Climatic niches and functional strategy jointly structure California remnant grasslands across a latitudinal gradient

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Background:

California grassland restoration efforts often select well-tested plants (~0.26% of the state's native grassland species) to achieve targets[1]. Preferential species selection may exclude less-known species that are well suited to site-specific conditions or maximizing functional diversity.

Plant functional traits and species' distribution data can inform species selection for restoration informing community assembly processes across environmental gradients. In turn, this may help match less-known species to site-specific conditions.

Research objectives and questions:

How are plant communities across three coastal California grasslands driven primarily by taxonomic turnover and by shared ecological strategies?

- How does species composition change across remnant grassland sites?
- Do plant functional traits or species' environmental niches explain compositional changes?
- Do environmental niches help explain how functionally different communities are from each other?

Methods:

Study sites & sampling:

- Three remnant grasslands across a ~1000 km latitudinal gradient (Humboldt, Sonoma, San Luis Obispo Counties)
- Species composition and percent cover in 45 quadrats per site

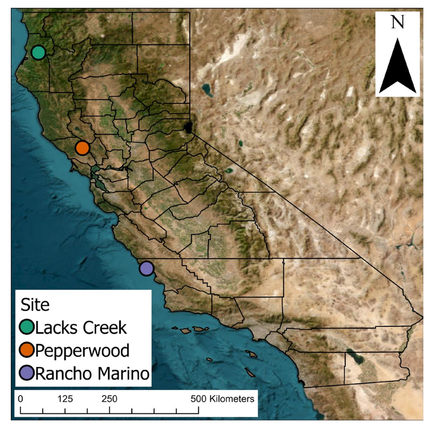

Figure 1: Sampled field site in California

Environmental niche and functional trait indices:

- Species occurrence data within California Floristic Province (CFP) from Global Biodiversity Information Facility (GBIF)
- Calculated species' medians for 6 key climate variables: annual precipitation, mean annual temperature, precipitation seasonality, temperature seasonality, mean annual vapor pressure deficit, and maximum annual vapor pressure deficit from Climatologies at High resolution for the Earths Land Surface Areas (CHELSA)
- Measured key functional traits related to ecological strategies: specific leaf area (SLA), leaf dry matter content (LDMC), leaf lobedness, and plant height
- We Calculated quadrat-level Community-Weighted Means (CWMs) for both functional traits and climatic niche indices by weighting each species' respective value by its relative abundance

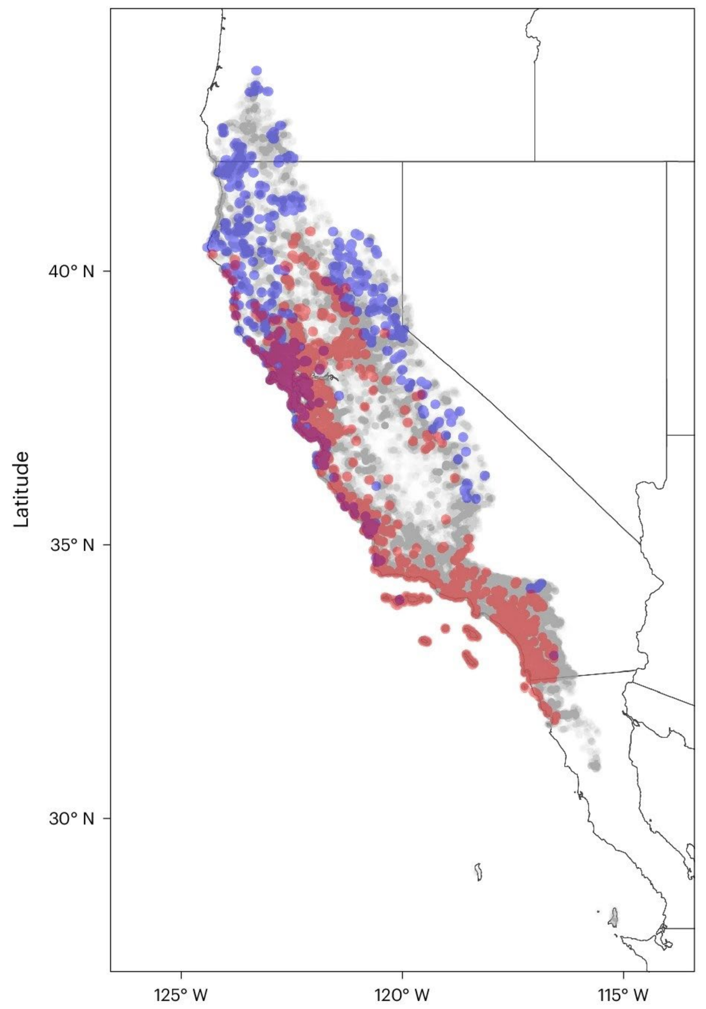

Figure 2: Occurrence data for *Stipa pulchra* and *Danthonia californica* in climatic of annual precipitation and mean annual temperature across the California Floristic Province.[2]

Statistical analyses:

- We assessed how taxonomic composition is explained by trait CWMs and niche index CWMs via PERMANOVA and NMDS.
- We assessed how functional composition is explained by niche index CWMs via PERMANOVA and NMDS

Results:

How does species composition change across remnant grassland sites?

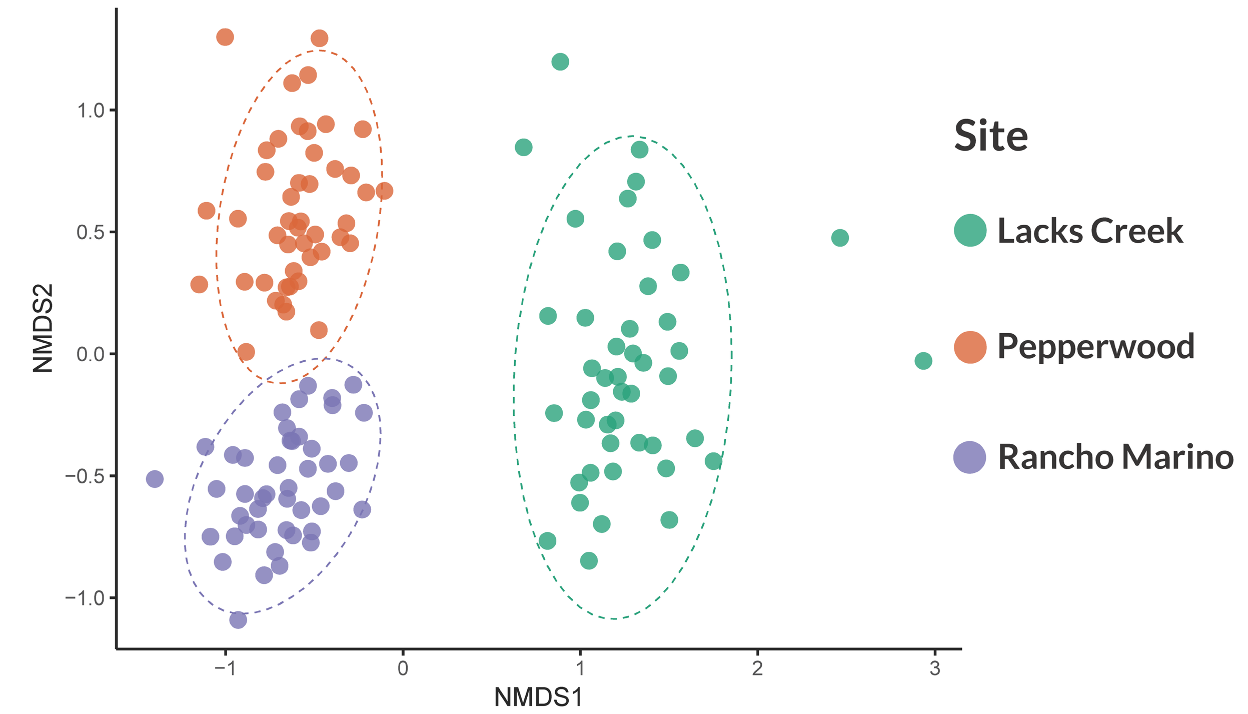

Figure 2: Non-metric Multidimensional Scaling (NMDS) ordination of taxonomic community composition based on Bray-Curtis dissimilarity. Points represent individual quadrats. Ellipses represent 95% confidence intervals around the site centroids.

- Sites have distinct species pools (SES =15.266, $p < 0.001$).
- Community weighted traits and niche indices cumulatively explain ~43% of compositional differences
- Niche indices cumulatively explain ~35% of functional dissimilarity

Do environmental niches help explain how functionally different communities are from each other?

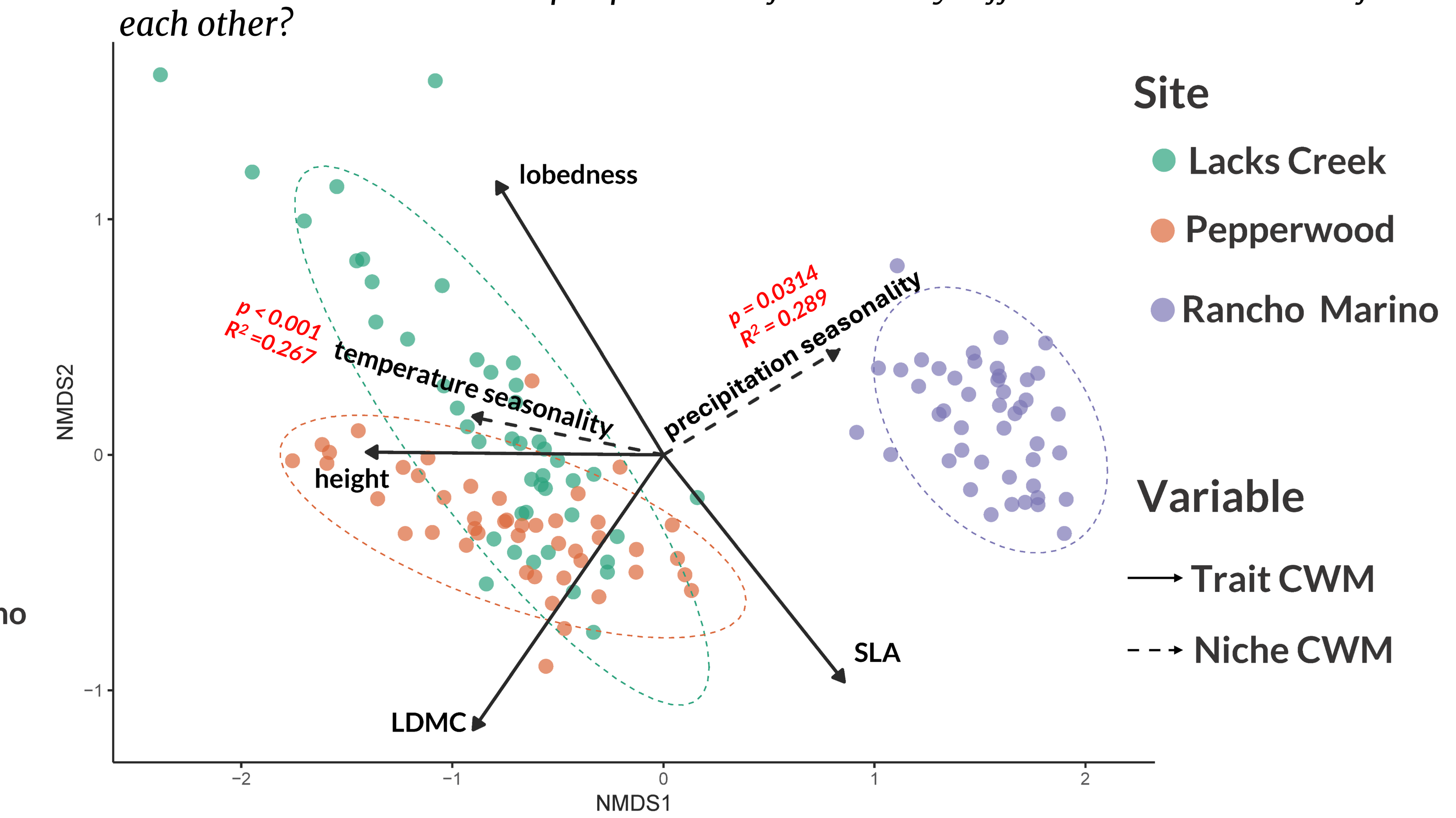

Figure 3: NMDS plot showing site differentiation in community-weighted mean (CWM) trait space (Euclidean distance). Points (quadrats) are colored by site, with 95% confidence ellipses. Solid vectors indicate the direction of key CWM traits (SLA, LDMC, height, lobedness) structuring the ordination axes. Dashed vectors represent Niche CWMs (temperature and precipitation seasonality) that are significantly correlated ($p < 0.05$) with quadrat positions in trait space.

- Dominant species converge on LDMC (SES = -3.726, $p = 0.002$) but diverge on height (SES = 2.41, $p = 0.036$) and lobedness (SES = 4.082, $p = 0.002$) within sites
- Both temperature seasonality ($p < 0.001$, $R^2 = 0.267$) and precipitation seasonality ($p = 0.0314$, $R^2 = 0.289$) niche indices best explain overall functional composition.

Do plant functional traits or species' environmental niches explain compositional changes?

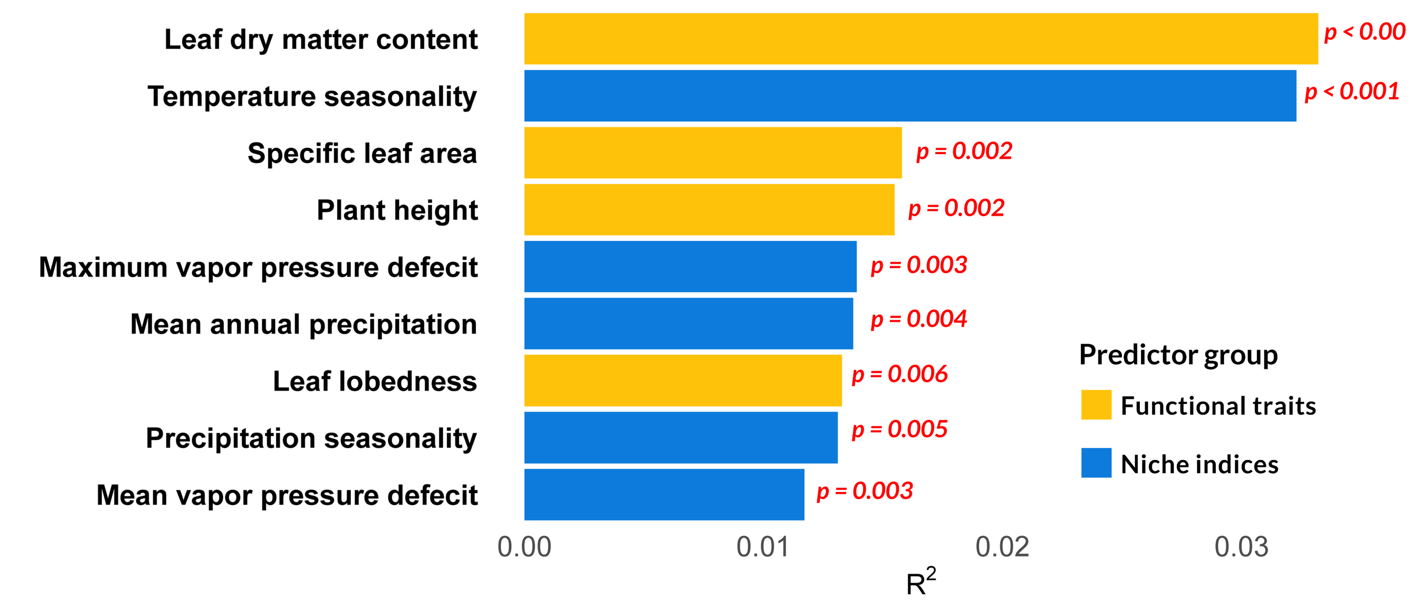

Figure 3: Relative importance of functional traits and climatic niches in explaining taxonomic composition. Bars show marginal R^2 (unique variance explained) from PERMANOVA predicting Bray-Curtis dissimilarity using trait CWMs (yellow) and niche index CWMs (blue). Significant p-values are shown in red (n=5000 permutations).

Do environmental niches help explain how functionally different communities are from each other?

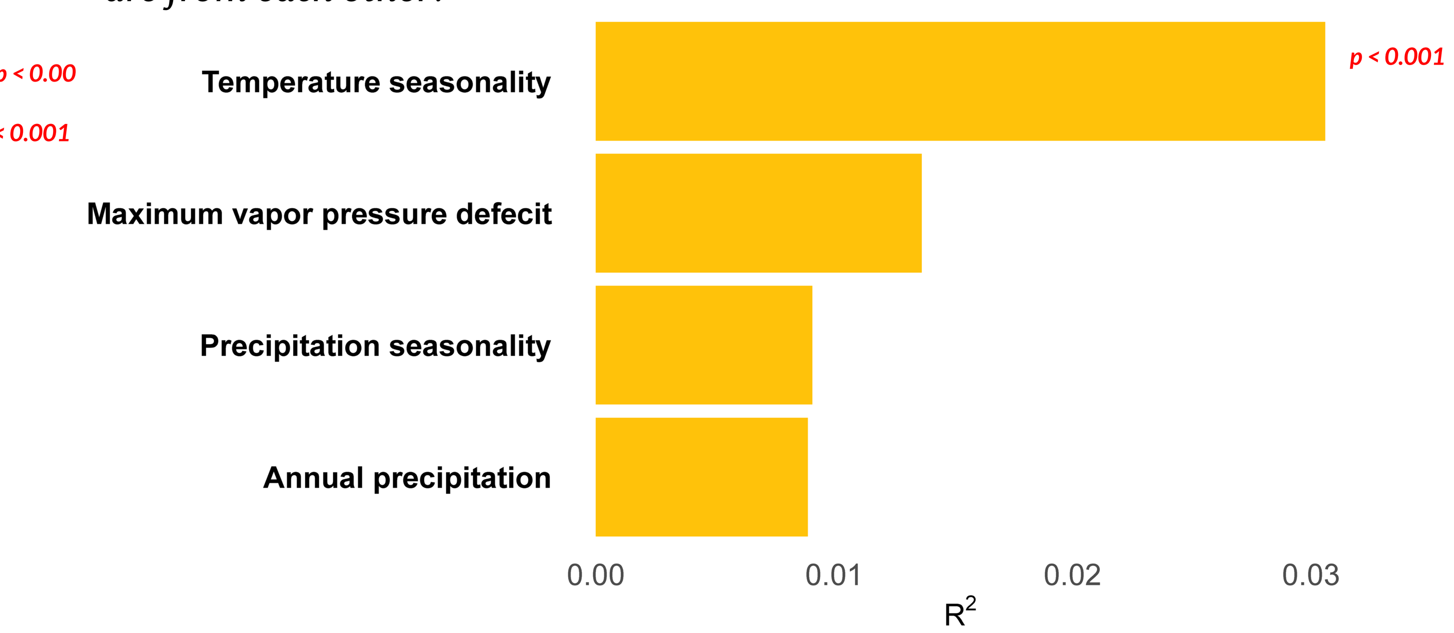

Figure 4: Marginal R^2 values from PERMANOVA showing the unique variance in abundance-weighted functional compositional differences (abundance-weighted functional MNTD turnover) explained by selected climatic niche index CWMs. Significant p-values are shown in red (n=10000 permutations).

Implications:

- Taxonomically distinct communities share functional composition
- Inferred community niches and measured functional traits uniquely explain a significant portion of compositional differentiation
- Environmental filtering may lead to similarity in key adaptive traits like LDMC while competition or fine-scale niche partitioning may promote differentiation in traits related to resource capture (height, SLA, and lobedness)
- Potential restoration species can be evaluated by matching both their realized climatic niche and functional traits (ecological strategy) to meet specific site conditions and goals

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References:

1. Luong, J. C. et al., Lessons learned from an interdisciplinary evaluation of long-term restoration outcomes on 37 restored coastal grasslands in California. Biological Conservation 280, 109956 (2023).

2. Zhu, K. et al. Rapid shifts in grassland communities driven by climate change. Nat Ecol Evol 1–13 (2024) doi:10.1038/s41559-024-02552-z.