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Calculating the predictability of climate change: the effect of climate change on moth species in the Pacific Northwest varies among functional groups.

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Introduction

- Climate change has driven shifts in phenology and distribution for many species. These effects are often idiosyncratic[3] and it remains unclear whether they vary consistently among functional groups, limiting our ability to draw broad conclusions about how climate change affects species[4].
- Previous studies have indicated that Lepidoptera (butterflies and moths) are sensitive to climate change.[1]
- We analyzed a large database of moth specimen records from the Pacific Northwest (PNW) to examine climate change responses over more than 100 years for a suite of 241 functionally diverse species, including spring and fall active species as well as dietary generalists and specialists (Table 1).
- Our goal was to investigate the effect of among-year variation in regional late winter to early spring temperatures on the seasonal timing of adult activity, and whether that effect differs among moth functional groups.
- We hypothesized that moths would have earlier flight dates in warmer years, and that this effect would be greatest for both early-season and dietary specialists.

Table 1. Moth functional groups compared in this study. Post-hoc analyses of the species-specific effects of temperature on flight date examined the effect of these two parameters.

Functional Group Category	Description
Adult Phenology	
Early Season	Main flight occurs between January and June
Mid Season	Main flight occurs between April and September
Late Season	Main flight occurs between July and December
Larval Diet Breadth	
Monophagous	Larvae only feed on plants within one genus.
Oligophagous	Larvae feed on plants of multiple genera, but within one family
Polyphagous	Larvae feed on plants of multiple families.

Methods

- We obtained annual temperatures anomalies for each year in which we had moth data (1895-2015), drawing from NOAA climate records[5] (Fig. 1).
- Only single-brooded moth species with at least 100 complete collection records were included in the analysis.
- Multiple records of a species from a locality in a given year were reduced to the median Julian Date (JD) of those records, to avoid pseudoreplication.
- We used generalized linear mixed models (GLMMs) to determine the effect of temperature anomaly on flight date for each species.
- Elevation, latitude, and longitude were included as random effects to account for phenological differences due to these factors[2].
- For each species, we determined the shift in flight date (days/˚C) resulting from a 1˚ C increase from the historical average temperature, based on the species-specific relationships between anomaly and flight date (Fig. 2a).
- To assess whether moths generally fly earlier in warmer years, we analyzed the distribution of slopes of these relationships using a one-tailed t-test.
- To determine if functional groups differ in the probability of exhibiting a significant response to temperature anomaly, we used G-tests.
- We used ANOVA to compare slopes for the anomaly-flight date relationship across functional groups, to test the hypothesis that the magnitude of the effect of temperature anomaly varies among groups.

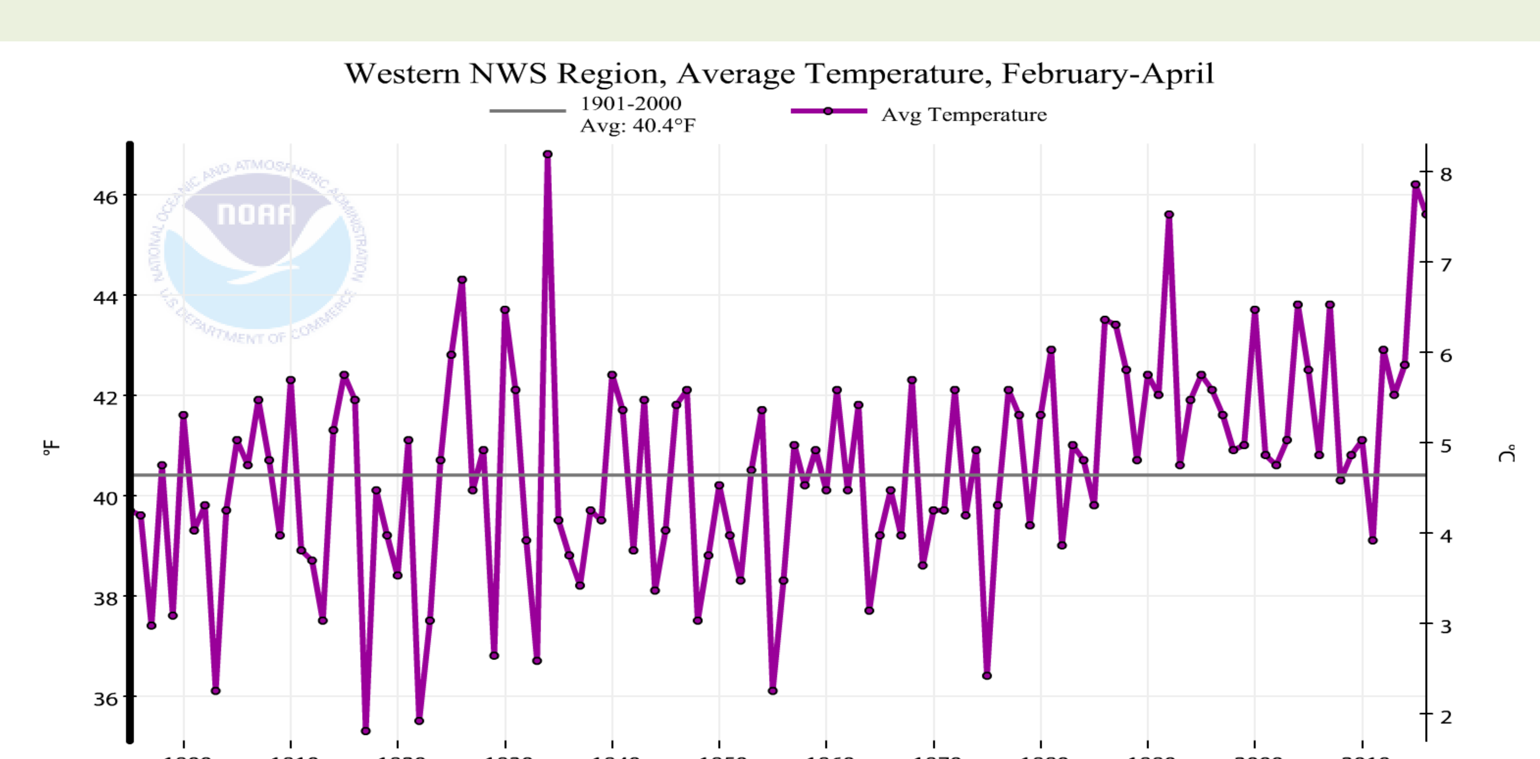

Figure 1. Average annual February – April temperature for the PNW region from 1895 – 2015. The gray horizontal line indicates the long-term average temperature for this period. The vertical difference between the yearly and long-term average is the temperature anomaly for a given year.

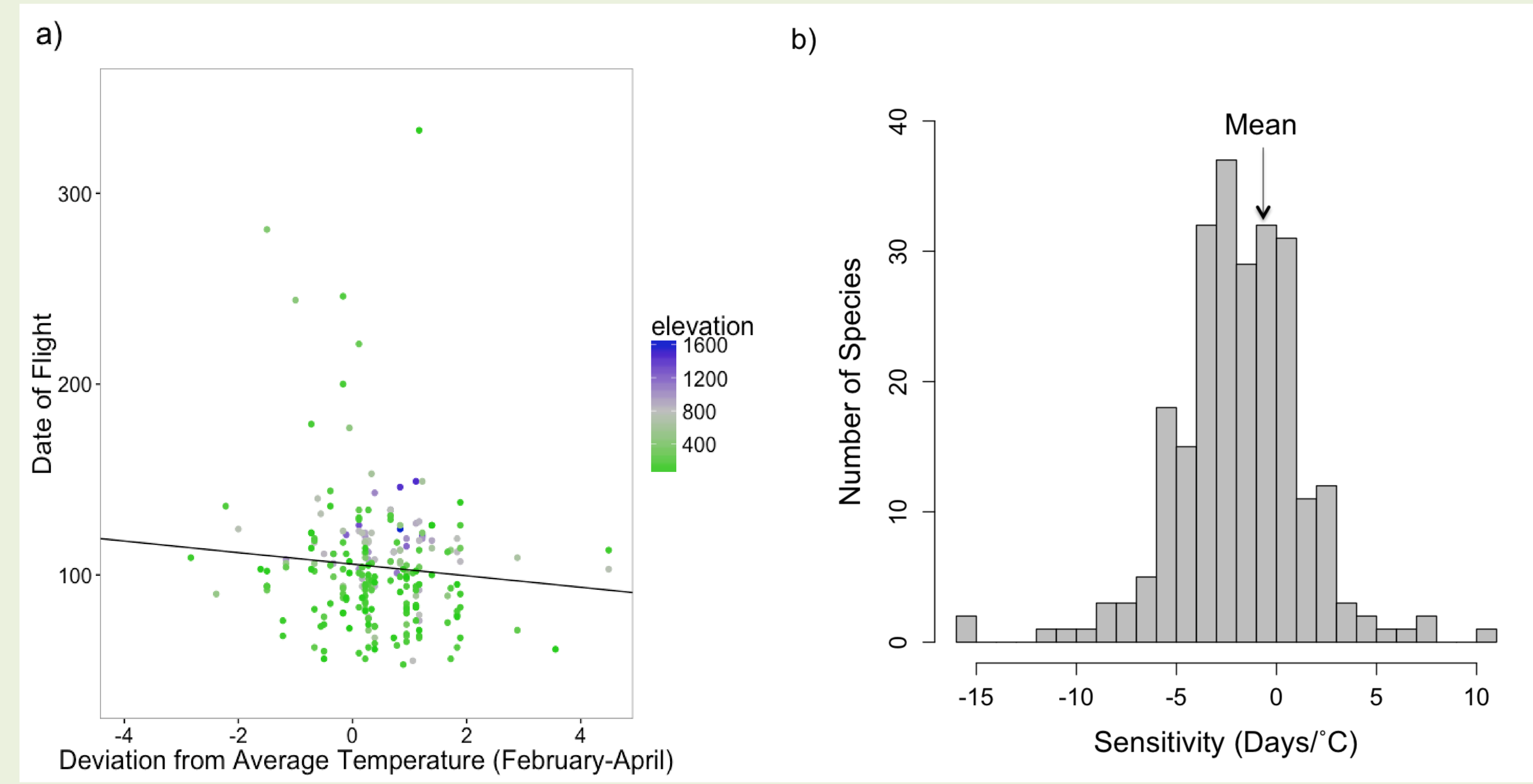

Figure 2. A) The relationship between temperature anomaly (deviation from average) and date of flight for *Orthosia hibisci*, a species that flies significantly earlier in warmer years. B) Distribution of phenological sensitivities of moth species to annual temperature anomalies (Sensitivity = (slope of flight date vs. anomaly)x(average flight date for a species under no anomaly); a sensitivity of 0 indicates no shift in flight date, negative sensitivities indicate earlier flight in warmer years, and positive sensitivities indicate later flight in warmer years).

Results

- Overall, moths flew on earlier dates during warmer years (p < 0.0001), with the average species flying 1.9 days earlier per ˚C (Fig. 2b); 37% of species flew significantly earlier in warmer years.
- Early-season specialists were more likely to exhibit such a phenological shift than were mid- and late-season specialists (Fig. 3a), and the magnitude of their shift was greater (Fig. 3c).
- Although the likelihood of a significant phenological shift varied with degree of dietary specialization (Fig. 3b), the magnitude of those shifts did not vary consistently with diet breadth (Fig. 3d).

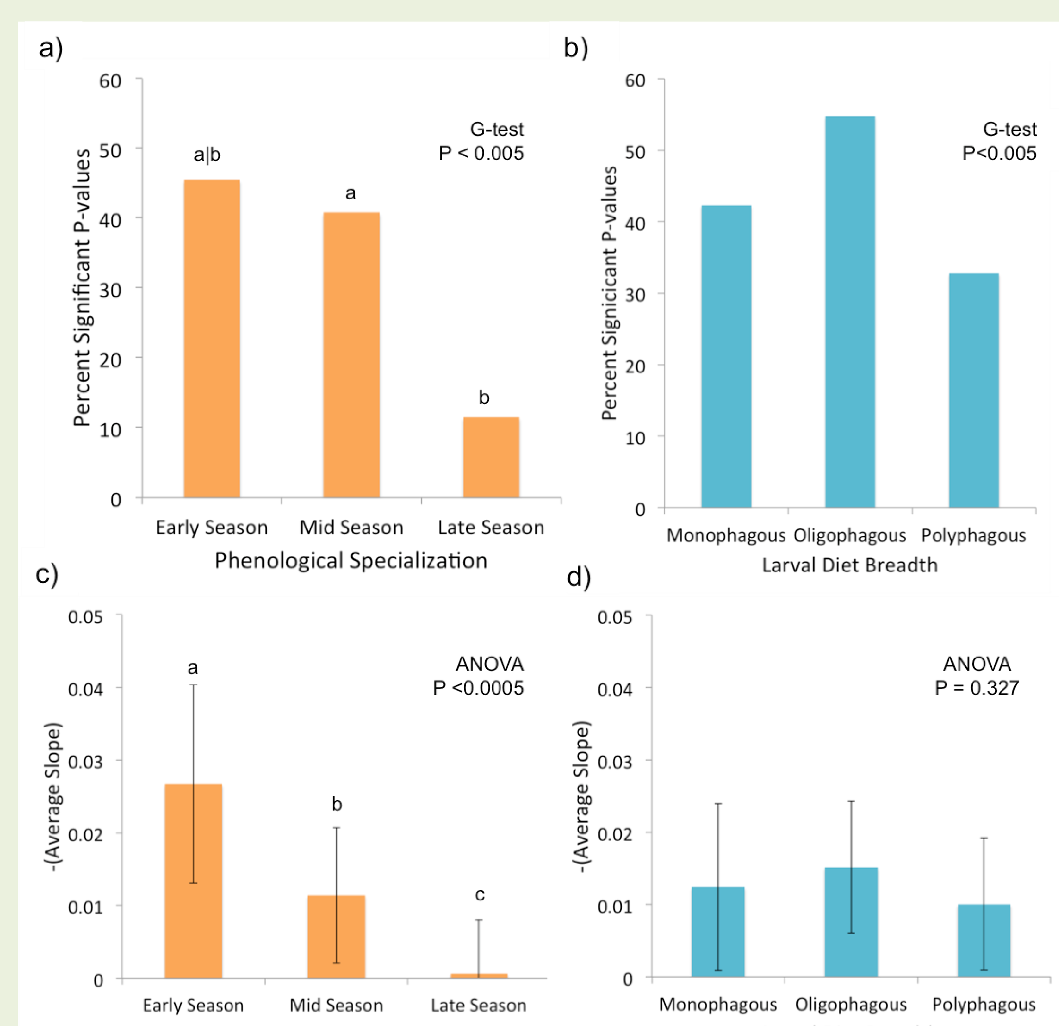

Figure 3. Comparisons among phenological (orange) and dietary (blue) functional groups for slopes of the relationship between temperature anomaly and date of flight (a, b) and proportion of species flying significantly earlier in warmer years (c,d). Overall test for variation among functional groups is indicated by p-values in the upper right corner of each panel, while significant pairwise differences are indicated by differences in letters above the bars (pairwise comparisons used Tukey HSD correction for average slopes and Bonferroni correction for percent significant).

Conclusions

- Our results show that sustained climate change has the potential to affect the phenology of many moth species.
- Significant differences among functional groups suggest that the responses of individual species to climate change are likely to be somewhat predictable.[1,3]
- These results demonstrate that messy, specimen-based data can be used to analyze the effects of climate change on organismal phenology.
- Our findings are similar to those of previous studies, which have shown that flight season timing of earlier fliers and less mobile butterfly species is more sensitive to temperature changes than later flying and more mobile species.[3]

Future Research

- Investigate how phylogenetic relatedness influences the responses of moths to climate change.
- Compare other functional groups such as migratory vs. non-migratory or single vs. multi-brooded groups.

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