Appendix D. The effect of measurement error on estimates of density dependence in recruitment.

Compared to other methods for measuring cover, such as ocular estimates, the pantograph mapping method minimizes measurement error. However, some error is inevitable. For example, deciding when to group tillers into one polygon or split into many polygons involves subjectivity, and different mappers may make different decisions. It is also possible for a mapper to simply miss a plant. With respect to our analysis and research questions, the most important potential impact of measurement error is on our estimates of density dependence. Our recruitment model, which is fit at the level of individual quadrats rather than individual genets (as in the case of the survival and growth models), is particularly prone to bias in estimated density dependence introduced by measurement error.

To test the potential impact of measurement error on the parameter estimates in our recruitment models, we conducted additional field measurements in the summer of 2013 for four species (ARTR, HECO, POSE and PSSP) at the SS, ID site. We establish six new quadrats, and had six observers map each quadrat two times. We then digitized these maps and calculated the percent cover of each species in each quadrat (the key independent variable for the recruitment model). After log transforming the cover values from each quadrat, we calculated the mean and variance of the replicated cover values for each species in each quadrat. We used the variances as our metric of measurement error. For ARTR, HECO, POSE, and PSSP, the variances were 0.0121, 0.0784, 0.0144, and 0.0729, respectively. We found no relationship between these variances and the mean cover in each quadrat.

In the recruitment model which does not account for measurement error, and which is described in the main text, we assume that the number of individuals, y, of species j recruiting at time t+1 in the location q follows a negative binomial distribution:

$$y_{jq,t+1} \sim NegBin((\lambda_{jq,t+1})^{obs}, \theta) \quad \text{D.1}$$

where λ is the mean intensity and θ is the size parameter.In turn, λ depends on the composition of the quadrat in the previous year:

$$(\lambda_{jq,t+1})^{obs} = (C'_{jq,t})^{obs} e^{\gamma_t^R + \phi_g^R + \omega_t^R \sqrt{(\boldsymbol{C'}_{q,t})^{obs}}} \quad \text{D.2}$$

where R refers to Recruitment, $C'_{jq,t}$ is the 'effective cover' (cm^2) of species j in quadrat q at time t, γ is a time-dependent intercept, φ is a coefficient for the effect of group location, ω is a vector of coefficients that determine the strength of intra- and interspecific density-dependence, and $\boldsymbol{C'}$ is the vector of 'effective' cover of each species. The superscript *obs* means that these terms are observed values.

To account for measurement error (Freckleton et al. 2006), we modify Eqns. D.1 and D.2 as follows:

$$y_{jq,t+1} \sim NegBin((\lambda_{jq,t+1})^{true}, \theta) \quad \text{D.3}$$

$$(\lambda_{jq,t+1})^{true} = (C'_{jq,t})^{true} e^{\gamma_t^R + \phi_g^R + \omega_t^R \sqrt{(\boldsymbol{C'}_{q,t})^{true}}} \quad \text{D.4}$$

Then we incorporate the measurement error through a normal distribution: the observed cover is normally distributed with an underlying mean 'true' cover and variance (i.e. measurement error):

$$(C'_{jq,t})^{obs} \sim Norm(\left(C'_{jq,t}\right)^{true}, \varepsilon_j) \quad \text{D.5}$$

The superscript *true* means that these terms are latent 'true' values after accounting for species-specific measurement error ε in the observations.We did not exclude positive interactions from this analysis.

After accounting for species-specific measurement error into the recruitment model, we re-fit the model and estimated the parameters of interest for SS, ID study site. We found that observed and ‘true’ cover for all four species are closely distributed around 1:1 lines (Fig. D1). We further found that measurement error had minor impact on the parameter estimates (Table D1) and corresponding community dynamics (Fig. D2).

TABLE D1. Comparison of the conspecific density dependence estimated from recruitment models with and without accounting for measurement error. The results without measurement error are in bold.

	ARTR	HECO	POSE	PSSP
ARTR	**-0.401**/-0.406			
HECO		**-1.834**/-1.764		
POSE			**-2.314**/-2.331	
PSSP				**-1.815**/-1.767

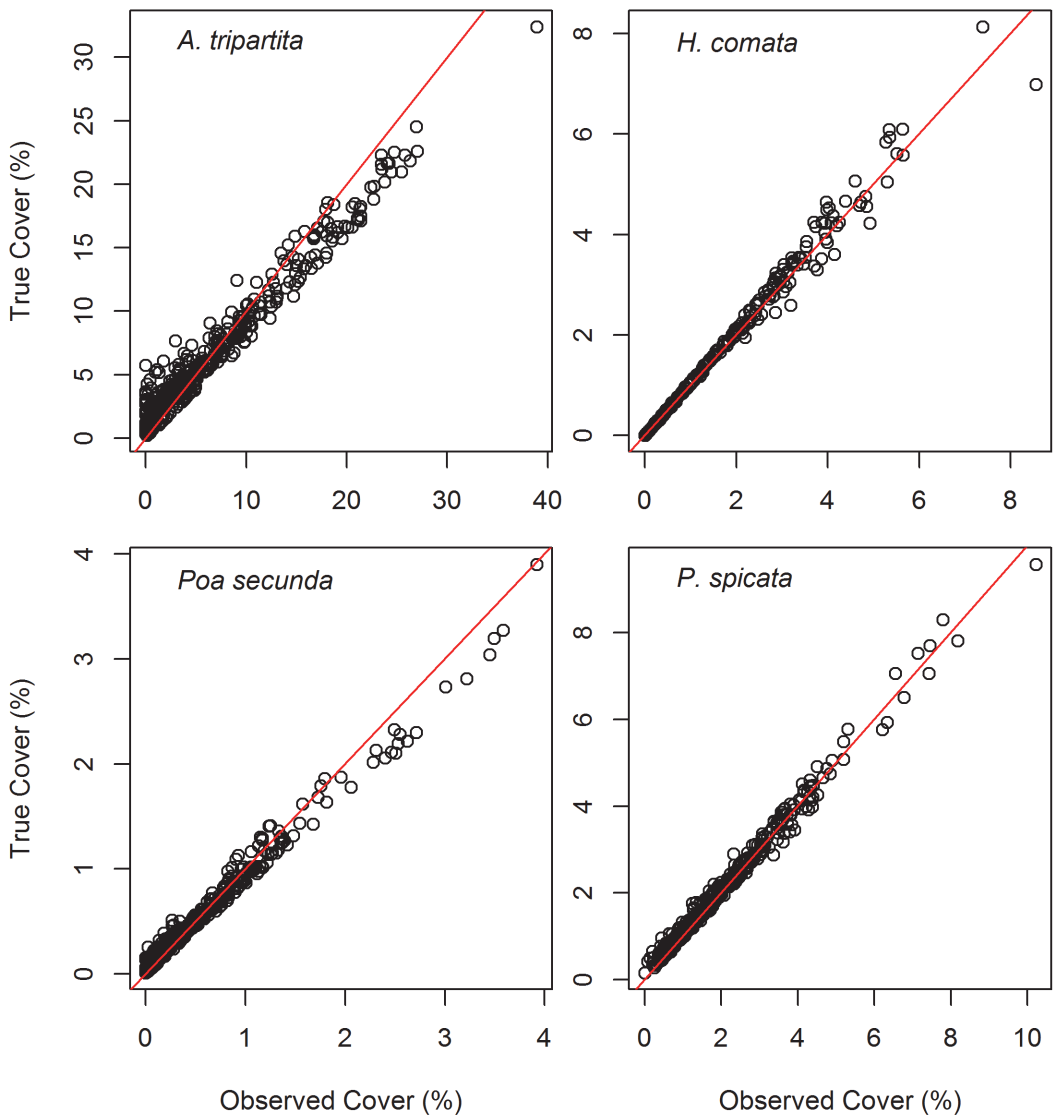

FIG. D1. Comparison between the observed vs. true quadrat-level cover (%). The true cover wasestimated from Bayesian analysis incorporating measurement error, which was obtained from our additional measurement. The red line shows a 1:1 relationship on each panel.

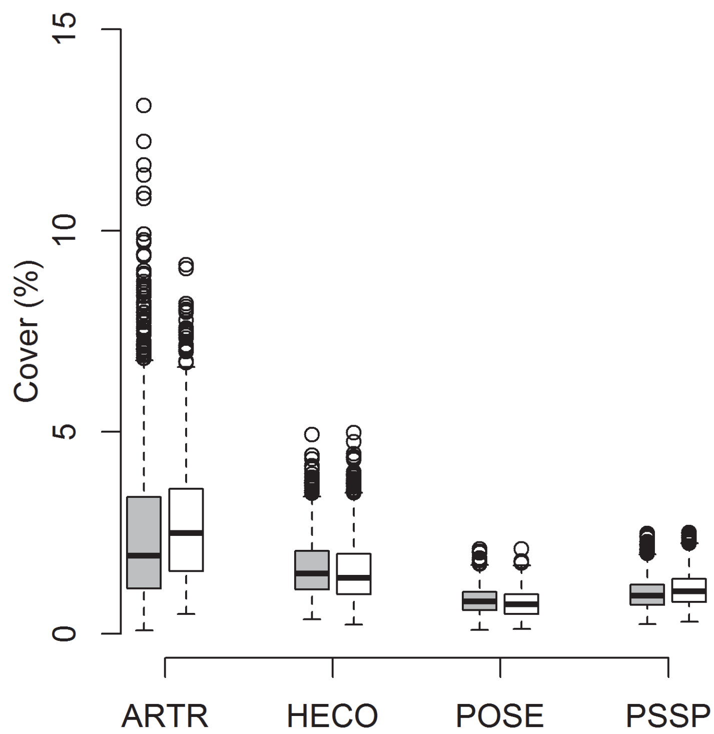

FIG. D2. Comparison of equilibrium cover (%) from IPMs simulations of the SS, Idaho community with (white bars) and without (gray bars) measurement error accounted for in the recruitment model. Incorporating measurement error had little influence on the equilibrium cover of coexisting species.

LITERATURE CITED

Freckleton, R. P., A. R. Watkinson, R. E. Green, and W. J. Sutherland. 2006. Census error and the detection of density dependence. Journal of Animal Ecology 75:837–851.