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Environmental Predictors of Abundance in Eastern Redback Salamander Ecomorphs

Abstract

The Eastern Redback Salamander is an ectothermic amphibian species from Eastern North America. Research analyzing their abundances in response to varying environmental parameters is limited. This study investigates abundance patterns of ecomorphs (Lead-backed and Red-backed) across different temperature and humidity measurements from 2004 to 2019. By manipulating cleaned data and fitting it to several multiple linear and quadratic models, we found a statistically significant difference in abundances between ecomorphs and temperatures but no significant effect of precipitation. Significant measurement error heavily impacted results, as temperature and precipitation are key ecological factors influencing salamander abundance. Therefore, they should be considered when developing conservation strategies to combat climate change for amphibious species.

Introduction

Climate change is an ever-impending issue concerning ecosystem functioning and species' existence. It significantly impacts ectothermic species due to their heightened physiological and behavioural sensitivity to various environmental variables[1,2,3]. One particularly vulnerable species is salamanders, which have continuously been affected by climatic variables[4,5]. A local salamander species that has not been well-studied in this context is the Eastern Redback Salamander. Understanding the Eastern Salamander populations' response to various environmental variables will provide a framework for scientists and conservationists to develop targeted climate change mitigation strategies. Eastern Salamanders, or *Plethodon cinereus*, are native to Eastern North America and exist in two different colouring morphologies, Red-backed and Lead-backed[7,8]. The Government of Canada holds an open access data set with 11,881 entries of these salamanders from the Bruce Peninsula from 2004 to 2019[6]. Within this data, both ecomorphs were co-jointly and independently accounted for. This project aims to understand how varying environmental variables–temperature, precipitation, soil pH and soil moisture–shape the abundances between different salamander colour morphologies. Previous literature has found no consistent results in differences in thermal niche selection for the ecomorphs, and limited studies have concluded that Lead-backed salamanders prefer to reside on soil surfaces, persisting better at higher temperatures and humidity[9,10]. To this end, we are interested in inferring differences in abundances for both ecomorphs and the effects of various environmental variables through generalized linear and quadratic models. We hypothesize that the abundance of the Eastern Redback Salamander will vary depending on the ecomorph. Specifically, we expect the Leadback morph to persist at higher abundances with increasing temperatures and humidity. However, due to the ectothermic nature of the Eastern Red-backed Salamander, we predict that both morphs will exhibit peak abundances at an intermediate temperature and humidity.

Methods

First, we loaded the raw "Salamander.csv" file into R-4.4.2 and removed observations for which salamander counts contained NA or null values, reducing the number of observations in the data frame from 11,881 to 6,359. We calculated the **Red-back and Lead-back abundances** for our response variable, grouping them by year, month, and survey location. Summing the totals, we combined both into one data frame. Next, we explored potential predictor variables: temperature, precipitation, soil moisture, and soil pH. Preliminary filtering revealed **soil moisture** was only recorded in 2016, and **soil pH** was not collected in any year with morph abundances. Consequently, we did not include these metrics in further analysis. Filtering **temperature** and **precipitation** did not yield similar results, so they were deemed sufficient for subsequent analyses. To align the structure of the predictor variables to the response variables, we calculated the average for each variable, grouping by year, month, and survey location. Using ggplot to visualize predictors against response variables for each ecomorph, a positive trend is observed for temperature; however, a slight clustering of higher abundances at an intermediate optimum was plausible, suggesting that quadratic or linear models could fit this data (Figure 1A&1B). Extreme clustering in the precipitation plots prompted us to include it in our model as a covariate to test for significance (Figure 1C&1D). We fit quadratic and linear models to the data, selecting the quadratic model as the specification of best fit by AIC comparison. Our data exploration suggested inconsistencies in sampling effort in the original dataset: we added **sampling effort** as a predictor by calculating the sum of observations for each year, month, and survey location combination. Additionally, we added year as another potential effect in our models to account for potential dependencies in abundance across the years.

Results

The models developed relied on the following predictors and their interactions: **temperature**, **precipitation**, **sampling effort**, **ecomorph**, and **year**. Models using the Poisson distribution were compared (Table 1) and were all deemed biologically plausible, adhering to standard statistical practice for count data. The best-fit model, with the lowest AIC (2129.936), was a linear model – with the equivalent quadratic model not marginally different at 2130.164 – contained precipitation, temperature, ecomorph, year, sampling effort, and year as predictors, with temperature and ecomorph as an interaction term. Other than precipitation, all of these were significant, with $p < 0.05$ (Table 2). To test the true influence of sampling effort and the non-independence of the data (year as a predictor), we plotted each against abundance. We kept the remainder of the covariates in this model consistent. From these visualizations (Figure 2&3), sampling effort significantly influences abundance. Thus, the lack of independence in the data may be less critical for these analyses than the systemic bias and inconsistencies in sampling effort across locations, months, and times.

Discussion/Conclusion

Our original hypotheses and predictions were partially supported: the results showed significant differences in the abundance of Eastern Salamander morphs at different temperature values and ecomorph types, while precipitation was not a significant predictor. This was unexpected, as prior literature has intensively discussed the considerable effect of precipitation on salamander species. Limitations, including insufficient data, inconsistent sampling effort, and poor methodology from the original dataset, constrained effective analysis. While soil moisture and pH data were potential environmental predictors, the few existing measurements had no morph abundance counts attached. Temperature and precipitation measurements were also recorded on a limited number of dates, likely not representing true climate conditions. Additionally, the effect of sampling effort was a highly statistically significant covariate in our final model, showing that measures of abundance are very sensitive to errors in sampling. With year as a highly significant predictor of abundance, the assumption of independence of observations was violated. While using annual growth rates as the response variable would have accounted for this, we prioritized maximizing sample size and statistical power over independence of observations due to data quality limitations. Overall, overwhelming data constraints likely obscured the relationships between environmental predictors, abundance, and statistical significance. Future studies should adopt standardized sampling approaches to produce better-unbiased datasets. Biologically, temperature and precipitation are widely recognized to influence ecomorph abundances, prompting further investigations to clarify the statistical significance of climate change and its effect on ecomorphs in salamanders[11, 12].

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Appendix

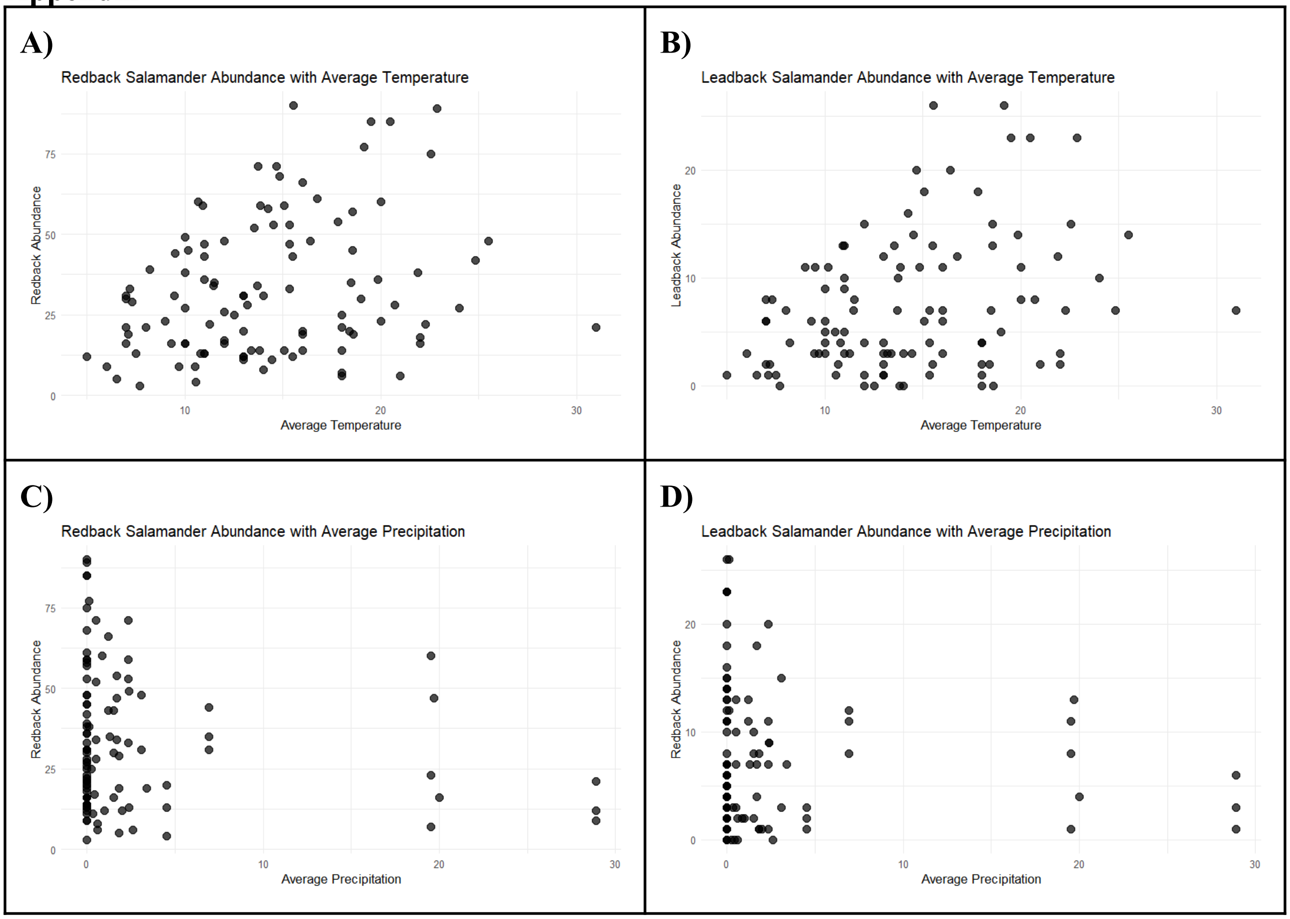

Figure 1: Plots generated using the ggplot function, visualizing two predictors against ecomorph abundances. **A)** Redback abundance against average temperature shows a positive trend, whereas as average temperature increases, redback abundance also increases. **B)** Leadback Abundance against Average Temperature, also showing a positive trend where Average Temperature increases, Leadback Abundance also increases. **C)** Plots Redback Abundance against Average Precipitation and shows clustering at lower average precipitation, and **D)** plots Leadback Abundance against Average Precipitation and also shows clustering at lower average precipitation, potentially representing insufficient precipitation measurements.

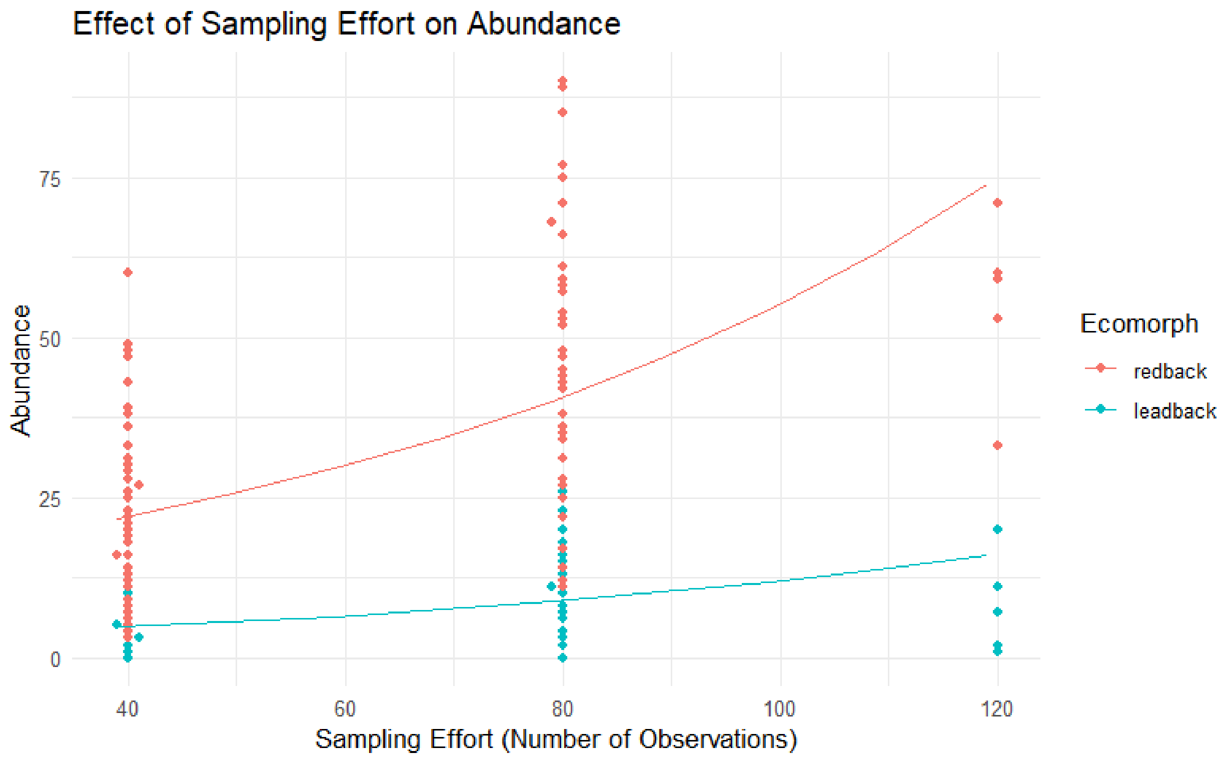

Figure 2: The effect of sampling effort (number of observations) on salamander abundance with all other model covariates held constant. Separate predictive lines for each ecomorph demonstrate expected abundance trends, with consistently higher redback abundances—data clusters at three sampling efforts since there was no variation of sampling effort beyond the clusters in the dataset.

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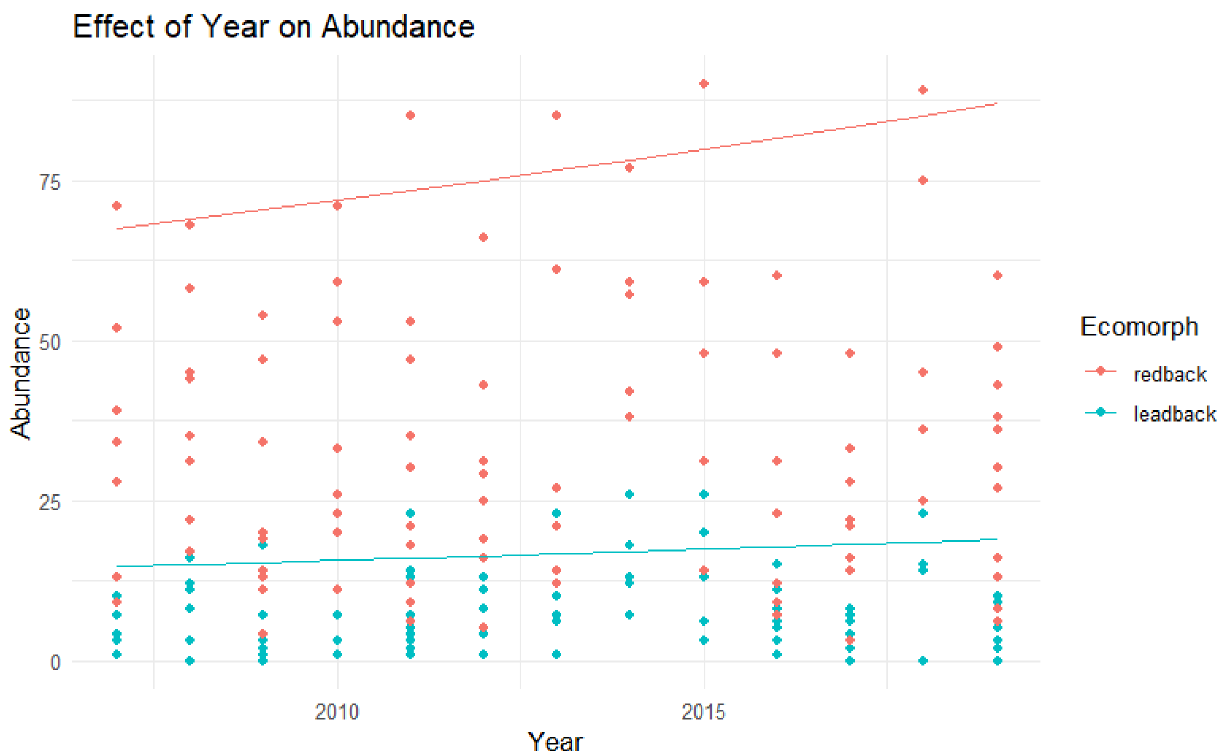

Figure 3: The effect of year on salamander abundance with all other model covariates held constant. Separate predictive lines for each ecomorph demonstrate expected abundance trends, with consistently higher redback abundances than leadback abundances.

Model	AIC
Linear temperature + ecomorphs + temperature*ecomorph	2712.5
Linear precipitation + ecomorph + precipitation *ecomorph	2842.8
Linear precipitation + temperature + ecomorph + temperature*ecomorph	2701.135
Linear precipitation + temperature + ecomorph + temperature*ecomorph + precipitation*ecomorph	2702.288
Linear precipitation + temperature + ecomorph + temperature*ecomorph + year	2703.09
***Linear* precipitation + temperature + ecomorph + temperature*ecomorph + year + sampling effort**	**2129.936**
Quadratic temperature + ecomorph + temperature*ecomorph	2642.326
Quadratic precipitation + temperature + ecomorph + temperature*ecomorph	2638.05
Quadratic precipitation + temperature + ecomorph + temperature*ecomorph + sampling effort	2155.55
Quadratic precipitation + temperature + ecomorph + temperature*ecomorph + year + sampling effort	2130.164

Table 1. Comparison of candidate linear and quadratic models for predicting Eastern Redback salamander abundance using temperature, precipitation, ecomorph, sampling effort, and year as predictors. All models assumed a Poisson distribution for count data. Models were selected based on biological plausibility and statistical performance. The best-supported model is bolded.

Predictors	Coefficient Estimate	Standard Error	Z-value	P-value
Precipitation	-4.228e+01	8.342e+00	-5.068	4.02e-07 ***
Temperature	4.483e-02	7.296e-03	6.144	8.05e-10 ***
Ecomorph	1.818e+00	1.311e-01	13.863	< 2e-16 ***
Year	2.117e-02	4.143e-03	5.111	3.21e-07 ***
Sampling Effort	1.527e-02	6.202e-04	24.627	< 2e-16 ***
Temperature*ecomorph	-2.071e-02	8.060e-03	-2.569	0.0102 *

Table 2. Coefficient estimates, standard errors, z-values, and p-values for the predictors in the best-supported regression model for Eastern Redback salamander abundance. The model included precipitation, temperature, ecomorph, year, sampling effort, and an interaction between temperature and ecomorph. Significant predictors ($p < 0.05$) were temperature, ecomorph, year, sampling effort, and the interaction between temperature and ecomorph. Precipitation did not display statistical significance.

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Supplemental Information

Data file name: *salamander.csv* – Each row corresponds to one sample point, with each column corresponding to the following:

Column	*Description*
Plot Name	Name of Location (plot of land) that each sample was collected within
Plot Number	A number assigned to each “Plot Name”
Artificial Cover Object Number	A number is assigned to different artificial cover objects. Objects that mimic real-life natural covers, located within each plot.
Year	Year of sample collection
Date	Specific date of sample collection, in DD/MM/YYYY format
Time	Time of sample collection, in standard time format
Survey Number	The number assigned to the survey completed
Eastern Redback Salamander Count	Total count of all Eastern Redback Salamanders in both morph forms (Redback and Leadback) within a given plot
Redback form of Eastern Redback Salamander Count	Count of Redback form of the Eastern Redback Salamanders within a given plot
Leadback form of Eastern Redback Salamander Count	Count of Leadback form of the Eastern Redback Salamanders within a given plot
Artificial Cover Object Age (years(s))	The age, in years, of the artificial cover object the sample was collected within
Observer Names	The names of the observers who collected the sample
Percipitation in the Last 24 hours (mm)	Precipitation, as a measure of rainfall on the plot surfaces over the previous 24 hours to collecting a sample – measured in millimeters (mm).
Air Temperature (degC)	Air temperature within the plot collected while sample was taken – measured in °C
Soil Temperature (degC)	Temperature of the soil within the plot collected while sample was taken – measured in °C
Soil Moisture	Amount of water in soil, expressed as a percentage of moisture

Soil pH	Acidity of the soil, measured by the concentration of H^+ ions in soil water