	0.75	0.506	0.985	0.765	0.944
predator	Trichoptera	Rhyacophila evoluta	49 (25 , 24)	0.583	0.163	1.000	0.583	0.755
predator	Trichoptera	Rhyacophila fasciata fasciata	32 (10 , 22)	0.291	0.268	0.7	0.591	0.623
predator	Trichoptera	Rhyacophila nubila	31 (14 , 17)	0.824	0.041	1.000	0.824	0.962
generalist	Ephemeroptera	Baetis alpinus	32 (9 , 23)	0.609	0.075	1.000	0.609	0.734
generalist	Ephemeroptera	Baetis fuscatus	52 (35 , 17)	0.592	0.534	0.886	0.706	0.817
generalist	Ephemeroptera	Baetis lutheri	55 (32 , 23)	0.713	0.542	0.844	0.87	0.929
generalist	Ephemeroptera	Baetis muticus	67 (49 , 18)	0.778	0.06	1.000	0.778	0.949
generalist	Ephemeroptera	Baetis niger	49 (28 , 21)	0.667	0.144	1.000	0.667	0.801
generalist	Ephemeroptera	Baetis scambus	32 (17 , 15)	0.816	0.474	0.882	0.933	0.965
generalist	Ephemeroptera	Baetis vernus	53 (46 , 7)	0.276	0.746	0.848	0.429	0.556
generalist	Ephemeroptera	Ephemerella mucronata	53 (34 , 19)	0.889	0.697	0.941	0.947	0.964
generalist	Ephemeroptera	Heptagenia sulphurea	49 (32 , 17)	0.476	0.804	0.594	0.882	0.721
generalist	Ephemeroptera	Serratella ignita	66 (62 , 4)	0.621	0.864	0.871	0.75	0.704
generalist	Ephemeroptera	Torleya major	81 (64 , 17)	0.91	0.69	0.969	0.941	0.992
generalist	Gastropoda	Bithynia tentaculata	38 (25 , 13)	0.498	0.303	0.96	0.538	0.751
generalist	Gastropoda	Potamopyrgus antipodarum	43 (29 , 14)	0.717	0.549	0.931	0.786	0.855
generalist	Gastropoda	Radix balthica	54 (32 , 22)	0.784	0.521	0.875	0.909	0.893
generalist	Malacostraca	Asellus aquaticus	101 (96 , 5)	0.506	0.906	0.906	0.6	0.588
generalist	Malacostraca	Gammarus pulex	129 (122 , 7)	0.521	0.978	0.664	0.857	0.756
generalist	Malacostraca	Gammarus roeselii	140 (131 , 9)	0.751	0.956	0.863	0.889	0.874
generalist	Plecoptera	Leuctra nigra	31 (12 , 19)	0.487	0.358	0.75	0.737	0.697
generalist	Plecoptera	Nemurella pictetii	32 (10 , 22)	0.636	0.106	1.000	0.636	0.8
generalist	Trichoptera	Anabolia nervosa	50 (34 , 16)	0.54	0.471	0.853	0.688	0.816
generalist	Trichoptera	Anomalopterygella chauviniana	78 (61 , 17)	0.824	0.168	1.000	0.824	0.959

Guild	group	Species	Total training sites (presence, absence)	Max TSS	Max TSS threshold	Sensitivity at Max TSS	Specificity at Max TSS	AUC
generalist	Trichoptera	Athripsodes bilineatus bilineatus	33 (13 , 20)	0.469	0.391	0.769	0.7	0.727
generalist	Trichoptera	Athripsodes cinereus	32 (12 , 20)	0.433	0.431	0.583	0.85	0.692
generalist	Trichoptera	Brachycentrus subnubilus	45 (30 , 15)	0.7	0.54	0.833	0.867	0.88
generalist	Trichoptera	Chaetopteryx villosa villosa	28 (13 , 15)	0.856	0.431	0.923	0.933	0.892
generalist	Trichoptera	Hydropsyche angustipennis angustipennis	39 (16 , 23)	0.726	0.452	0.813	0.913	0.889
generalist	Trichoptera	Hydropsyche instabilis	36 (16 , 20)	0.825	0.628	0.875	0.95	0.966
generalist	Trichoptera	Hydropsyche saxonica	44 (23 , 21)	0.667	0.121	1.000	0.667	0.834
generalist	Trichoptera	Hydropsyche siltalai	108 (98 , 10)	0.667	0.855	0.867	0.8	0.888
generalist	Trichoptera	Lepidostoma basale	76 (59 , 17)	0.797	0.872	0.797	1.000	0.954
generalist	Trichoptera	Lepidostoma hirtum	36 (21 , 15)	0.571	0.476	0.905	0.667	0.806
generalist	Trichoptera	Micrasema longulum	43 (24 , 19)	0.811	0.613	0.917	0.895	0.961
generalist	Trichoptera	Mystacides azurea	39 (21 , 18)	0.468	0.664	0.524	0.944	0.728
generalist	Trichoptera	Odontocerum albicorne	43 (24 , 19)	0.8	0.61	0.958	0.842	0.925
generalist	Trichoptera	Psychomyia pusilla	37 (23 , 14)	0.568	0.578	0.783	0.786	0.748

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Table S2: Predictors used in the SDMs and alpha-diversity models

type	Predictor	Description
climatic	bio_01	mean annual temperature
	bio_08	Mean Temperature of Wettest Quarter
land-cover	urban	relative urban land use cover in the upper sub-catchment
	pastu	relative pasture land use cover in the upper sub-catchment
	agric	relative agriculture land use cover in the upper sub-catchment
topographic	slope	degrees inclination
	aspect	orientation in cardinal degrees (North, South...)
geology	baslt	relative basalt geology cover in the upper sub-catchment
	limst	relative sandstone geology cover in the upper sub-catchment
	sndst	relative limestone geology cover in the upper sub-catchment
hydrology	year_	mean annual discharge / river flow
	ave_yds200	mean high flow days (days with discharge equivalent to 2x annual discharge)

Supporting information S1:

Poisson-binomial distribution approximations of the alpha-adjusted SDM

In the main body of the manuscript we develop the alpha-adjusted by listing all possible realization of a given alpha diversity out of a given gamma diversity. As the number of realizations increases quickly with alpha and gamma increases, listing all realization may become computationally difficult. However, estimates similar to eqn4 of the main text can be achieved without listing all realizations using various approximations of the Poisson-binomial distribution. In short, eqn2, which gives the probability of any given realization can be estimated with the probability mass function:

$$R_{j,\alpha} = \frac{1}{S+1}\sum_{n=0}^{S}\left[e^{-i2\pi n\alpha/(S+1)} \cdot \prod_{s=1}^{S}\left[P_{s,j} \cdot e^{\frac{i2\pi n}{S+1}} + (1-P_{s,j})\right]\right]$$

eqn5

where $i = \sqrt[2]{-1}$ is the imaginary unit. Then, for focal species μ, eqn5 can be used to estimate the overall probability of having α-1 species, using the PoO of all species other than μ. This will provide the overall probability of having α-1 species in site j, with species μ not being one of them.

$$R_{j,\alpha-1,-\mu} = \frac{1}{S_{-\mu}+1}\sum_{n=0}^{S_{-\mu}}\left[e^{-i2\pi n\alpha/(S_{-\mu}+1)} \cdot \prod_{s=1}^{S_{-\mu}}\left[P_{s,j} \cdot e^{\frac{i2\pi n}{S_{-\mu}+1}} + (1-P_{s,j})\right]\right]$$

eqn6

With $S_{-\mu}$ being the number of species excluding species μ. Thus, multiplying this value by the PoO of μ will yield the probability of having α species, with species μ being one of them. The ratio between this multiplied value and eqn5 should approximate rqn4:

$$adjP_{\mu,j,\alpha} = \frac{P_{\mu,j} \cdot \frac{1}{S_{-\mu}+1}\sum_{n=0}^{S_{-\mu}}\left[e^{-i2\pi n\alpha/(S_{-\mu}+1)}\cdot\prod_{s=1}^{S_{-\mu}}\left[P_{s,j}\cdot e^{\frac{i2\pi n}{S_{-\mu}+1}}+(1-P_{s,j})\right]\right]}{\frac{1}{S+1}\sum_{n=0}^{S}\left[e^{-i2\pi n\alpha/(S+1)}\cdot\prod_{s=1}^{S}\left[P_{s,j}\cdot e^{\frac{i2\pi n}{S+1}}+(1-P_{s,j})\right]\right]}$$

eqn7

R codes for computing the adjusted probabilities based on both eqn4 and eqn7 are given in supporting information 2, while the csv file in supporting information 3 provide a simplified example data sets with the 8 gatherer species.
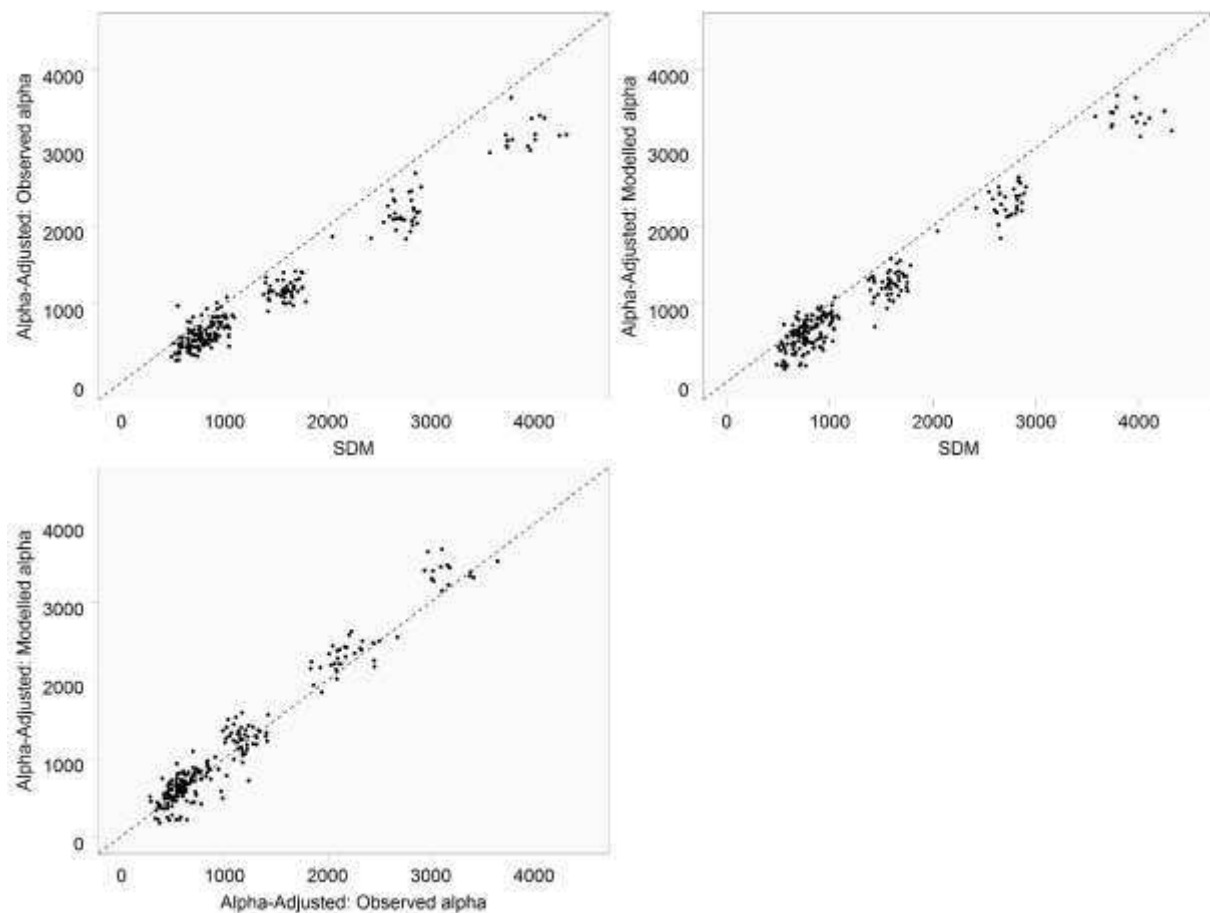
Figure S1

Figure S1: Comparison of the total number of occupancies predicted for each of the 230

communities (point in the figure) by stacking the PA maps of the original SDMs and the two alpha-

adjusted SDMs (based on observed or modelled alpha). In each community, the PoO maps where

transformed to PA maps by selecting the threshold that maximized TSS. Then the resulting set of PA

map here summed over all species and site to produce the total number of occupancies. Dashed line

is the line of unity. THe four group of points represent communities with gamma diversity equaling

35 species (top-right corner), 24 species, 14 species and a joined cluster for 6 or 8 species (lower-left

corner).