Ecography

ECOG-01205
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Supplementary material

Appendix 1. Conditions for change in probability of occurrence under georeferencing error.

For a species with a parabolic response to environment, the probability of occupancy, ψ, in location z is given by

$$\psi(z) = \exp(\theta)\,/[1 + \exp(\theta)]$$

where,

$$\theta = a + bX(z) + cX(z)^2$$

and X(z) is the environmental variable in location z.

Whether or not the georeferencing error matters depends on whether or not ψ changes appreciably between actual location z and the observed location z + **Δ**z. To find this, we calculate $\Delta\psi$:

$$\Delta\psi = \psi(z + \Delta\text{z}) - \psi(z) \approx \frac{d\psi}{dz}\Delta\text{z} + \frac{1}{2}\frac{d^2\psi}{dz^2}\Delta\text{z}^2 + \cdots$$

So, to first order, we can focus on $\frac{d\psi}{dz}$, which is given by:

$$\frac{d\psi}{dz} = \psi(1 - \psi)[b + 2cX(z)]\frac{dX}{dz}$$

From this, we observe that $\frac{d\psi}{dz}$ is close to 0 whenever:

1. ψ is close to 0 or 1.
2. The environment does not change much with distance (i.e. spatial autocorrelation is high so that dX/dz is close to 0).
3. If b and c are close to 0, which implies a high environmental tolerance.

Appendix 2. OpenBUGS code to fit the measurement model for species distribution modeling.

Required data are: `sites`: the number of occurrences; `Y`: a vector of species occurrences (presence = 1, absence = 0); `env1Table`, `env2Table` & `env1sqTable`: matrices in which each row corresponds to a site and columns are filled with all the possible environmental values for each site, which is a function of the radius of error; `pCatTable`: a matrix with probabilities for sampling a particular cell within a radius of error (column) for a particular site (row).

```
model {
	for (i in 1:sites) {
		#Likelihood
		Y[i]~dbin (p[i],1)
		logit(p[i])<-z.lim[i]
		z.lim[i]<-min(999,max(-999,z.ub[i]))
		z.ub[i] <-
		 betas[1]+betas[2]*env1[i]+betas[3]*env2[i]+betas[4]*env1sq[i]
		#Measurement model
		env1[i] <- env1Table[i,k[i]]
		env2[i] <- env2Table[i,k[i]]
		env1sq[i] <- env1sqTable[i,k[i]]
		k[i]~dcat(pcatTable[i,])
	}
	#Regression priors
	betas[1] ~ dnorm(0,0.001)
	betas[2] ~ dnorm(0,0.001)
	betas[3] ~ dnorm(0,0.001)
	betas[4] ~ dnorm(0,0.001)
}
```

Appendix 3. Additional Figures.

Figure A1. Gelman-Rubin convergence statistic ($\hat{R}$) of regression coefficients calculated for all measurement model + regression prior combinations using the 10 datasets generated for species Snarrow in experiment 1. $\hat{R}$ values closer to 1 indicate convergence.

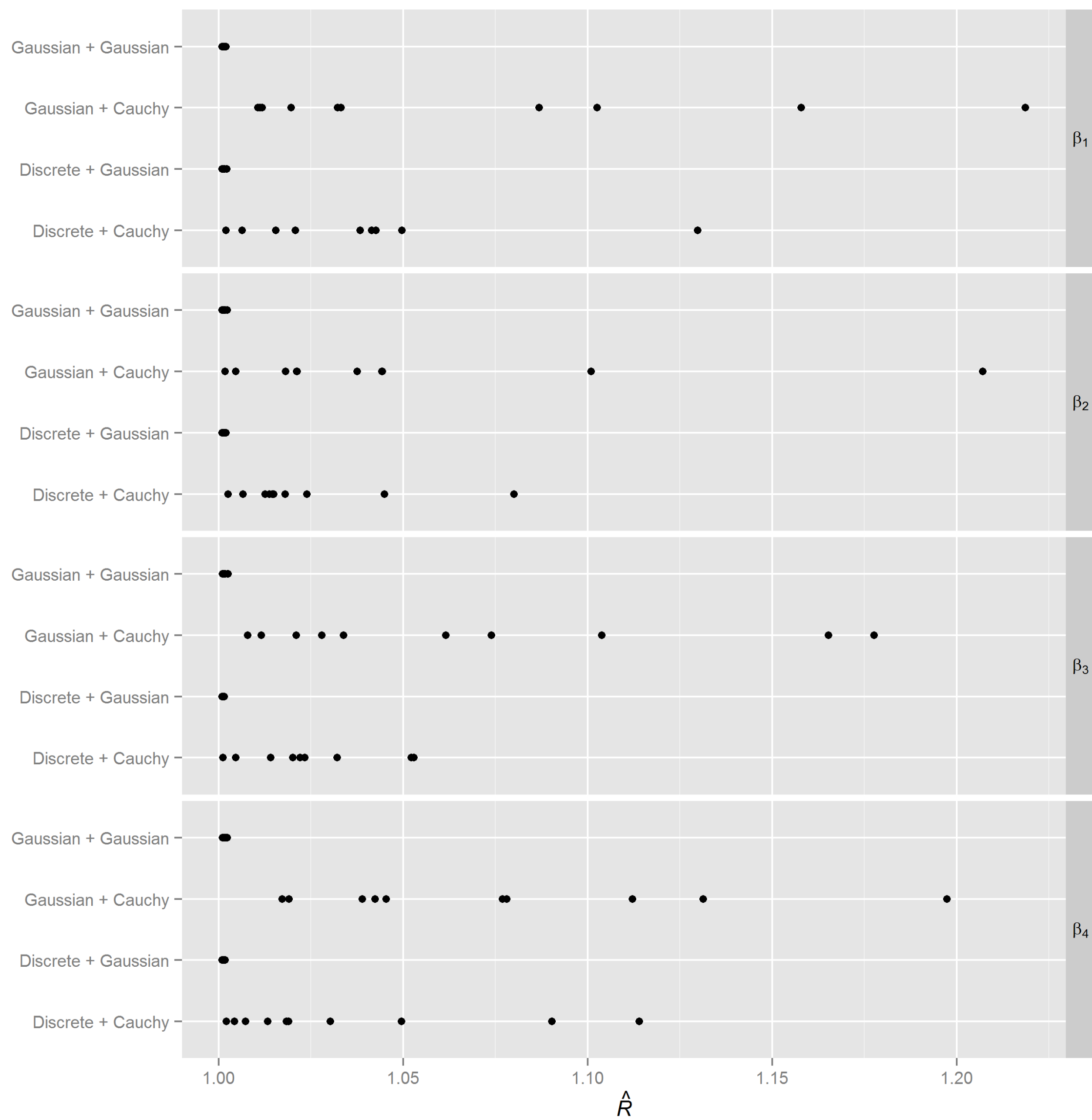

Figure A2. Comparison of performance as measured by mean absolute error of probability of occurrence for combinations of measurement model + regression prior using the 10 datasets generated for species S_{narrow} in experiment 1.

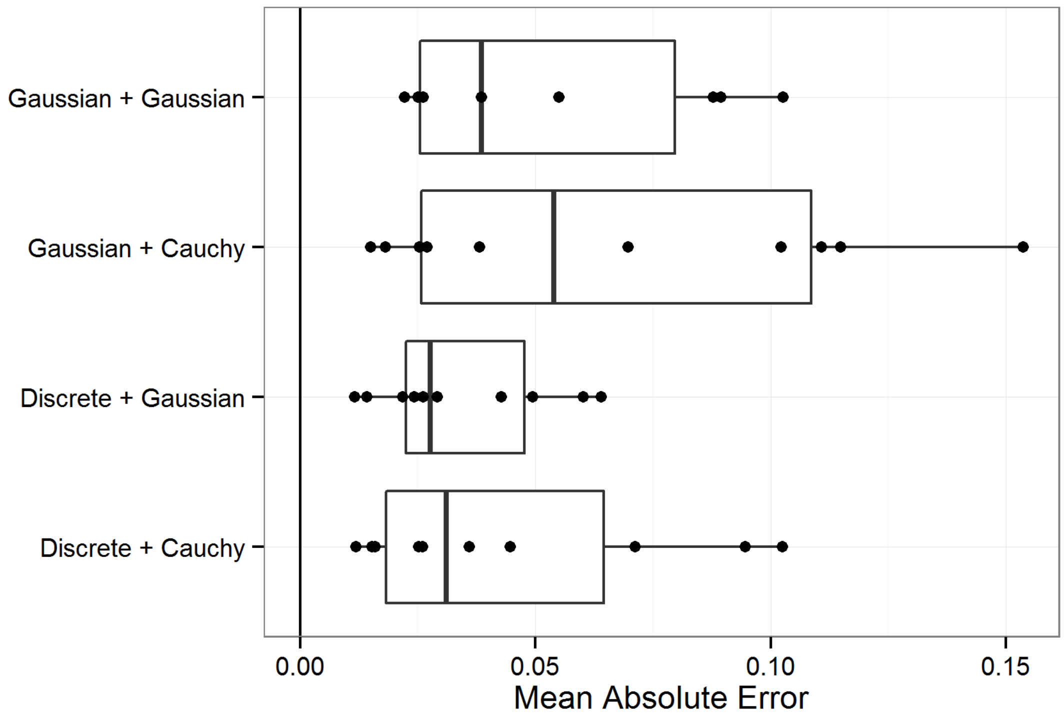

Figure A3. Example from a single simulation of true and predicted response curves of relative probability of occurrence of species S_{narrow} to covariates X_1 and X_2.

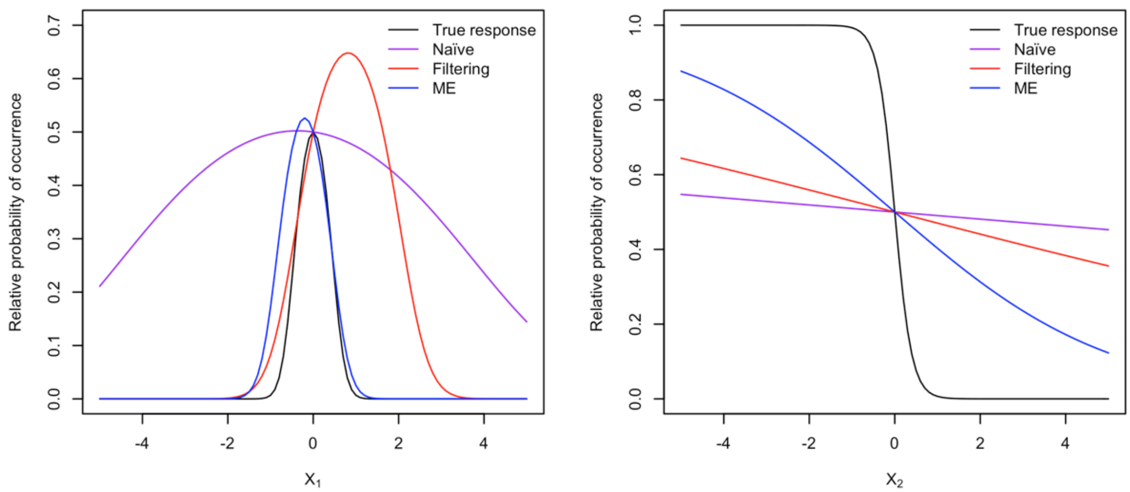

Figure A4. Mean absolute error of prior and posterior covariate distributions at the mode for a fixed-error dataset (Experiment 2).

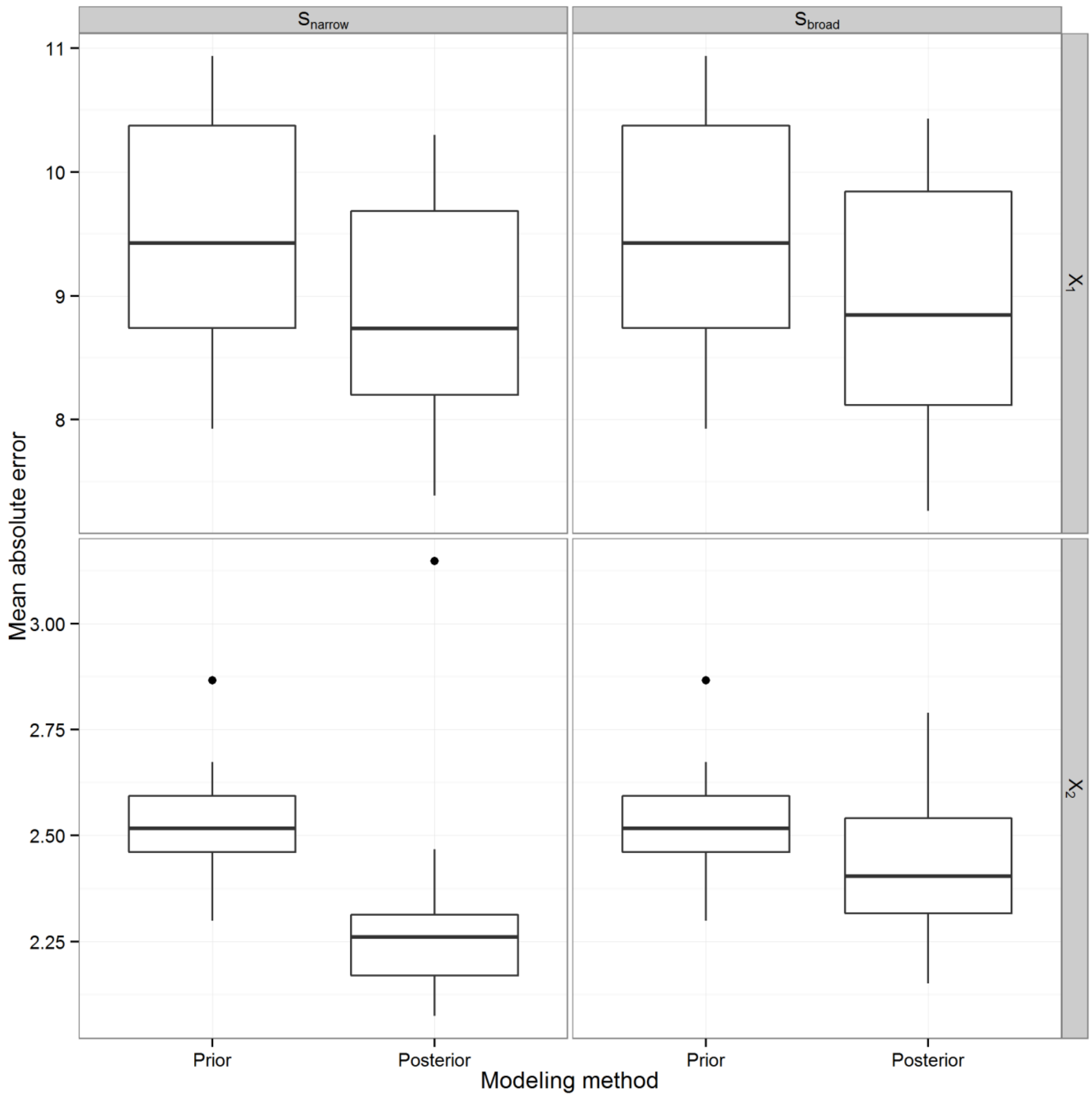

Table A1. Performance of modeling methods across experiments.

Experiment	Modeling method	Species	Mean MAE	SD MAE	Mean r	SD r	Mean AUC	SD AUC
1	Avg.	Broad	0.142	0.025	0.779	0.145	0.853	0.052
1	Filtering	Broad	0.186	0.042	0.614	0.242	0.862	0.037
1	ME	Broad	0.158	0.021	0.748	0.133	0.876	0.036
1	Naïve	Broad	0.184	0.018	0.624	0.165	0.811	0.077
1	True	Broad	0.036	0.011	0.982	0.013	0.915	0.004
1	Avg.	Narrow	0.223	0.017	0.619	0.131	0.927	0.063
1	Filtering	Narrow	0.040	0.022	0.905	0.073	0.989	0.014
1	ME	Narrow	0.034	0.019	0.917	0.064	0.990	0.009
1	Naïve	Narrow	0.242	0.030	0.360	0.372	0.773	0.273
1	True	Narrow	0.015	0.005	0.981	0.012	0.998	0.001
2	Avg.	Broad	0.274	0.089	0.226	0.571	0.634	0.256
2	ME	Broad	0.151	0.054	0.732	0.268	0.883	0.063
2	Naïve	Broad	0.219	0.033	0.249	0.480	0.653	0.249
2	True	Broad	0.034	0.012	0.984	0.013	0.917	0.005
2	Avg.	Narrow	0.307	0.061	0.271	0.329	0.741	0.169
2	ME	Narrow	0.076	0.087	0.774	0.333	0.957	0.097
2	Naïve	Narrow	0.272	0.039	0.194	0.413	0.608	0.359
2	True	Narrow	0.016	0.007	0.978	0.017	0.998	0.001
3	Avg.	Broad	0.105	0.018	0.883	0.055	0.887	0.021
3	Filtering	Broad	0.123	0.038	0.838	0.117	0.896	0.023
3	ME	Broad	0.099	0.044	0.880	0.090	0.902	0.018
3	Naïve	Broad	0.165	0.021	0.738	0.097	0.855	0.040
3	True	Broad	0.034	0.018	0.979	0.024	0.915	0.006
3	Avg.	Narrow	0.183	0.020	0.747	0.051	0.959	0.020
3	Filtering	Narrow	0.030	0.010	0.940	0.030	0.994	0.004
3	ME	Narrow	0.024	0.012	0.956	0.035	0.996	0.005
3	Naïve	Narrow	0.221	0.030	0.639	0.121	0.929	0.050
3	True	Narrow	0.015	0.003	0.984	0.007	0.998	0.000
4	Avg.	Broad	0.173	0.021	0.751	0.141	0.851	0.061
4	Filtering	Broad	0.180	0.067	0.615	0.345	0.857	0.096
4	ME	Broad	0.162	0.033	0.756	0.133	0.874	0.043
4	Naïve	Broad	0.203	0.030	0.347	0.480	0.687	0.250
4	True	Broad	0.037	0.014	0.984	0.012	0.917	0.004
4	Avg.	Narrow	0.210	0.012	0.721	0.021	0.960	0.019
4	Filtering	Narrow	0.060	0.050	0.827	0.193	0.979	0.033
4	ME	Narrow	0.028	0.006	0.946	0.018	0.995	0.002
4	Naïve	Narrow	0.266	0.022	0.311	0.300	0.760	0.289
4	True	Narrow	0.015	0.006	0.980	0.016	0.998	0.001
5	Avg.	Broad	0.154	0.028	0.695	0.139	0.821	0.052
5	Filtering	Broad	0.160	0.068	0.743	0.166	0.880	0.080

5	ME	Broad	0.130	0.004	0.862	0.026	0.910	0.011
5	Naïve	Broad	0.186	0.033	0.452	0.347	0.730	0.145
5	True	Broad	0.081	0.029	0.918	0.060	0.906	0.011
5	Avg.	Narrow	0.209	0.029	0.633	0.088	0.923	0.040
5	Filtering	Narrow	0.065	0.035	0.825	0.117	0.981	0.019
5	ME	Narrow	0.043	0.019	0.894	0.065	0.992	0.005
5	Naïve	Narrow	0.251	0.036	0.267	0.305	0.719	0.216
5	True	Narrow	0.027	0.008	0.945	0.025	0.995	0.003
6	Avg.	Broad	0.133	0.026	0.843	0.078	0.880	0.034
6	Filtering	Broad	0.114	0.029	0.887	0.096	0.905	0.026
6	ME	Broad	0.087	0.036	0.924	0.091	0.907	0.026
6	Naïve	Broad	0.196	0.017	0.623	0.212	0.795	0.125
6	True	Broad	0.027	0.008	0.994	0.003	0.918	0.002
6	Avg.	Narrow	0.199	0.017	0.734	0.041	0.956	0.017
6	Filtering	Narrow	0.026	0.009	0.955	0.022	0.997	0.002
6	ME	Narrow	0.024	0.008	0.957	0.024	0.996	0.002
6	Naïve	Narrow	0.252	0.021	0.575	0.093	0.911	0.042
6	True	Narrow	0.010	0.003	0.992	0.005	0.998	0.000