**Title: "Environmental Context Dependency in Species Interactions"**
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Supplementary Information

| Species	Predictors	θ	ρ	MAE	Const
Macrocystis	Macrocystis >1m, Laminaria, Purple urchin, Multivariate ENSO Index, Pacific Decadal Oscillation, North Pacific Gyre Oscillation, Sea Surface Temperature	4	0.784	0.357	0.410
Purple Urchin	Purple urchin, Laminaria, Macrocystis >1m, Red urchin, Multivariate ENSO Index, Pacific Decadal Oscillation, North Pacific Gyre Oscillation	4	0.860	0.310	0.741
Laminaria	Laminaria, Macrocystis >1m, Pterygophora, Purple urchin, Macrocystis <1m, Pacific Decadal Oscillation, North Pacific Gyre Oscillation	4	0.718	0.380	0.441
Young Macrocystis	Macrocystis <1m, Laminaria, Macrocystis >1m, Pterygophora, Purple urchin, Red urchin, Multivariate ENSO Index, Pacific Decadal Oscillation, North Pacific Gyre Oscillation, Sea Surface Temperature	6	0.812	0.320	0.337
Red Urchin	Red urchin, Laminaria, Macrocystis >1m, Purple urchin, Macrocystis <1m, Multivariate ENSO Index, Pacific Decadal Oscillation, North Pacific Gyre Oscillation, Significant Wave Height, Sea Surface Temperature	2	0.630	0.441	0.567
Pterygophora	Pterygophora, Macrocystis >1m, Purple urchin, Multivariate ENSO Index, Pacific Decadal Oscillation, North Pacific Gyre Oscillation, Significant Wave Height, Sea Surface Temperature	4	0.771	0.345	0.547

Table S1. Characteristics of multivariate S-map models for each of the six focal kelp forest species. Shown are the predictors for each species based on convergent cross mapping, the fitted degree of nonlinearity (θ), the correlation between observations and predictions in leave-one-out cross-validation (ρ), the mean absolute error, and the correlation between observations and predictions when only a constant predictor is used, with no nonlinearity (Const.).
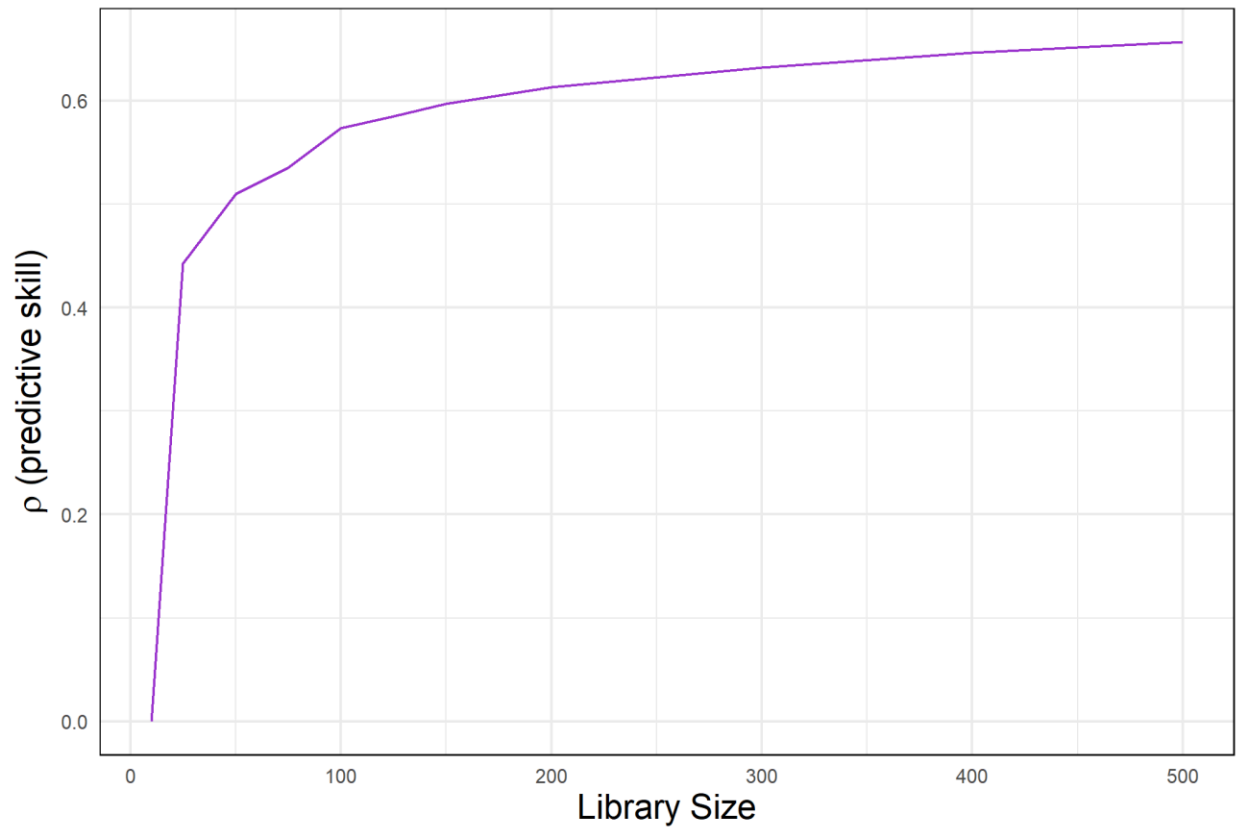
Supplemental Figures
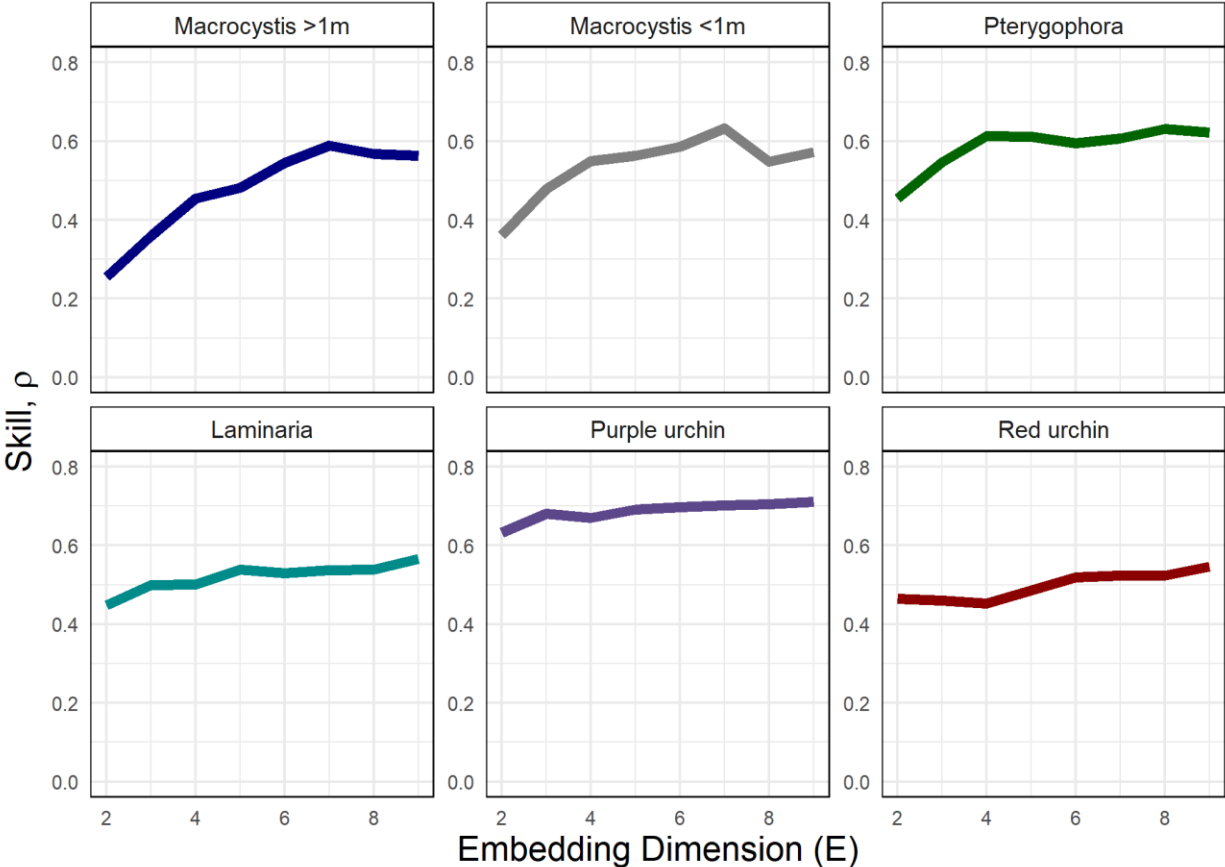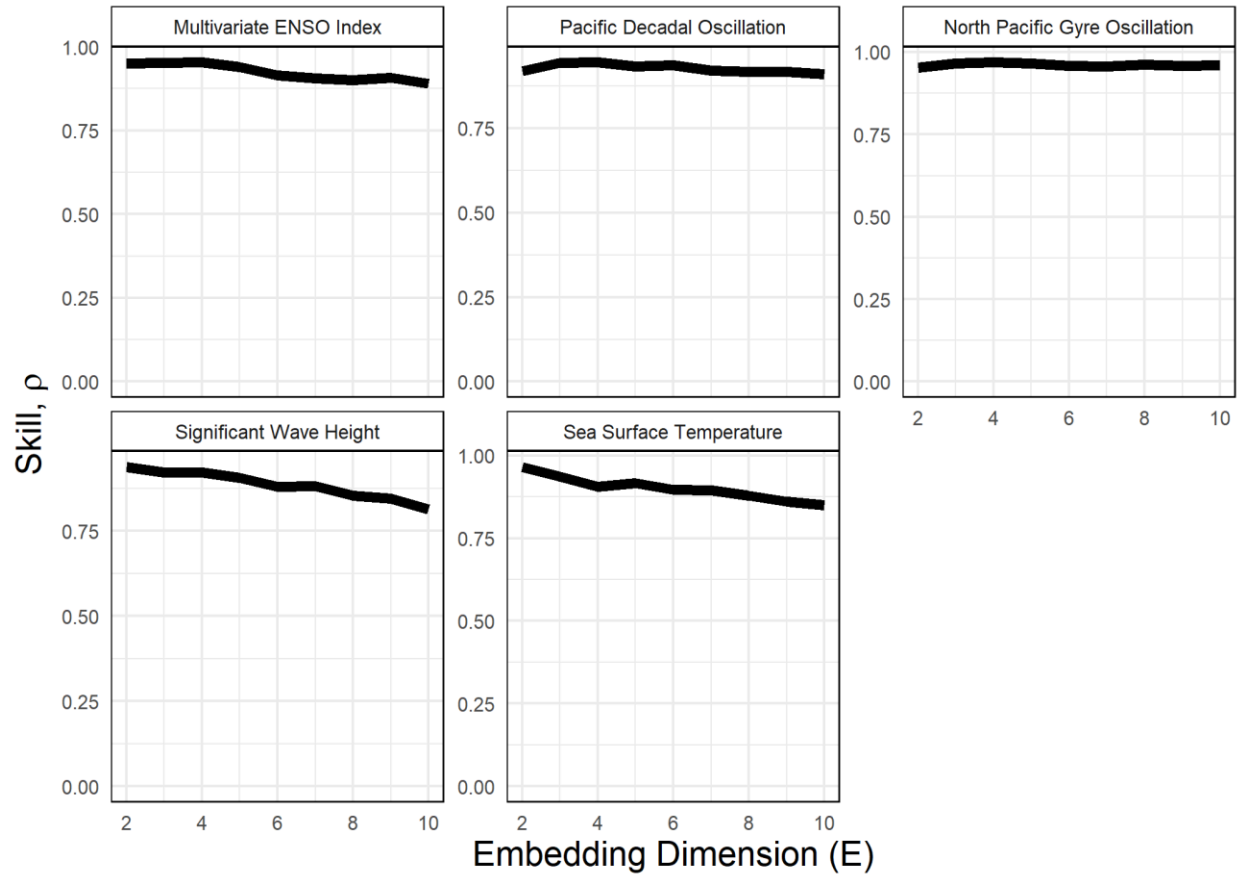
Supplemental Figure 1: Output of simplex forecasting for all species (top) and physical variables (bottom), relating embedding dimension (the number of lags of each variable to use in attractor reconstruction) to forecast skill measured as the Pearson correlation between observations and predictions. The embedding dimension that produced the best forecast skill was used in all further analyses
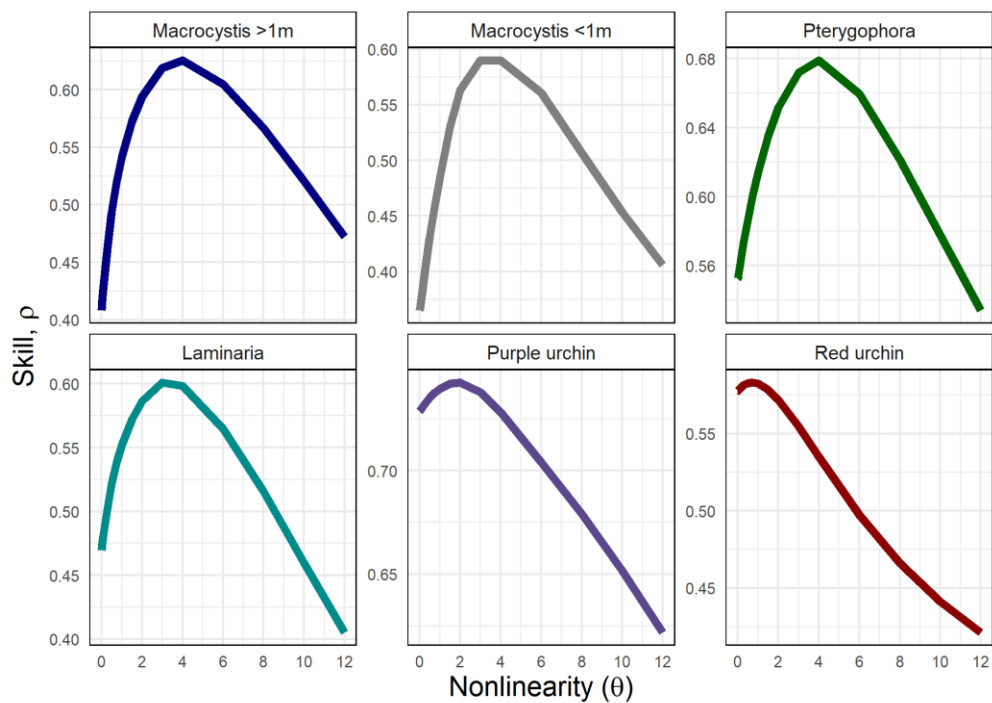
Supplemental Figure 2: Output of univariate S-map forecasting for all species, relating degree of nonlinearity (see Methods) to forecast skill measured as the Pearson correlation between observations and predictions. All species showed increased forecast skill for values of greater than zero, suggesting significant state-dependent dynamics. The value of theta that produced the best forecast skill was used in all further analyses.

Supplemental Figure 3: Example of convergent cross mapping (CCM, see Methods). Here, a library of vectors from the Macrocystis time series is used to predict contemporaneous values of the purple urchin time series. If Macrocystis significantly cross-maps purple urchin (which in this case it does), we say that purple urchin displays a significant causal signal on Macrocystis. Solid line shows the mean predictive skill at each library size, and the shaded area represents the 5th and 95th percentiles of all sampled libraries
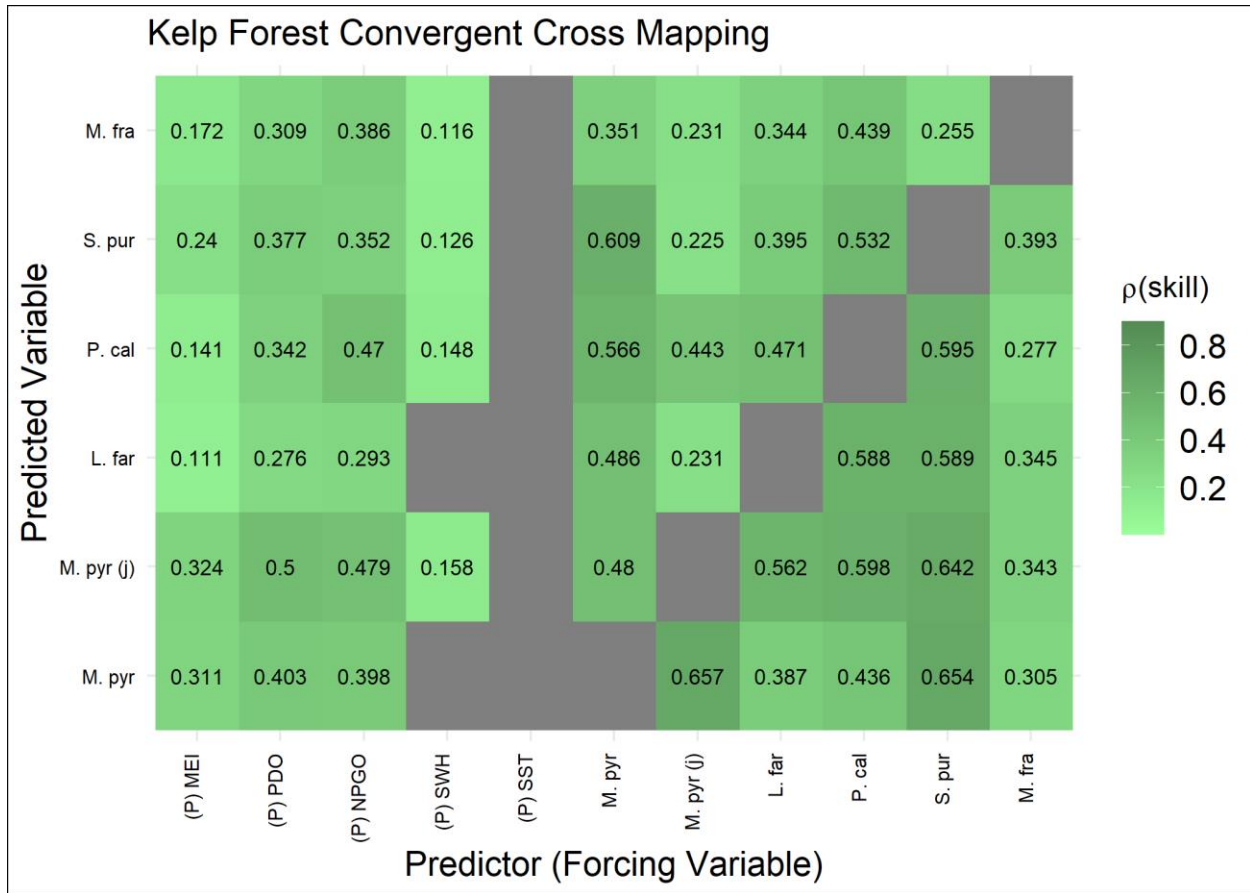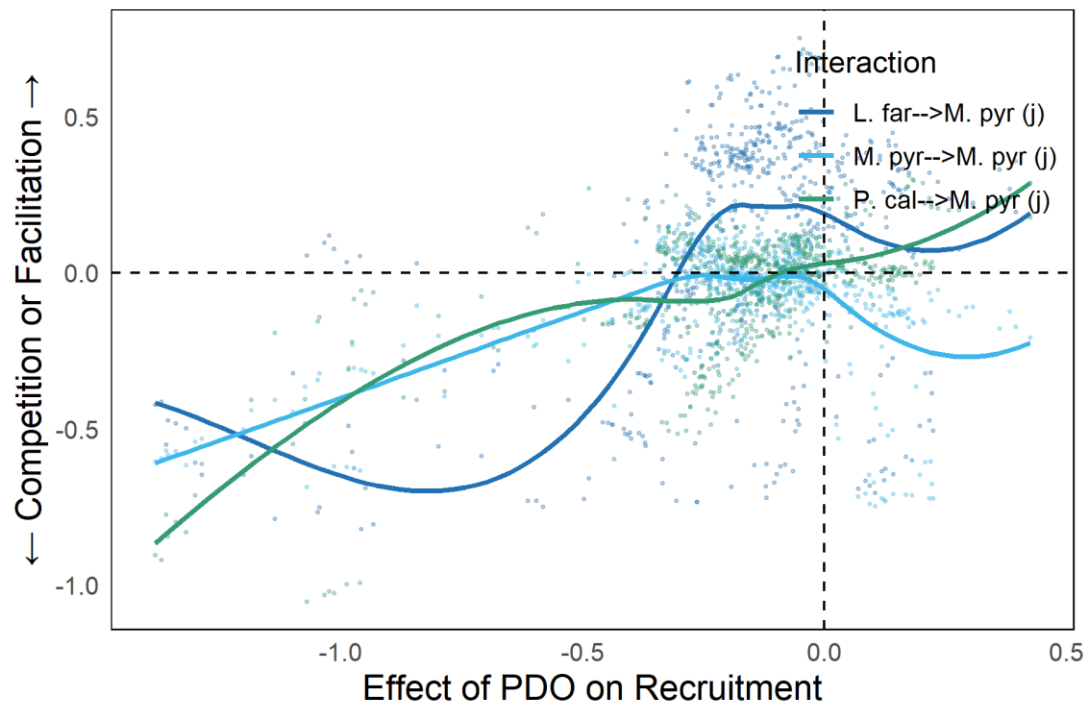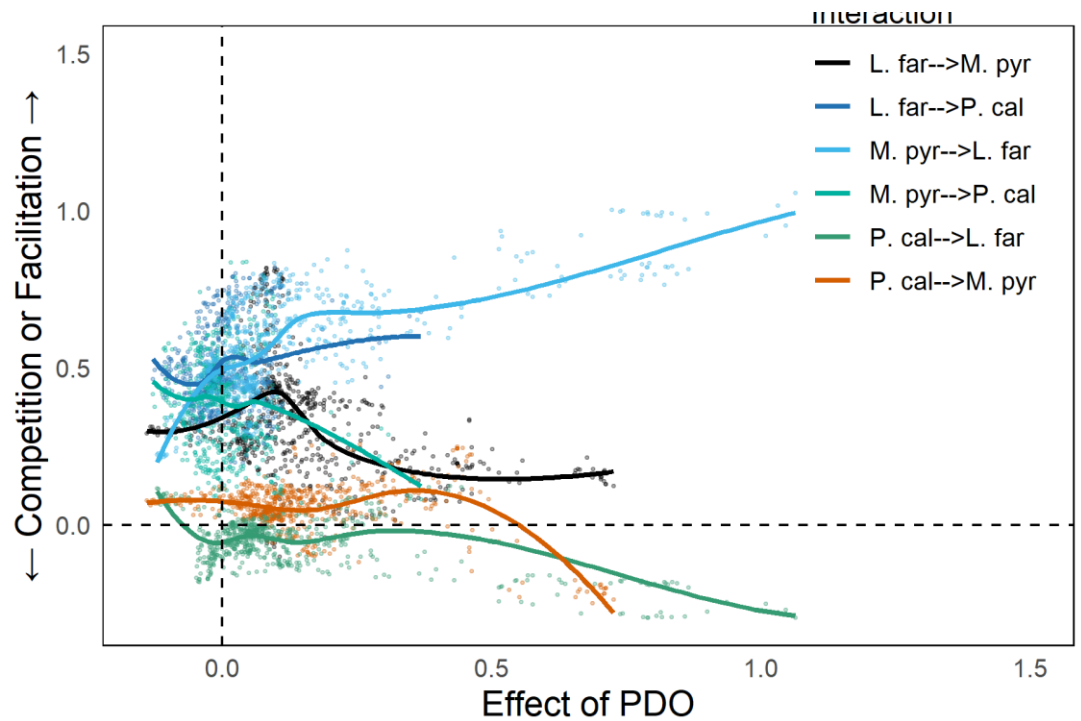
Supplemental Figure 4: The result of applying CCM to all species-species and species-environment interactions. Putative forcing variables are on the x-axis, while predicted variables are on the y-axis. Numbers are the mean predictive skill at library size 500. All non-significant links are grey. Aligns with Figure 2 in the main text. Species abbreviations: M. pyr: Macrocystis pyrifera; L.far: Laminaria farlowii; P.cal: Pterygophora californica; M.fra: Mesocentrotus franciscanus; S.pur: Strongylocentrotus purpuratus. Physical drivers: NPGO: North Pacific Gyre Oscillation; MEI: Multivariate El Niño Index; PDO: Pacific Decadal Oscillation; SST: Sea surface temperature; SWH: Significant wave height.
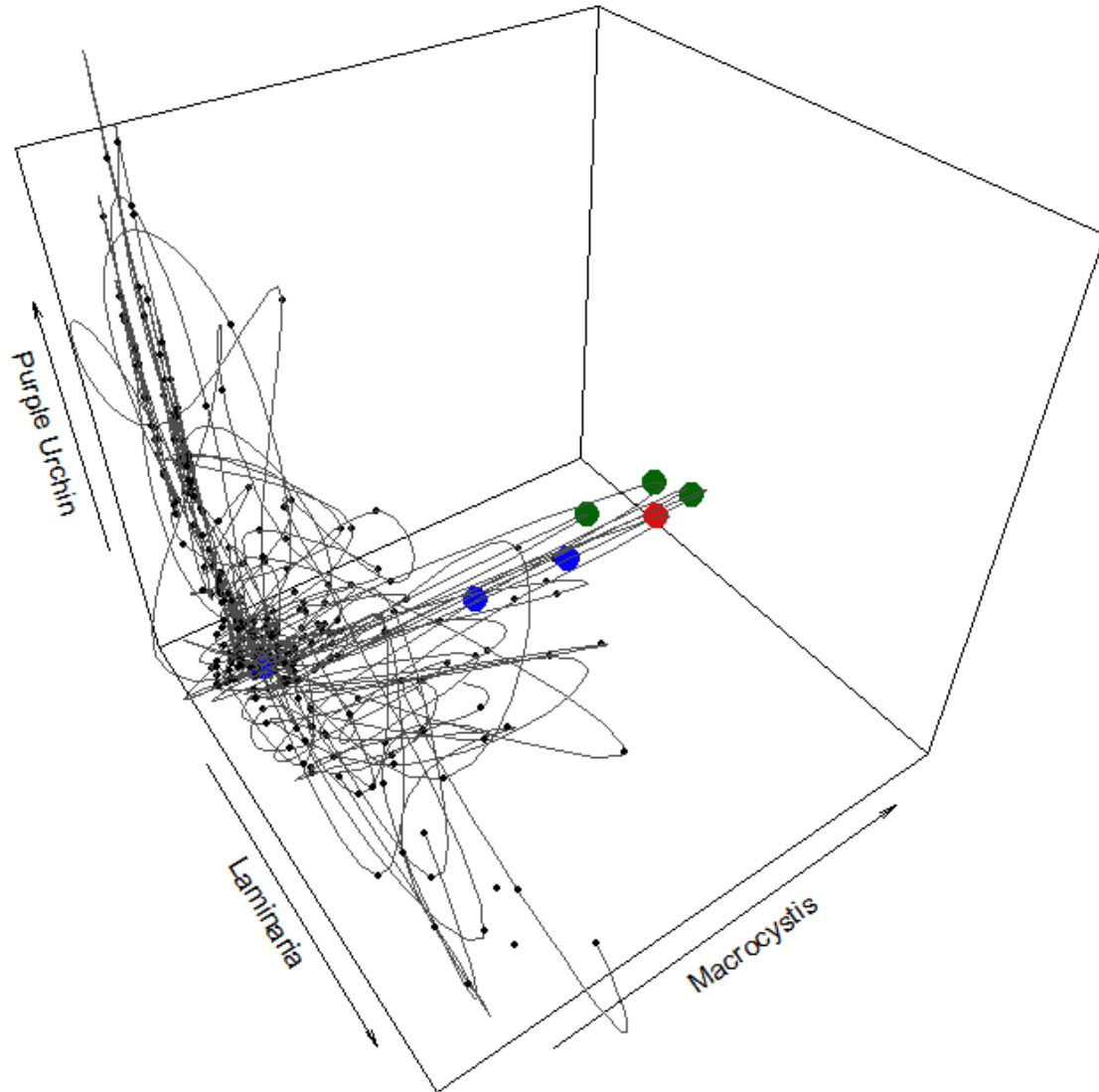
Supplemental Figure 5: An example multivariate attractor using real data from San Nicolas Island. To make predictions for the red point using simplex projection, we take the average of the nearest neighbors (in this case, the 3 green points), projected forward one step in time. For an S-map model, all points in the state space would be used, with each point exponentially weighted by its distance to the target (red) point.
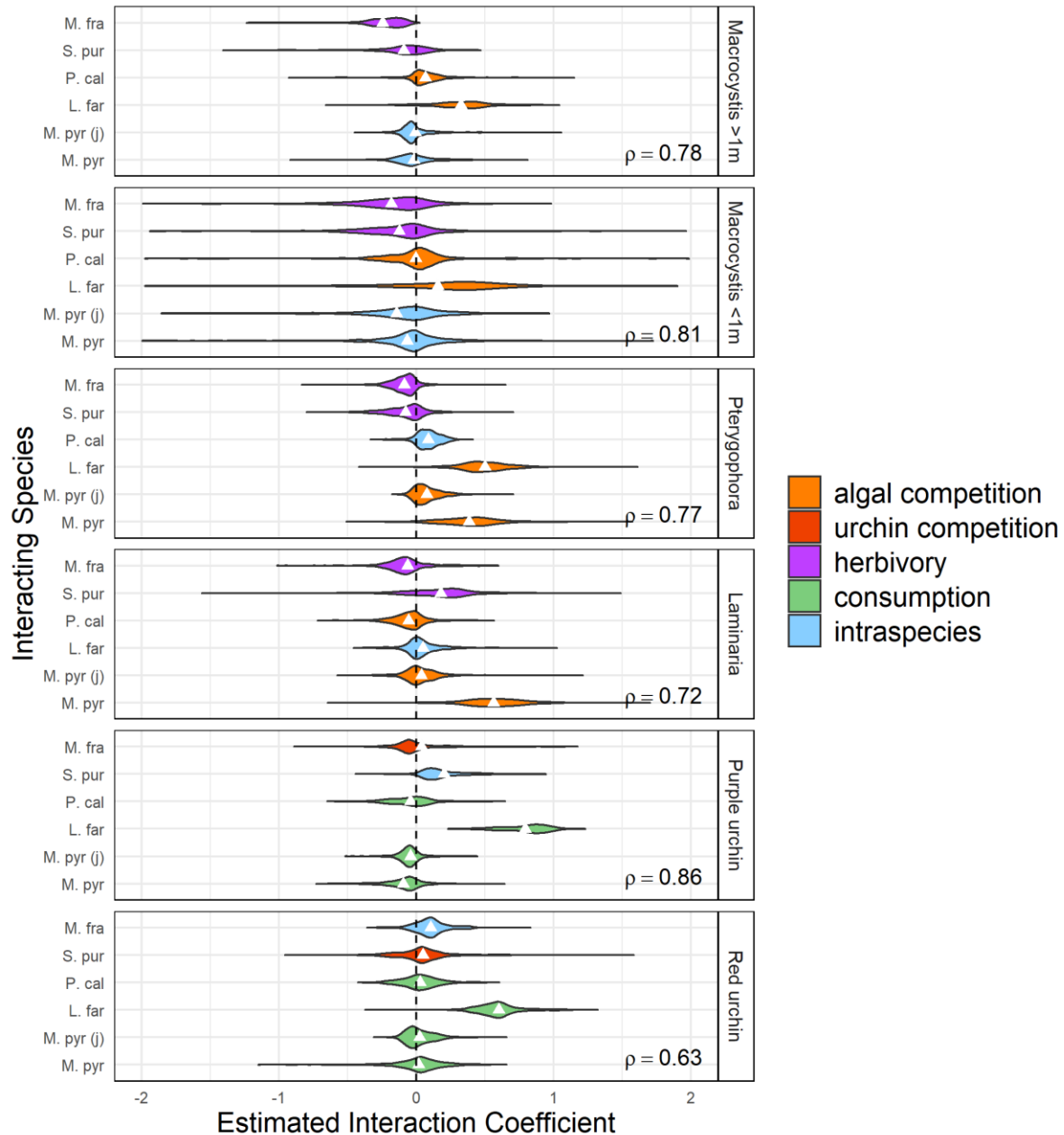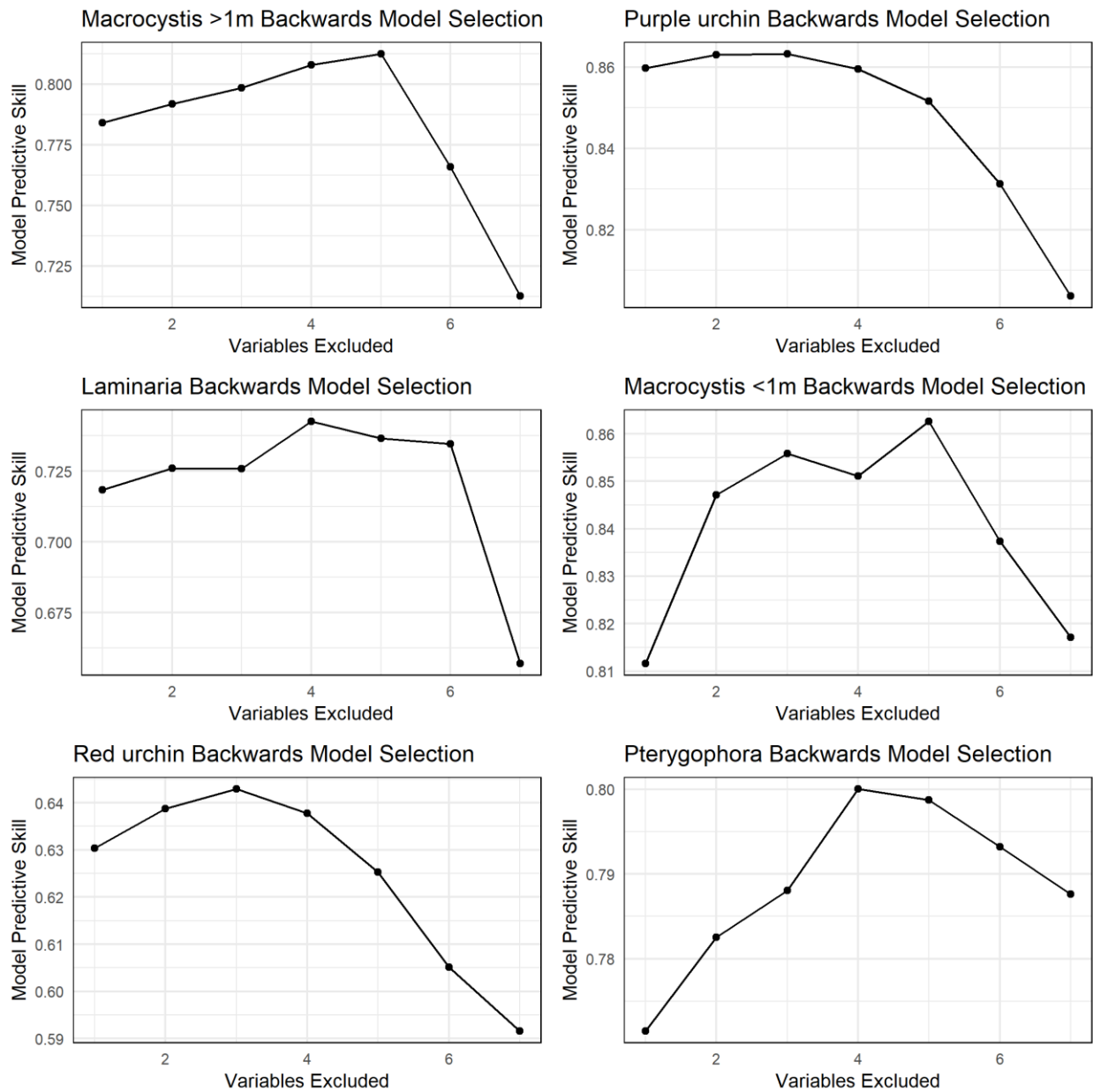
Supplemental Figure 6: Violin plots of estimated species interaction strengths from main-text S-map models for the five focal species (panels top to bottom): Macrocystis adults, Macrocystis juveniles, Pterygophora, Laminaria, purple urchin, and red urchin. Each colored box represents the distribution of all estimated interaction coefficients (x-axis) of an interacting or forcing species (left y-axis) on the modeled species across all data for a given model (white triangles: mean; vertical lines: median). Each box represents 500-520 estimated interactions. Correlation coefficient between predictions and observations denoted for each model. Color denotes hypothesized interaction type, including interspecific competition (between algae species or between urchin species), herbivory (urchin effect on algae), consumption (algae effect on urchins), and intraspecies interaction (the estimated interaction of a species with itself). Abbreviations: S. pur, Strongylocentrotus purpuratus; P cal., Pterygophora californica; M. pyr, Macrocystis pyrifera; M. fra, Mesocentrotus franciscanus; L. far, Laminaria farlowii.

Supplemental Figure 7: Variation in the strength of interactions between algae species relative to the effect of the PDO. Top: Interacting effects of PDO and competition on mature *Macrocystis, Laminaria,* and *Pterygophora*. Bottom: Effect of *Macrocystis, Laminaria,* and *Pterygophora* relative to effect of the PDO on *Macrocystis* recruitment. Points indicate species interaction strengths averaged amongst the 30 nearest state-space neighbors. Solid lines are loess smooths.
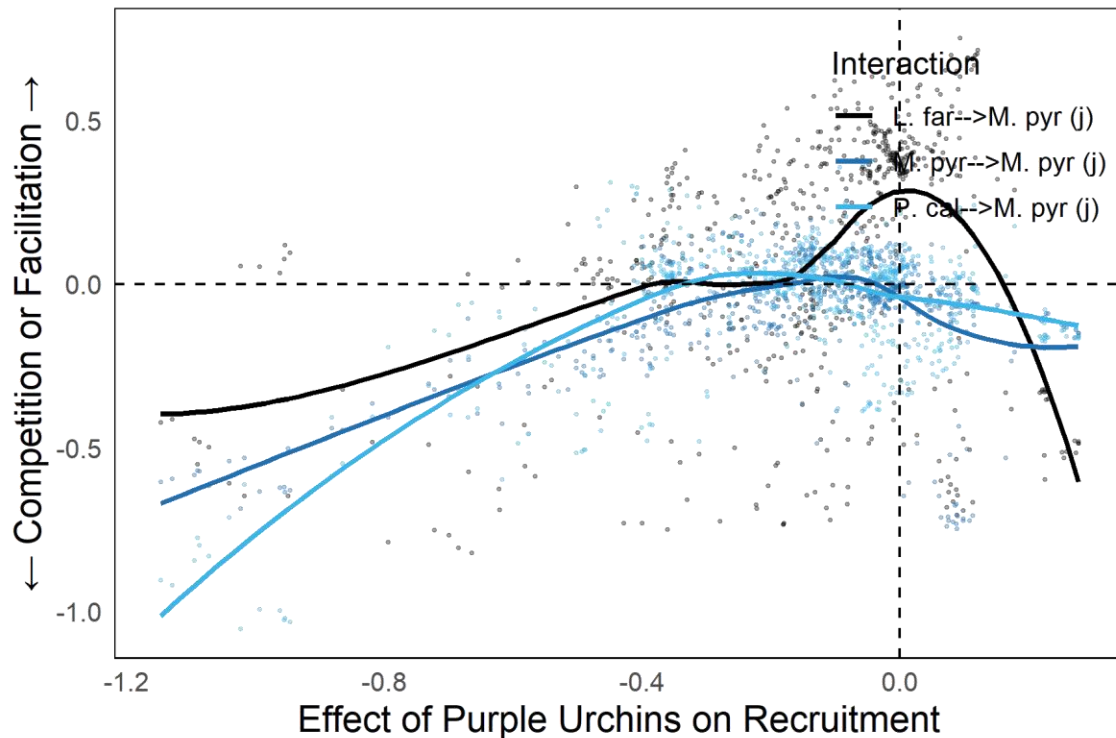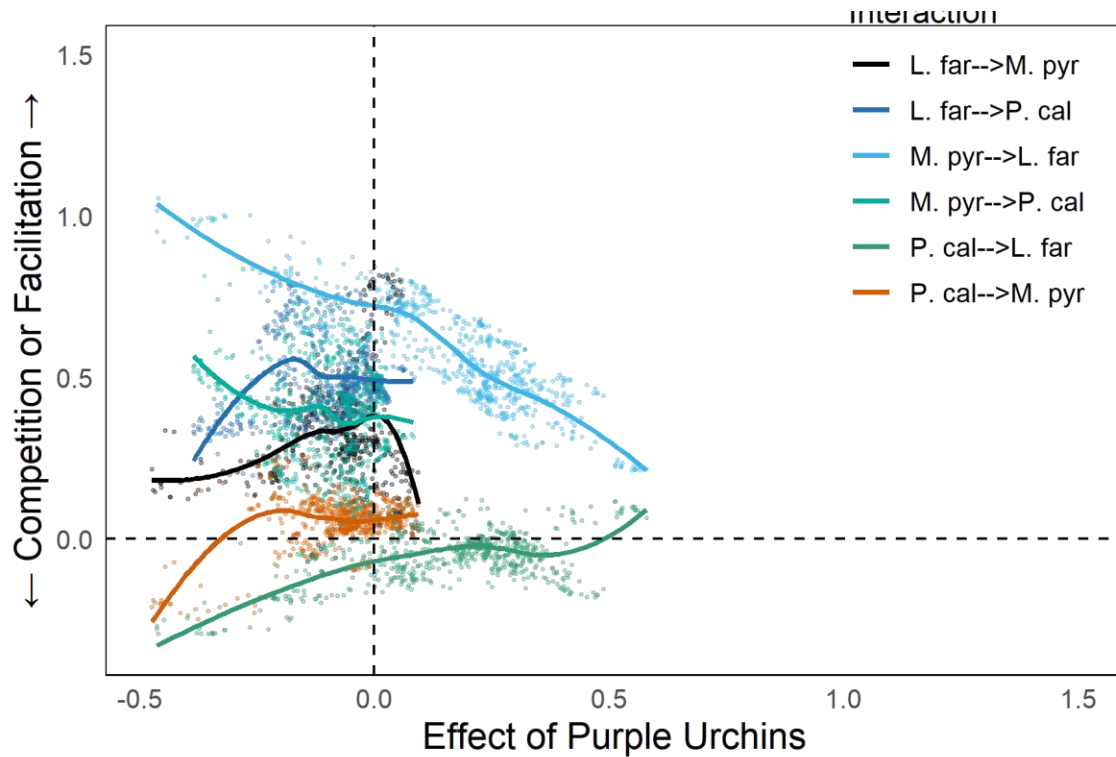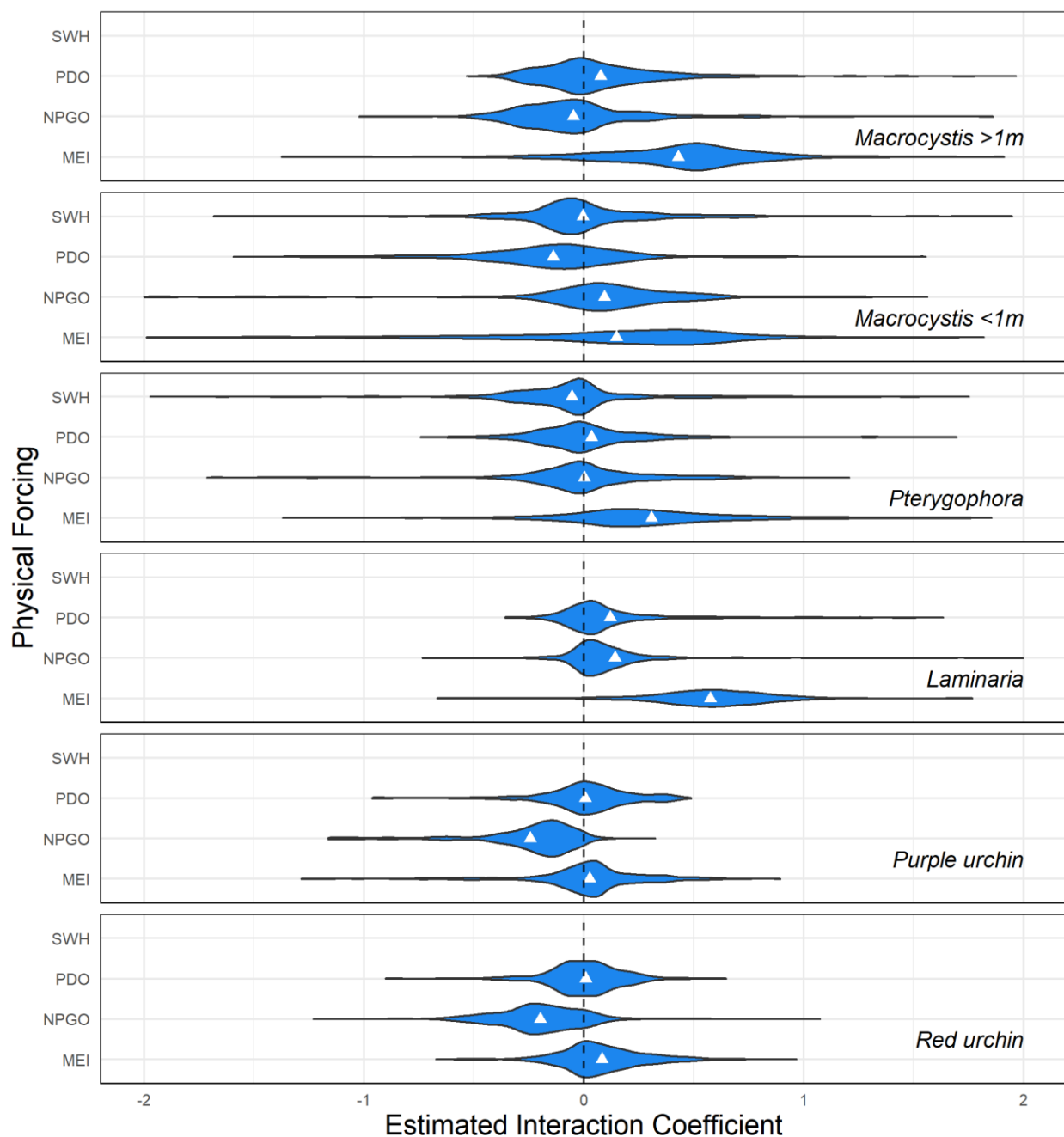
Supplemental Figure 8: Variation in the strength of interactions between algae species relative to the effect of presumptive herbivory by purple urchin *Strongylocentrotus purpuratus*. Top: Interacting effects of herbivory and competition on mature *Macrocystis, Laminaria,* and *Pterygophora*. Bottom: Effect of *Macrocystis, Laminaria,* and *Pterygophora* relative to effect of herbivory on *Macrocystis* recruitment. Points indicate species interaction strengths averaged amongst the 30 nearest state-space neighbors. Solid lines are loess smooths.
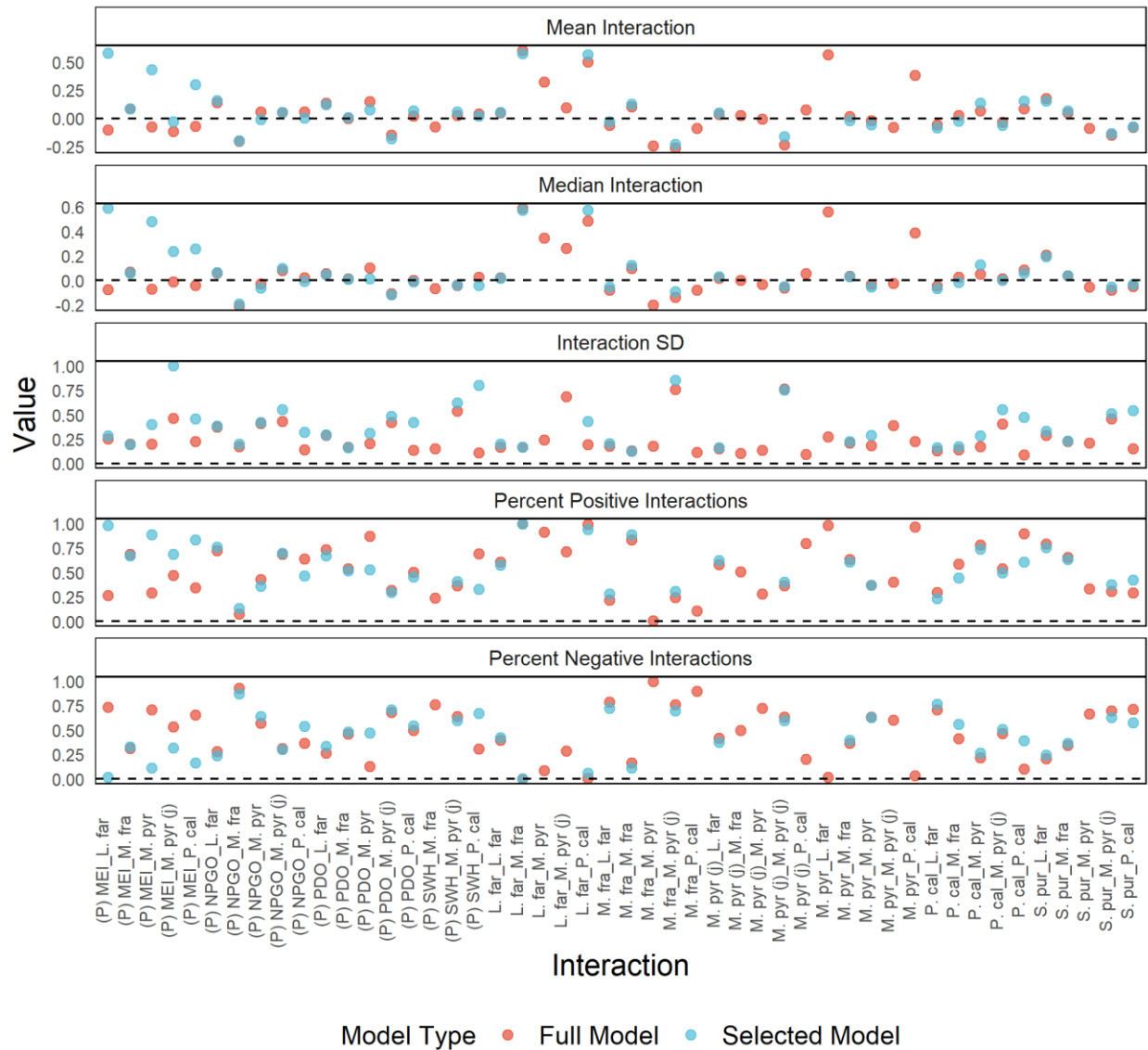
Supplemental Figure 9: Backwards model selection for multivariate models. The selection process for each species' model began with the full suite of inferred causal variables used in the main analysis. Then, variables were sequentially removed based on whether the exclusion of that variable improved model predictive skill. Note the different scales on the x and y axes because not all model selections began with the same number of variables.
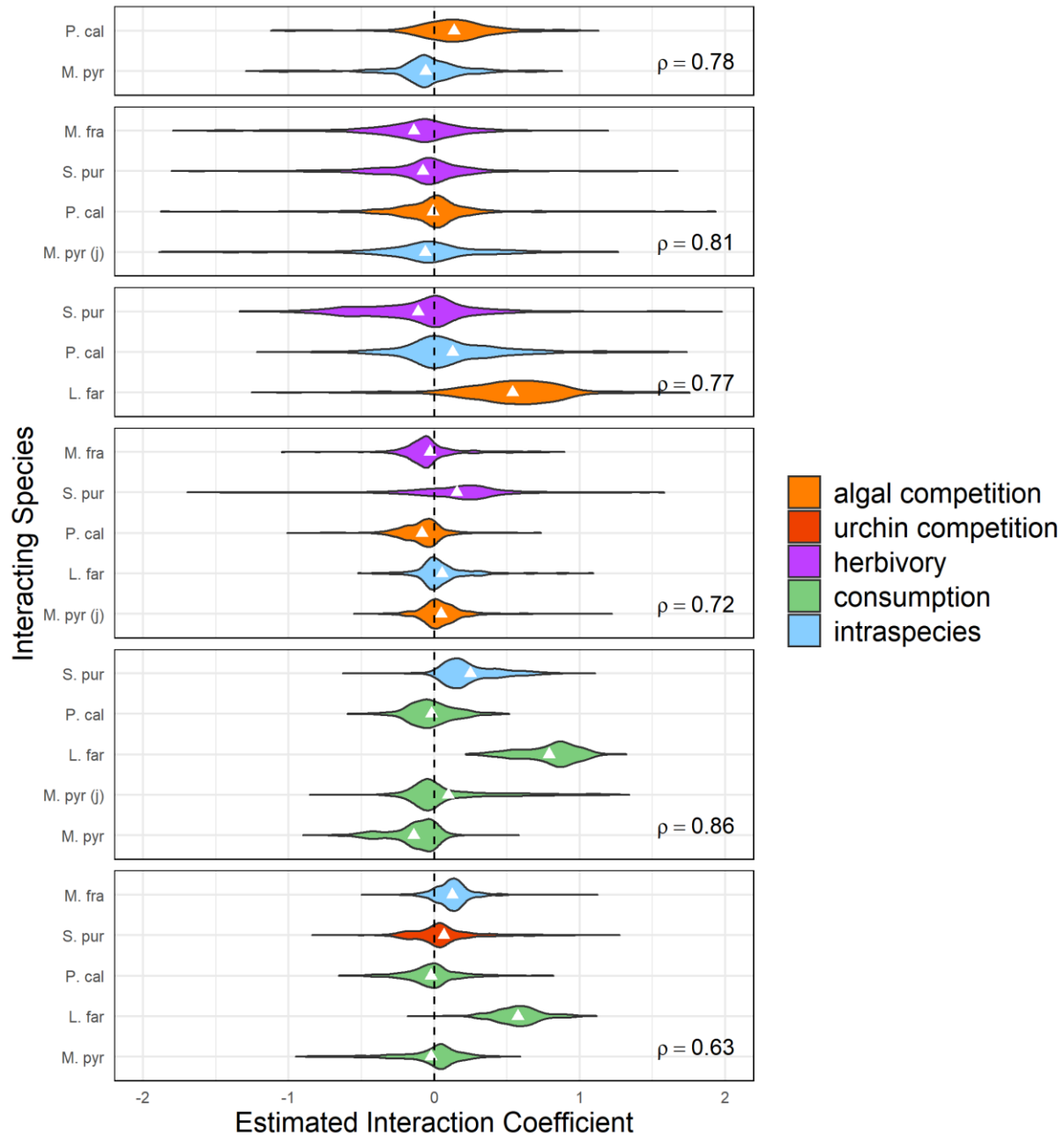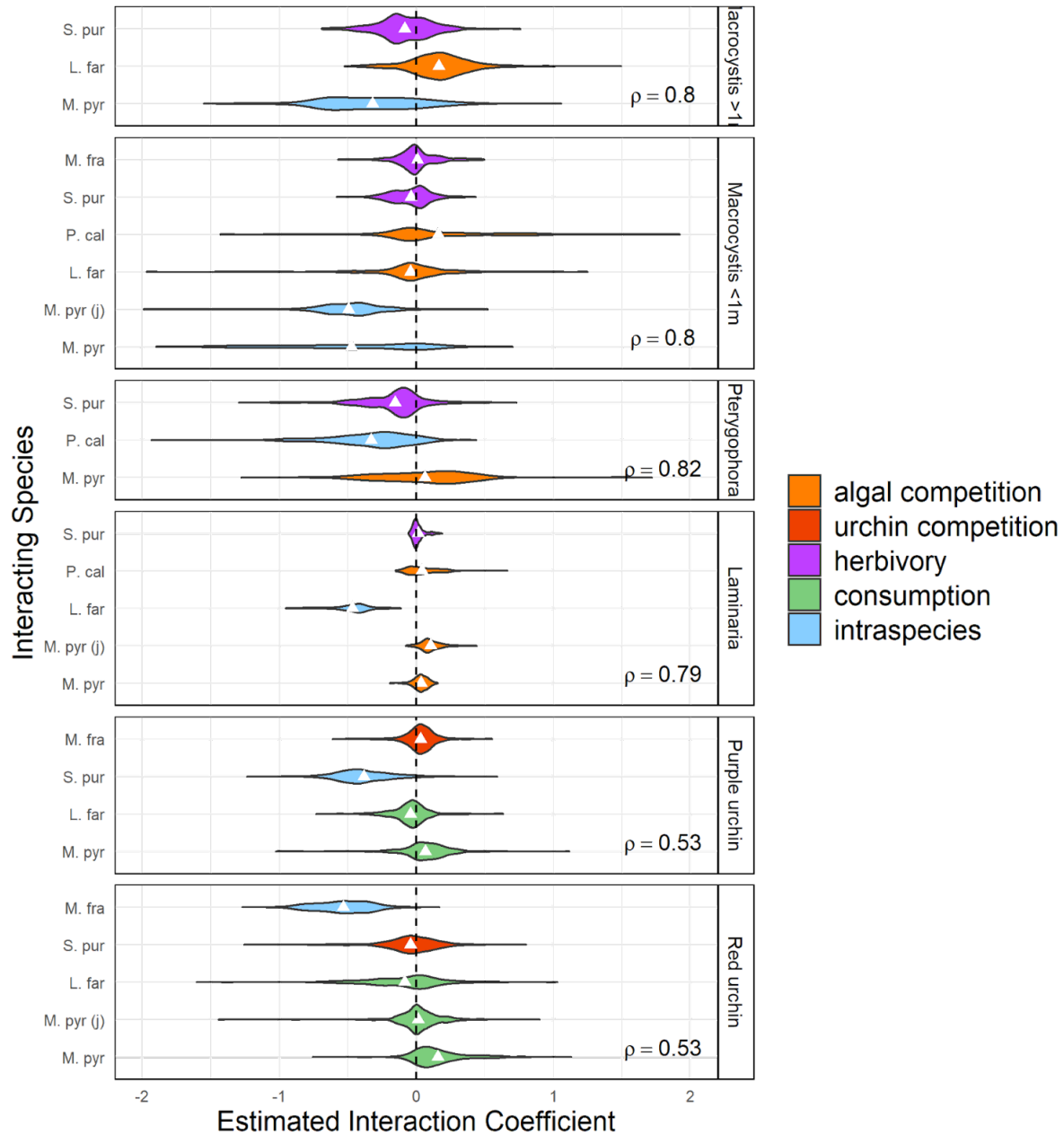
Supplemental Figure 10: Violin plots of estimated species interaction strengths from backwards-selected S-map models for the five focal species (panels top to bottom): Macrocystis adults, Macrocystis juveniles, Pterygophora, Laminaria, purple urchin, and red urchin. Each colored box represents the distribution of all estimated interaction coefficients (x-axis) of an interacting or forcing species (left y-axis) on the modeled species across all data for a given model (white triangles: mean; vertical lines: median). Each box represents 500-520 estimated interactions. Correlation coefficient between predictions and observations denoted for each model. Color denotes hypothesized interaction type, including interspecific competition (between algae species or between urchin species), herbivory (urchin effect on algae), consumption (algae effect on urchins), and intraspecies interaction (the estimated interaction of a species with itself). Abbreviations: S. pur, Strongylocentrotus purpuratus; P cal., Pterygophora californica; M. pyr, Macrocystis pyrifera; M. fra, Mesocentrotus franciscanus; L. far, Laminaria farlowii.

Supplemental Figure 11. Violin plots of estimated effects of physical variables on focal species from backwards-selected S-map models (panels top to bottom): Macrocystis adults, Macrocystis juveniles, Pterygophora, Laminaria, purple urchin, and red urchin. Empty rows indicate physical variables that were not included in specific species models because of a lack of an inferred causal signal from our CCM. Abbreviations: SWH, significant wave height; SST, sea surface temperature; PDO, Pacific Decadal Oscillation; NPGO, North Pacific Gyre Oscillation; MEI, Multivariate ENSO Index.
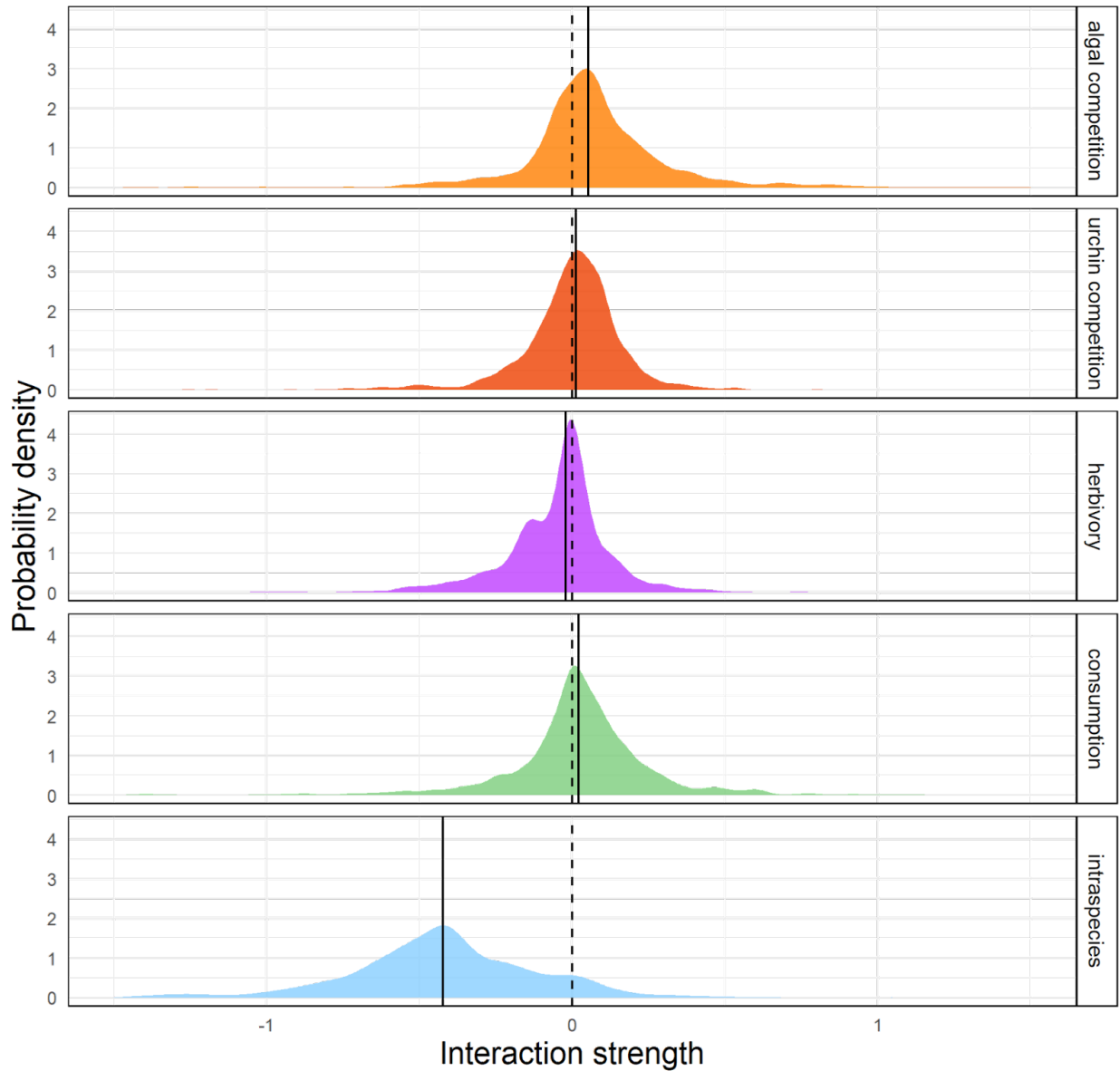
Supplemental Figure 12: Comparison of full with backward-selected models. All estimated interactions across the x-axis, in the form predictor-predicted. Top to bottom: mean, median, standard deviation, percent of estimated interactions that were positive, percent of estimated interactions that were negative. For interactions that were excluded as a result of backwards model selection (i.e., the predictor species was removed from multivariate embedding), only full model values are shown. Abbreviations: S. pur, Strongylocentrotus purpuratus; P cal., Pterygophora californica; M. pyr, Macrocystis pyrifera; M. fra, Mesocentrotus franciscanus; L. far, Laminaria farlowii.

Supplemental Figure 13: Violin plots of estimated species interaction strengths from S-map models from first-differenced abundance data for the five focal species (panels top to bottom): Macrocystis adults, Macrocystis juveniles, Pterygophora, Laminaria, purple urchin, and red urchin. Each colored box represents the distribution of all estimated interaction coefficients (x-axis) of an interacting or forcing species (left y-axis) on the modeled species across all data for a given model (white triangles: mean; vertical lines: median). Each box represents 500-520 estimated interactions. Correlation coefficient between predictions and observations denoted for each model. Color denotes hypothesized interaction type, including interspecific competition (between algae species or between urchin species), herbivory (urchin effect on algae), consumption (algae effect on urchins), and intraspecies interaction (the estimated interaction of a species with itself). Abbreviations: S. pur, Strongylocentrotus purpuratus; P cal., Pterygophora californica; M. pyr, Macrocystis pyrifera; M. fra, Mesocentrotus franciscanus; L. far, Laminaria farlowii.

Supplemental Figure 14. Smoothed kernel density histograms of all estimated interactions by type from S-map models with first-differenced data. From top to bottom: Algal competition, urchin competition, herbivory, consumption (i.e., urchin effect on algae), intraspecies (a species' effect on itself). Solid lines denote medians across all estimated interactions of that type.