Urbanization influences communities of milkweed-specialist herbivorous insects

ON_herb Analyses

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Contents

Background & Questions

We examined how urbanization could disrupt specialized plant-herbivores species interactions, comparing responses by different cities and by traits of the herbivore species. We surveyed arthropod communities in the early and late growing season of the common milkweed (*Asclepias syriaca*) across six cities in southern Ontario (Fig. 1).

We asked the following five questions:

(Q1) Is insect herbivore species abundance, richness, and diversity lower in urban compared to rural habitats?

(Q2) Does leaf herbivory vary with urbanization?

(Q3) Does the response of the herbivore community vary with urbanization?

(Q4) Is dispersal ability related to urbanization?

(Q5) How does urbanization influence herbivore species interactions?

Load Data

```
## Read in data
# Toronto
toronto.herbivores  <- read_csv(
    "data/toronto_herbivores.csv",
    col_types = c("ffffnfiiiiiiiiii"),
    show_col_types = FALSE
    )
toronto.leaf.damage <- read_csv(
    "data/toronto_leaf_damage.csv",
    col_types = c("fffnfn"),
    show_col_types = FALSE
    )

# Five Cities
five.cities.herbivores  <- read_csv(
    "data/five_cities_herbivores.csv",
    col_types = c("ffffnfiiiiiiiiii"),
    show_col_types = FALSE
    )
five.cities.leaf.damage <- read_csv(
    "data/five_cities_leaf_damage.csv",
    col_types = c("ffffnfn"),
    show_col_types = FALSE
    )

# Species dispersal traits
species.traits <- read.csv("data/species_dispersal_traits.csv")
```

Biodiversity Calculations

We used two complementary measures of biodiversity: species richness and Shannon's index. Species richness captures the number of species present at a site, and Shannon's index quantifies how the distribution of abundances for species present at a site. Species richness was quantified using `specnumber()` and Shannon's index (hereafter "diversity") was quantified using `diversity()`.

```
## Calculate species richness (Richness) and Shannon's index (Diversity) for each population
# Toronto richness
toronto.herbivores$Richness <- specnumber(
    toronto.herbivores[, 7:15]
)
# Toronto diversity
toronto.herbivores$Diversity <- diversity(
    toronto.herbivores[, 7:15],
    index = "shannon"
)

# 5 Cities richness
five.cities.herbivores$Richness <- specnumber(
    five.cities.herbivores[, 7:15]
)
# 5 Cities diversity
five.cities.herbivores$Diversity <- diversity(
    five.cities.herbivores[, 7:15],
    index = "shannon"
)
```

Abundance & Diversity Analyses

We analyzed the effects of urbanization on community abundance, richness, and diversity using a combination of ANOVAs and ANCOVAs. Toronto was analyzed separately for the 5 Cities because Toronto was sampled more intensively along an urbanization gradient, while the 5 Cities were sampled using urban-rural pairs for each city. Toronto ANCOVAs followed the form of:

$$Response = Distance + Season + Distance : Season$$

where the effects of distance, season, and the two-way interaction were evaluated. Abundance was fitted using a negative-binomial GLM (`glm.nb()`), richness was fitted using a Poisson GLM (`glm()`), and diversity was fitted using a linear model (`lm()`). The 5 Cities ANOVAs were of the form:

$$Response = City\ [C] + Habitat\ [H] + Season[S] + C : H + C : S + H : S + C : H : S$$

where city, habitat, season, and all two- and three-way interactions were evaluated. Abundance was fitted using a negative-binomial GLM (`glm.nb()`) and richness and diversity were fitted with linear models (`lm()`). All model assumptions were inspected graphically using `check_model()`, and influence of main effects and interactions was determined with Type III sums-of-squares using `Anova()`. Abundances for each herbivore species were summed for each site, and these summed abundances were used to quantify species richness and diversity.

Toronto ANCOVAs

Abundance

```
toronto.abundance.ANCOVA <- glm.nb(
    Summed_Abundance ~ Distance * Season,
    data = toronto.herbivores
)
```

Table 1: Results of the Toronto abundance ANCOVA, comparing abundance by distance from the city center, season, and the two-way interaction.

	LR_chi-squared	df	P-value
Distance	2.396	1	0.122
Season	0.052	1	0.820
Distance:Season	0.004	1	0.949

Richness

```
toronto.richness.ANCOVA <- glm(
    Richness ~ Distance * Season,
    family = poisson,
    data = toronto.herbivores
)
```

Table 2: Results of the Toronto richness ANCOVA, comparing richness by distance from the city center, season, and the two-way interaction.

	LR_chi-squared	df	P-value
Distance	0.304	1	0.581
Season	0.132	1	0.716
Distance:Season	0.019	1	0.891

Diversity

```
toronto.diversity.ANCOVA <- lm(
    Diversity ~ Distance * Season,
    data = toronto.herbivores
)
```

Table 3: Results of the Toronto diversity ANCOVA, comparing diversity by distance from the city center, season, and the two-way interaction.

	Sums-of-Squares	df	F	P-value
(Intercept)	5.326	1	41.673	0.000
Distance	0.040	1	0.312	0.577
Season	0.021	1	0.166	0.684
Distance:Season	0.003	1	0.021	0.885
Residuals	17.253	135	NA	NA

5 Cities ANOVAs

Abundance

```
five.cities.abundance.ANOVA <- glm.nb(
    Summed_Abundance ~ City * Habitat * Season,
    data = five.cities.herbivores
)
```

Table 4: Results of the 5 Cities abundance ANOVA, comparing abundance by city, habitat, season, and all two- and three-way interactions.

	LR_chi-squared	df	P-value
City	14.622	4	0.006
Habitat	1.435	1	0.231
Season	1.626	1	0.202
City:Habitat	9.149	4	0.057
City:Season	13.528	4	0.009
Habitat:Season	7.781	1	0.005
City:Habitat:Season	12.966	4	0.011

Richness

```
five.cities.richness.ANOVA <- lm(
    Richness ~ City * Habitat * Season,
    data = five.cities.herbivores
)
```

Table 5: Results of the 5 Cities richness ANOVA, comparing richness by city, habitat, season, and all two- and three-way interactions.

	Sums-of-Squares	df	F	P-value
(Intercept)	33.333	1	43.575	0.000
City	2.400	4	0.784	0.542
Habitat	1.500	1	1.961	0.169
Season	10.667	1	13.944	0.001
City:Habitat	0.867	4	0.283	0.887
City:Season	7.021	4	2.295	0.076
Habitat:Season	3.000	1	3.922	0.055
City:Habitat:Season	4.932	4	1.612	0.191
Residuals	29.833	39	NA	NA

Diversity

```
five.cities.diversity.ANOVA <- lm(
    Diversity ~ City * Habitat * Season,
    data = five.cities.herbivores
)
```

Table 6: Results of the 5 Cities diversity ANOVA, comparing diversity by city, habitat, season, and all two- and three-way interactions.

	Sums-of-Squares	df	F	P-value
(Intercept)	3.838	1	24.437	0.000
City	0.310	4	0.494	0.740
Habitat	0.413	1	2.628	0.113
Season	1.919	1	12.219	0.001
City:Habitat	0.191	4	0.304	0.874
City:Season	0.794	4	1.264	0.301
Habitat:Season	0.399	1	2.543	0.119
City:Habitat:Season	0.418	4	0.665	0.620
Residuals	6.125	39	NA	NA

Leaf Herbivory Analyses

We analyzed the effects of urbanization on leaf herbivory using linear mixed-effects models. The Toronto model was fitted as:

$$Mean\ Leaf\ Herbivory\ = Distance + Season + Distance : Season + (Season \mid Population) +$$

where distance, season, and the two-way interaction were fitted as fixed effects, and population was fitted as a random intercept with a random slope for each season. The Toronto model with a random slope and intercept had better fit compared to the model with only a random intercept (random slope and intercept: $AIC_c = 2094.771$, $R^2_{marginal} = 0.201$, $R^2_{conditional} = 0.419$; random intercept only: $AIC_c = 2108.466$, $R^2_{marginal} = 0.203$, $R^2_{conditional} = 0.364$). The 5 Cities model was fitted as:

$$Mean\ Leaf\ Herbivory\ = City\,[C] + Habitat\,[H] + Season[S] + C : H + C : S + H : S + C : H : S + (1 \mid Population)$$

where city, habitat, season, and all two- and three-way interactions were fitted as fixed effects and population was fitted as a random intercept. The Toronto model with a random slope and intercept had better fit compared to the model with only a random intercept (random slope and intercept: $AIC_c = 629.515$, $R^2_{marginal} = 0.645$, $R^2_{conditional} = 0.787$; random intercept only: $AIC_c = 660.430$, $R^2_{marginal} = 0.639$, $R^2_{conditional} = 0.756$), but the 5 Cities random slope and intercept model failed to converge Therefore. we fitted the 5 Cities model with just a random intercept for population.

Both the Toronto and 5 Cities leaf herbivory models were fitted using `lmer()`. All model assumptions were inspected graphically using `check_model()`, and we applied a square-root transformation to mean leaf herbivory for both the Toronto and 5 Cities models to better meet model assumptions. Influence of main effects and interactions was determined with Type III sums-of-squares, with degrees of freedom estimated using the Kenward-Roger method.

References:

Bates, D., et al. 2015. Fitting linear mixed-effects models using `lme4`. Journal of Statistical Software 67: 1-48.

Bolker, B. M., et al. 2009. Generalized linear mixed models: a practical guide for ecology and evolution. Trends in Ecology and Evolution 24: 127-135.

Grueber, C. E., et al. 2011. Multimodel inference in ecology and evolution: challenges and solutions. Journal of Evolutionary Biology 24: 699-711.

Harrison, X. a., et al. 2018. A brief introduction to mixed effects modelling and multi-model inference in ecology. PeerJ 6: e4794.

Johnson, J. B., and K. S. Ormland. 2004. Model selection in ecology and evolution. Trends in Ecology and Evolution 19: 101-108.

Silk, M. J., et al. 2020. Perils and pitfalls of mixed-effects regression models in biology. PeerJ 8: e9522.

Toronto

```
toronto.leaf.herbivory.LMM <- lmer(
    sqrt(Mean_Leaf_Herbivory) ~ Distance * Season + (Season | Population),
    data = toronto.leaf.damage
    )

## Intercept AICc = 2108.466 (R2m = 0.203, R2c = 0.364)
## Slope (Season) + Intercept AICc = 2094.771 (R2m = 0.201, R2c = 0.419)
```

Table 7: Results of the ANOVA for the Toronto leaf herbivory linear mixed-effects model, comparing leaf herbivory by distance from the city center, season, and the two-way interaction. Variation explained by the model: $R^2_{Marginal} = 0.203, R^2_{Conditional} = 0.364$.

	Sums-of-Squares	Mean Square	Num_df	Den_df	F	P-value
Distance	20.881	20.881	1	68.692	22.510	0.000
Season	1.649	1.649	1	66.338	1.777	0.187
Distance:Season	12.296	12.296	1	64.546	13.256	0.001

5 Cities

```
five.cities.leaf.herbivory.LMM <- lmer(
    sqrt(Mean_Leaf_Herbivory) ~ City * Habitat * Season + (1 | Population),
    data = five.cities.leaf.damage
    )

## Population Intercept AICc = 660.430 (R2m = 0.639, R2c = 0.756)
## Slope (Season) + Population Intercept AICc = 629.515 (R2m = 0.645, R2c = 0.787)
# Failed to converge
```

Table 8: Results of the ANOVA for the 5 Cities leaf herbivory linear mixed-effects model, comparing leaf herbivory by city, habitat, season, and all two- and three-way interactions. Variation explained by the model: $R^2_{Marginal} = 0.639, R^2_{Conditional} = 0.756$

	Sums-of-Squares	Mean Square	Num_df	Den_df	F	P-value
City	4.240	1.060	4	56.685	2.646	0.043
Habitat	6.169	6.169	1	107.386	15.455	0.000
Season	183.884	183.884	1	148.483	460.713	0.000
City:Habitat	5.228	1.307	4	86.041	3.261	0.015
City:Season	1.295	0.324	4	55.820	0.810	0.524
Habitat:Season	1.065	1.065	1	58.911	2.668	0.108
City:Habitat:Season	0.564	0.141	4	87.897	0.353	0.841

Herbivore Communities & Urbanization

We evaluated whether community composition and individual herbivore species varied with urbanization by using multivariate generalized linear models. In this approach, separate GLMs with shared predictor variables are fitted using `manyglm()` and then resampling methods are used to test which variables or factors are associated with the multivariate abundances. With this approach, it is possible to answer: (1) do communities vary in composition with urbanization and (2) which herbivore species are influenced by urbanization?

We first created a separate site-by-species abundance matrix for the Toronto and 5 Cities datasets, and these matrices were the response in the resulting `manyglm()` models. We fitted the Toronto model as:

$$Abundance\ Matrix = Distance + Season + Distance : Season$$

where the effects of distance, season, and the two-way interaction were evaluated. The 5 Cities model was fitted as:

$$Abundance\ Matrix = City\ [C] + Habitat\ [H] + Season[S] + C : H + C : S + H : S + C : H : S$$

where city, habitat, season, and all two- and three-way interactions were evaluated. Both models were fitted using GLMs with a negative-binomial error distribution, and model assumptions were evaluated graphically. The influence of main effects and interactions in the model was determined using likelihood ratio tests and resampling, resulting in a multivariate test for the overall abundance matrix and univariate tests for each herbivore species. We used 999 resampling iterations, with P-values adjusted for multiple testing through an automated step-down resampling procedure.

References:

Wang, Y., et al. 2012. `mvabund`-an R package for model-based analysis of multivariate abundance data. Methods in Ecology and Evolution 3: 471-474.

Warton, D. I., et al. 2012, Distance-based multivariate analyses confound location and dispersion effects. Methods in Ecology and Evolution 3: 89-101.


```
## Set the Toronto community matrix
toronto.community.matrix <- toronto.herbivores[, 7:15] %>%
    as.data.frame()

## Set the 5 Cities community matrix
five.cities.community.matrix <- five.cities.herbivores[, 7:15] %>%
    as.data.frame()
```

Toronto

```
## Fit the Toronto herbivore community model
toronto.herbivore.community.model <- manyglm(
    mvabund(toronto.community.matrix) ~ Distance * Season,
    data = toronto.herbivores,
    family = "negative_binomial"
    )
```

```
## ANOVA on the Toronto herbivore community manyglm
toronto.herbivore.community.anova <- anova(
    toronto.herbivore.community.model,
    nBoot = 999,
    p.uni = "adjusted"
    )
```

```
## Time elapsed: 0 hr 1 min 17 sec
```

Table 9: Overall summary of the Toronto herbivore community manyglm.

	Residual df	df	Test Statistic	P-value
(Intercept)	138	NA	NA	NA
Distance	137	1	60.895	0.001
Season	136	1	0.778	1.000
Distance:Season	135	1	0.235	0.999

Table 10: Test statistics for each species in the Toronto herbivore community manyglm.

	Danaus	Rhyssomatus	Aphis	Myzocallis	Euchaetes	Lygaeus	Oncopeltus	Tetraopes	Liriomyza
(Intercept)	NA	NA	NA	NA	NA	NA	NA	NA	NA
Distance	0.556	10.423	0.141	11.575	10.661	7.875	2.148	0.140	17.375
Season	0.022	0.007	0.001	0.519	0.004	0.000	0.002	0.055	0.168
Distance:Season	0.001	0.001	0.000	0.181	0.001	0.000	0.003	0.012	0.035

Table 11: P-values associated with the test statistics for each species in the Toronto herbivore community manyglm.

	Danaus	Rhyssomatus	Aphis	Myzocallis	Euchaetes	Lygaeus	Oncopeltus	Tetraopes	Liriomyza
(Intercept)	NA	NA	NA	NA	NA	NA	NA	NA	NA
Distance	0.818	0.014	0.889	0.010	0.014	0.044	0.473	0.889	0.002
Season	1.000	1.000	1.000	0.999	1.000	1.000	1.000	1.000	1.000
Distance:Season	1.000	1.000	1.000	0.999	1.000	1.000	1.000	1.000	1.000

5 Cities

```
## Fit the 5 Cities herbivore community model
five.cities.herbivore.community.model <- manyglm(
    mvabund(five.cities.community.matrix) ~ City * Habitat * Season,
    data = five.cities.herbivores,
    family = "negative_binomial"
    )
```

```
## ANOVA on the 5 Cities herbivore community manyglm
five.cities.herbivore.community.anova <- anova(
    five.cities.herbivore.community.model,
    nBoot = 999,
    p.uni = "adjusted"
    )
```

```
## Time elapsed: 0 hr 1 min 23 sec
```

Table 12: Overall summary of the 5 Cities herbivore community manyglm.

	Residual df	df	Test Statistic	P-value
(Intercept)	58	NA	NA	NA
City	54	4	53.995	0.041
Habitat	53	1	19.208	0.036
Season	52	1	75.566	0.003
City:Habitat	48	4	55.259	0.025
City:Season	44	4	31.835	0.126
Habitat:Season	43	1	15.424	0.097
City:Habitat:Season	39	4	14.481	0.163

Table 13: Test statistics for each species in the 5 Cities herbivore community manyglm.

	Danaus	Rhyssomatus	Aphis	Myzocallis	Euchaetes	Lygaeus	Oncopeltus	Tetraopes	Liriomyza
(Intercept)	NA	NA	NA	NA	NA	NA	NA	NA	NA
City	4.447	10.385	11.905	0	4.835	4.082	6.174	3.510	8.658
Habitat	0.068	4.692	0.782	0	3.023	0.099	0.489	0.058	9.997
Season	33.229	25.537	3.252	0	3.342	3.058	1.808	3.625	1.715
City:Habitat	2.608	18.713	2.643	0	0.001	3.236	2.702	14.861	10.495
City:Season	14.698	5.650	1.090	0	0.001	0.000	3.122	4.272	3.001
Habitat:Season	1.861	0.000	3.684	0	0.000	0.000	4.310	3.142	2.427
City:Habitat:Season	4.403	0.000	8.498	0	0.000	0.000	0.001	0.000	1.577

Table 14: P-values associated with the test statistics for each species in the 5 Cities herbivore community manyglm.

	Danaus	Rhyssomatus	Aphis	Myzocallis	Euchaetes	Lygaeus	Oncopeltus	Tetraopes	Liriomyza
(Intercept)	NA	NA	NA	NA	NA	NA	NA	NA	NA
City	0.766	0.262	0.207	1	0.766	0.766	0.703	0.766	0.402
Habitat	0.985	0.270	0.945	1	0.524	0.985	0.949	0.985	0.017
Season	0.004	0.004	0.424	1	0.424	0.424	0.424	0.387	0.424
City:Habitat	0.953	0.040	0.953	1	0.953	0.932	0.953	0.102	0.275
City:Season	0.055	0.751	0.892	1	0.892	0.892	0.892	0.889	0.892
Habitat:Season	0.439	0.784	0.439	1	0.439	0.784	0.421	0.439	0.439
City:Habitat:Season	0.610	0.897	0.303	1	0.897	0.897	0.897	0.897	0.897

Dispersal-Urbanization Relationships

We evaluated whether abundances of different dispersal traits varied with urbanization using a similar approach to the multivariate GLMs for community composition and herbivore species. Instead of supplying a site-by-species abundance matrix as the response, we calculated the abundances of each trait for each site and provided a site-by-trait-abundance matrix as the response. With this modification, we can test (1) whether dispersal trait abundances vary with urbanization and (2) which specific dispersal traits are influenced by urbanization?

We fitted the Toronto and 5 Cities `manyglm()` models exactly like the community composition and herbivore species models, except for the site-by-trait-abundance matrix as the response. Both models were fitted using GLMs with a negative-binomial error distribution, and model assumptions were evaluated graphically. The influence of main effects and interactions in the model was determined using likelihood ratio tests and resampling, resulting in a multivariate test for the overall abundance matrix and univariate tests for each herbivore species. We used 999 resampling iterations, with P-values adjusted for multiple testing through an automated step-down resampling procedure.

```r
## Function to calculate trait abundances for each site
trait_by_population_abundance <- function(j) {
    ## Load required packages
    require(dplyr)

    ## Set trait matrix
    trait.matrix <- species.traits

    ## Sequentially calculate abundances for each trait for all sites in the supplied taxa matrix
    dispersal.1000_km  <- j * trait.matrix[, 2] [match(names(j), trait.matrix$Species)][col(j)]
    dispersal.100_km   <- j * trait.matrix[, 3] [match(names(j), trait.matrix$Species)][col(j)]
    dispersal.30_40_km <- j * trait.matrix[, 4] [match(names(j), trait.matrix$Species)][col(j)]
    dispersal.10_15_km <- j * trait.matrix[, 5] [match(names(j), trait.matrix$Species)][col(j)]
    dispersal.1_2_km   <- j * trait.matrix[, 6] [match(names(j), trait.matrix$Species)][col(j)]

    ## Set list of traits; remove UID column
    trait.list <- list(
        dispersal.1000_km[, -1], dispersal.100_km[, -1], dispersal.30_40_km,
        dispersal.10_15_km[, -1], dispersal.1_2_km[, -1]
    )


    ## Sum trait abundances by site
    trait.abundances.bin.1 <- sapply(trait.list, FUN = rowSums, USE.NAMES = TRUE) %>%
        as_tibble()

    ## Rename trait columns
    colnames(trait.abundances.bin.1)[1:5] <- colnames(trait.matrix)[2:6]

    ## Set final trait abundance tibble
    trait.abundances <- trait.abundances.bin.1 %>%
        as_tibble()
}
```

```r
## Calculate Toronto trait abundances
toronto.trait.abundances <- trait_by_population_abundance(
    toronto.community.matrix
    )

## Calculate 5 Cities trait abundances
five.cities.trait.abundances <- trait_by_population_abundance(
    five.cities.community.matrix
    )
```

Toronto

```
## Fit the Toronto herbivore community model
toronto.dispersal.traits.model <- manyglm(
    mvabund(toronto.trait.abundances) ~ Distance * Season,
    data = toronto.herbivores,
    family = "negative_binomial"
    )
```

```
## ANOVA on the Toronto herbivore community manyglm
toronto.dispersal.traits.anova <- anova(
    toronto.dispersal.traits.model,
    nBoot = 999,
    p.uni = "adjusted"
    )
```

```
## Time elapsed: 0 hr 0 min 27 sec
```

Table 15: Overall summary of the Toronto dispersal traits manyglm.

	Residual df	df	Test Statistic	P-value
(Intercept)	138	NA	NA	NA
Distance	137	1	38.998	0.001
Season	136	1	0.235	0.998
Distance:Season	135	1	0.065	1.000

Table 16: Test statistics for each species in the Toronto dispersal traits manyglm.

	X1000_km	X100_km	X30.40_km	X10.15_km	X1.2_km
(Intercept)	NA	NA	NA	NA	NA
Distance	10.661	0.397	0.142	17.375	10.423
Season	0.004	0.004	0.053	0.168	0.007
Distance:Season	0.001	0.016	0.012	0.035	0.001

Table 17: P-values associated with the test statistics for each species in the Toronto dispersal traits manyglm.

	X1000_km	X100_km	X30.40_km	X10.15_km	X1.2_km
(Intercept)	NA	NA	NA	NA	NA
Distance	0.006	0.623	0.684	0.001	0.006
Season	1.000	1.000	1.000	0.996	1.000
Distance:Season	1.000	1.000	1.000	1.000	1.000

5 Cities

```
## Fit the 5 Cities herbivore community model
five.cities.dispersal.traits.model <- manyglm(
    mvabund(five.cities.trait.abundances) ~ City * Habitat * Season,
    data = five.cities.herbivores,
    family = "negative_binomial"
    )
```

```
## ANOVA on the 5 Cities herbivore community manyglm
five.cities.dispersal.traits.anova <- anova(
    five.cities.dispersal.traits.model,
    nBoot = 999,
    p.uni = "adjusted"
    )
```

```
## Time elapsed: 0 hr 0 min 58 sec
```

Table 18: Overall summary of the 5 Cities dispersal traits manyglm.

	Residual df	df	Test Statistic	P-value
(Intercept)	58	NA	NA	NA
City	54	4	40.945	0.064
Habitat	53	1	19.063	0.004
Season	52	1	34.621	0.001
City:Habitat	48	4	41.468	0.017
City:Season	44	4	13.286	0.758
Habitat:Season	43	1	6.992	0.307
City:Habitat:Season	39	4	24.062	0.039

Table 19: Test statistics for each species in the 5 Cities dispersal traits manyglm.

	X1000_km	X100_km	X30.40_km	X10.15_km	X1.2_km
(Intercept)	NA	NA	NA	NA	NA
City	4.835	11.905	5.162	8.658	10.385
Habitat	3.023	0.782	0.569	9.997	4.692
Season	3.342	3.252	0.775	1.715	25.537
City:Habitat	0.001	2.643	9.616	10.495	18.713
City:Season	0.001	1.090	3.544	3.001	5.650
Habitat:Season	0.000	3.684	0.881	2.427	0.000
City:Habitat:Season	0.000	8.498	13.986	1.577	0.000

Table 20: P-values associated with the test statistics for each species in the 5 Cities dispersal traits manyglm.

	X1000_km	X100_km	X30.40_km	X10.15_km	X1.2_km
(Intercept)	NA	NA	NA	NA	NA
City	0.847	0.279	0.847	0.509	0.370
Habitat	0.312	0.601	0.601	0.009	0.154
Season	0.322	0.322	0.393	0.393	0.001
City:Habitat	0.744	0.744	0.272	0.272	0.023
City:Season	0.942	0.942	0.942	0.942	0.766
Habitat:Season	0.468	0.419	0.468	0.419	0.526
City:Habitat:Season	0.911	0.270	0.083	0.911	0.911

Piecewise SEMs

We used pSEMs to draw causal inference on the interactions between urbanization, season, and milkweed herbivores in Toronto, the largest city, since there was insufficient data from the 5 city dataset. Piecewise SEM is a flexible form of confirmatory path analysis that allows for non-normal distributions, hierarchical data structures, and correlated data (Lefcheck, 2015). In contrast to traditional SEM that assesses the variance-covariance of the entire model structure (i.e., global estimation; Grace, 2006), pSEM separately evaluates each model in the structural equation set (i.e., local estimation; Lefcheck, 2015). We fitted pSEMs to test for: (1) effects of urbanization on herbivore species [**pSEM 1**], (2) interactions among herbivore species [**pSEM 2**], and (3) effects of urbanization on interacting herbivore species [**pSEM 3**].

Briefly, pSEM structures were as follows: (1) the urbanization pSEM only fitted distance from the city center as a predictor on each herbivore; (2) the species interaction pSEM only fitted relationships between herbivores without any accounting for effects of urbanization; and (3) the urbanization and species interactions pSEM integrated distance from the city center with species interactions. For the pSEMs incorporating species interactions, we fitted all pairwise correlations between the focal herbivores within the same season and we also fitted causal pathways between the early and late season for the same species.

We used the same pSEM model structures to fit abundance and presence-absence data. Abundance models were fitted using GLMs with a Poisson distribution and a log-link function or negative binomial GLM to account for overdispersion. Presence-absence models were fitted using GLMs with a binomial distribution and logit-link function. Prior to fitting the pSEMs, each individual model within the structured set was fitted and assumptions were visually inspected using `check_model()`. Models fitted to presence-absence data better met assumptions and were therefore reported as the main results; models fitted to abundance data are reported in the appendix and have nearly identical ecological interpretation as the presence-absence models. Overall fit of the Toronto pSEMs were examined using Shipley's test of directed separation, which determines if there are missing pathways between unconnected variables (Shipley, 2009). Hypothesized pSEMs were considered consistent with the data when the sum of all conditional independence claims in the pSEM, measured as Fisher's C statistic, was not statistically significant (Lefcheck, 2015). After confirming adequate model fit, we compared each pSEM using Akaike information criterion with sample size correction (AIC_c), in which the pSEM with the lowest AI_cC value was the best fitting model. Results of the pSEMs were reported as standardized path coefficients, which show the direction and magnitude of causal relationships between variables and allow for comparison of relationship strengths within the pSEM (Wright, 1934; Grace, 2006; Lefcheck, 2015).

References:

Grace, J. B. 2006. Structural Equation Modeling and Natural Systems. *Cambridge University Press.*

Grace, J. B., et al. 2010. On the specification of structural equation models for ecological systems. *Ecological Monographs* 80: 67-87.

Lefcheck, J. S. 2015, piecewiseSEM: Piecewise structural equation modelling in R for ecology, evolution, and systematics. *Methods in Ecology & Evolution* 7: 573-579.

Shipley, B. 2009. Confirmatory path analysis in a generalized multilevel context. *Ecology* 90: 363-368.

Wright, S. 1934. The method of path coefficients. *The Annals of Mathematical Statistics* 5: 161-215.

Pathway Matrix

Table 21: Matrix of causal pathways from early (columns) to late (rows) taxa, with 1 indicating a causal pathway between the two taxa from early to late period. Correlations within trial periods were fitted for herbivores as a measure of potential competition or antagonism.

	Danaus	Rhyssomatus	Aphis	Tetraopes	Liriomyza
Danaus	1	0	1	1	1
Rhyssomatus	1	1	1	1	1
Aphis	1	0	1	1	1
Tetraopes	1	0	1	1	1
Liriomyza	1	0	1	1	1

Urbanization (pSEM 1) | Presence-Absence

```
## Specify the urbanization pSEM
urbanization.pSEM.presence.absence <- psem(
  ## Danaus
  danaus.presence.absence.early.urb <- glm(
    Danaus.early ~ Distance,
    data = final.presence.absence.data,
    family = binomial(link = "logit")
    ),
  danaus.presence.absence.late.urb <- glm(
    Danaus.late ~ Distance,
    data = final.presence.absence.data,
    family = binomial(link = "logit")
    ),

  ## Rhyssomatus
  rhyssomatus.presence.absence.early.urb <- glm(
    Rhyssomatus.early ~ Distance,
    data = final.presence.absence.data,
    family = binomial(link = "logit")
    ),
  rhyssomatus.presence.absence.late <- glm(
    Rhyssomatus.late ~ Distance,
    data = final.presence.absence.data,
    family = binomial(link = "logit")
    ),

  ## Aphis
  aphis.presence.absence.early.urb <- glm(
    Aphis.early ~ Distance,
    data = final.presence.absence.data,
    family = binomial(link = "logit")
    ),
  aphis.presence.absence.late.urb <- glm(
    Aphis.late ~ Distance,
    data = final.presence.absence.data,
    family = binomial(link = "logit")
    ),

  ## Tetraopes
  tetraopes.presence.absence.early.urb <- glm(
    Tetraopes.early ~ Distance,
    data = final.presence.absence.data,
    family = binomial(link = "logit")
    ),
  tetraopes.presence.absence.late.urb <- glm(
    Tetraopes.late ~ Distance,
    data = final.presence.absence.data,
    family = binomial(link = "logit")
    ),

  ## Liriomyza
  liriomyza.presence.absence.early.urb <- glm(
```

```
    Liriomyza.early ~ Distance,
    data = final.presence.absence.data,
    family = binomial(link = "logit")
    ),
  liriomyza.presence.absence.late.urb <- glm(
    Liriomyza.late ~ Distance,
    data = final.presence.absence.data,
    family = binomial(link = "logit"),
    )
  )
```

```
## pSEM summary
urbanization.pSEM.presence.absence.summary <- summary(
    urbanization.pSEM.presence.absence,
    conserve = TRUE
    )

## Test of directed separation
urbanization.pSEM.presence.absence.directed.separation <- dSep(
    urbanization.pSEM.presence.absence,
    conserve = TRUE
    )

## Get Fisher's C statistics of model fit
fisherC(urbanization.pSEM.presence.absence, conserve = TRUE)
# Fisher's C = 62.180, df = 90, P = 0.989

## R-squared values for endogenous variables
urbanization.pSEM.presence.absence.R.squared <- rsquared(
    urbanization.pSEM.presence.absence
    )

## Standardized coefficients
urbanization.pSEM.presence.absence.path.coefficients <- coefs(
    urbanization.pSEM.presence.absence,
    standardize.type = "latent.linear"
    )
```

Table 22: Path coefficients for each causal and correlational pathway in the urbanization pSEM (presence-absence). Global model fit: Fisher's $C = 62.180, df = 90, P = 0.989$; AICc = 148.827. R^2 values for endogenous variables: $Danaus_{early} = 0.04, Danaus_{late} = 0.04, Rhyssomatus_{early} = 0.09, Rhyssomatus_{late} = 0.09, Aphis_{early} = 0.01, Aphis_{late} = 0.01, Tetraopes_{early} = 0.01, Tetraopes_{late} = 0.01, Liriomyza_{early} = 0.01, Liriomyza_{late} = 0.01$.

Response	Predictor	Estimate	Std.Error	DF	Crit.Value	P.Value	Std.Estimate
Danaus.early	Distance	-0.035	0.025	65	-1.394	0.163	-0.220
Danaus.late	Distance	-0.035	0.025	65	-1.394	0.163	-0.220
Rhyssomatus.early	Distance	0.059	0.036	65	1.634	0.102	0.351
Rhyssomatus.late	Distance	0.059	0.036	65	1.634	0.102	0.351
Aphis.early	Distance	-0.026	0.070	65	-0.378	0.706	-0.167
Aphis.late	Distance	-0.026	0.070	65	-0.378	0.706	-0.167
Tetraopes.early	Distance	0.011	0.021	65	0.501	0.616	0.069
Tetraopes.late	Distance	0.011	0.021	65	0.501	0.616	0.069
Liriomyza.early	Distance	-0.021	0.033	65	-0.631	0.528	-0.133
Liriomyza.late	Distance	-0.021	0.033	65	-0.631	0.528	-0.133

Herbivore Interactions (Hypothesized pSEM 2) | Presence-Absence

```
## Specify the herbivore interactions pSEM
herbivore.pSEM.presence.absence <- psem(
  ## Danaus
  danaus.presence.absence.late.herb.toronto <- glm(
    Danaus.late ~ Danaus.early + Rhyssomatus.early + Aphis.early + Tetraopes.early + Liriomyza.early,
    data = final.presence.absence.data,
    family = binomial(link = "logit")
    ),

  # Correlations
  Danaus.early %~~% Rhyssomatus.early,
  Danaus.early %~~% Aphis.early,
    Danaus.early %~~% Tetraopes.early,
  Danaus.early %~~% Liriomyza.early,
  Danaus.late %~~% Rhyssomatus.late,
  Danaus.late %~~% Aphis.late,
    Danaus.late %~~% Tetraopes.late,
    Danaus.late %~~% Liriomyza.late,

  ## Rhyssomatus
  rhyssomatus.presence.absence.late.herb.toronto <- glm(
    Rhyssomatus.late ~ Rhyssomatus.early,
    data = final.presence.absence.data,
    family = binomial(link = "logit")
    ),

  # Correlations
  Rhyssomatus.early %~~% Liriomyza.early,
  Rhyssomatus.late %~~% Liriomyza.late,

  ## Aphis
  aphis.presence.absence.late.herb.toronto <- glm(
    Aphis.late ~ Danaus.early + Rhyssomatus.early + Aphis.early + Tetraopes.early + Liriomyza.early,
    data = final.presence.absence.data,
    family = binomial(link = "logit")
    ),

  # Correlations
  Aphis.early %~~% Rhyssomatus.early,
  Aphis.early %~~% Tetraopes.early,
  Aphis.early %~~% Liriomyza.early,
  Aphis.late %~~% Rhyssomatus.late,
  Aphis.late %~~% Tetraopes.late,
    Aphis.late %~~% Liriomyza.late,

  ## Tetraopes
  tetraopes.presence.absence.late.herb.toronto <- glm(
    Tetraopes.late ~ Danaus.early + Rhyssomatus.early + Aphis.early + Tetraopes.early + Liriomyza.early
    data = final.presence.absence.data,
    family = binomial(link = "logit")
    ),
```

```
  # Correlations
  Tetraopes.early %~~% Rhyssomatus.early,
  Tetraopes.early %~~% Liriomyza.early,
  Tetraopes.late %~~% Rhyssomatus.late,
    Tetraopes.late %~~% Liriomyza.late,

  ## Liriomyza
  liriomyza.presence.absence.late.herb.toronto <- glm(
    Liriomyza.late ~ Danaus.early + Rhyssomatus.early + Aphis.early + Tetraopes.early + Liriomyza.early
    data = final.presence.absence.data,
    family = binomial(link = "logit"),
    )
  )
```

```
## pSEM summary
herbivore.pSEM.presence.absence.summary <- summary(
    herbivore.pSEM.presence.absence,
    conserve = TRUE
    )

## Test of directed separation
herbivore.pSEM.presence.absence.directed.separation <- dSep(
    herbivore.pSEM.presence.absence,
    conserve = TRUE
    )

## Get Fisher's C statistics of model fit
fisherC(herbivore.pSEM.presence.absence, conserve = TRUE)
# Fisher's C < 0.001, df = 8, P = 0.999

## R-squared values for endogenous variables
herbivore.pSEM.presence.absence.R.squared <- rsquared(
    herbivore.pSEM.presence.absence
    )

## Standardized coefficients
herbivore.pSEM.presence.absence.path.coefficients <- coefs(
    herbivore.pSEM.presence.absence,
    standardize.type = "latent.linear"
    )
```

Table 23: Path coefficients for each causal and correlational pathway in the herbivore interactions pSEM (presence-absence). Global model fit: Fisher's $C = 0, df = 8, P = 0.999$; AICc = 87.100. R^2 values for endogenous variables: $Danaus_{late} = 1, Rhyssomatus_{late} = 1, Aphis_{late} = 1, Tetraopes_{late} = 1, Liriomyza_{late} = 1$.

Response	Predictor	Estimate	Std.Error	DF	Crit.Value	P.Value	Std.Estimate	
Danaus.late	Danaus.early	53.132	109555.9318	61	0.000	1.000	0.997	
Danaus.late	Rhyssomatus.early	0.000	156494.9567	61	0.000	1.000	0.000	
Danaus.late	Aphis.early	0.000	264171.5189	61	0.000	1.000	0.000	
Danaus.late	Tetraopes.early	0.000	94865.2104	61	0.000	1.000	0.000	
Danaus.late	Liriomyza.early	0.000	145397.4877	61	0.000	1.000	0.000	
~~Danaus.early	~~Rhyssomatus.early	-0.096	-	65	-0.777	0.440	-0.096	
~~Danaus.early	~~Aphis.early	-0.126	-	65	-1.020	0.311	-0.126	
~~Danaus.early	~~Tetraopes.early	-0.176	-	65	-1.446	0.153	-0.176	
~~Danaus.early	~~Liriomyza.early	-0.056	-	65	-0.448	0.655	-0.056	
~~Danaus.late	~~Rhyssomatus.late	-0.096	-	67	-0.771	0.222	-0.096	
~~Danaus.late	~~Aphis.late	-0.126	-	67	-1.013	0.158	-0.126	
~~Danaus.late	~~Tetraopes.late	-0.176	-	67	-1.435	0.078	-0.176	
~~Danaus.late	~~Liriomyza.late	-0.056	-	67	-0.445	0.329	-0.056	
Rhyssomatus.late	Rhyssomatus.early	53.132	152369.5553	65	0.000	1.000	0.993	
~~Rhyssomatus.early	~~Liriomyza.early	-0.064	-	65	-0.515	0.608	-0.064	
~~Rhyssomatus.late	~~Liriomyza.late	-0.064	-	67	-0.511	0.306	-0.064	
Aphis.late	Danaus.early	0.000	109555.9293	61	0.000	1.000	0.000	
Aphis.late	Rhyssomatus.early	0.000	156494.94	61	0.000	1.000	0.000	
Aphis.late	Aphis.early	53.132	264171.5581	61	0.000	1.000	0.981	
Aphis.late	Tetraopes.early	0.000	94865.1986	61	0.000	1.000	0.000	
Aphis.late	Liriomyza.early	0.000	145397.4689	61	0.000	1.000	0.000	
~~Aphis.early	~~Rhyssomatus.early	-0.055	-	65	-0.444	0.658	-0.055	
~~Aphis.early	~~Tetraopes.early	0.214	-	65	1.762	0.083	0.214	
~~Aphis.early	~~Liriomyza.early	0.060	-	65	0.484	0.630	0.060	
~~Aphis.late	~~Rhyssomatus.late	-0.055	-	67	-0.441	0.330	-0.055	
~~Aphis.late	~~Tetraopes.late	0.214	-	67	1.748	0.043	0.214	*
~~Aphis.late	~~Liriomyza.late	0.060	-	67	0.480	0.316	0.060	
Tetraopes.late	Danaus.early	0.000	109555.936	61	0.000	1.000	0.000	
Tetraopes.late	Rhyssomatus.early	0.000	156494.9537	61	0.000	1.000	0.000	
Tetraopes.late	Aphis.early	0.000	264171.5354	61	0.000	1.000	0.000	
Tetraopes.late	Tetraopes.early	53.132	94865.2068	61	0.001	1.000	0.998	
Tetraopes.late	Liriomyza.early	0.000	145397.4717	61	0.000	1.000	0.000	
~~Tetraopes.early	~~Rhyssomatus.early	0.169	-	65	1.379	0.173	0.169	
~~Tetraopes.early	~~Liriomyza.early	0.181	-	65	1.485	0.142	0.181	
~~Tetraopes.late	~~Rhyssomatus.late	0.169	-	67	1.368	0.088	0.169	
~~Tetraopes.late	~~Liriomyza.late	0.181	-	67	1.474	0.073	0.181	
Liriomyza.late	Danaus.early	0.000	109555.8202	61	0.000	1.000	0.000	
Liriomyza.late	Rhyssomatus.early	0.000	156494.8521	61	0.000	1.000	0.000	
Liriomyza.late	Aphis.early	0.000	264170.9607	61	0.000	1.000	0.000	
Liriomyza.late	Tetraopes.early	0.000	94865.0963	61	0.000	1.000	0.000	
Liriomyza.late	Liriomyza.early	53.132	145397.4694	61	0.000	1.000	0.994	

Urbanization & Herbivore Interactions (Hypothesized pSEM 3) | Presence-Absence

```
## Specify the urbanization pSEM
urbanization.herbivore.pSEM.presence.absence <- psem(
   ## Danaus
  danaus.presence.absence.early.urb_herb.toronto <- glm(
    Danaus.early ~ Distance,
    data = final.presence.absence.data,
    family = binomial(link = "logit")
    ),
  danaus.presence.absence.late.urb_herb.toronto <- glm(
    Danaus.late ~ Distance + Danaus.early + Rhyssomatus.early + Aphis.early + Tetraopes.early + Liriomyz
    data = final.presence.absence.data,
    family = binomial(link = "logit")
    ),

  # Correlations
  Danaus.early %~~% Rhyssomatus.early,
  Danaus.early %~~% Aphis.early,
    Danaus.early %~~% Tetraopes.early,
  Danaus.early %~~% Liriomyza.early,
  Danaus.late %~~% Rhyssomatus.late,
  Danaus.late %~~% Aphis.late,
    Danaus.late %~~% Tetraopes.late,
    Danaus.late %~~% Liriomyza.late,

  ## Rhyssomatus
  rhyssomatus.presence.absence.early.urb_herb.toronto <- glm(
    Rhyssomatus.early ~ Distance,
    data = final.presence.absence.data,
    family = binomial(link = "logit")
    ),
  rhyssomatus.presence.absence.late.urb_herb.toronto <- glm(
    Rhyssomatus.late ~ Distance + Rhyssomatus.early,
    data = final.presence.absence.data,
    family = binomial(link = "logit")
    ),

  # Correlations
  Rhyssomatus.early %~~% Liriomyza.early,
  Rhyssomatus.late %~~% Liriomyza.late,

  ## Aphis
  aphis.presence.absence.early.urb_herb.toronto <- glm(
    Aphis.early ~ Distance,
    data = final.presence.absence.data,
    family = binomial(link = "logit")
    ),
  aphis.presence.absence.late.urb_herb.toronto <- glm(
    Aphis.late ~ Distance + Danaus.early + Rhyssomatus.early + Aphis.early + Tetraopes.early + Liriomyza
    data = final.presence.absence.data,
    family = binomial(link = "logit")
    ),
```

```
# Correlations
Aphis.early %~% Rhyssomatus.early,
Aphis.early %~% Tetraopes.early,
Aphis.early %~% Liriomyza.early,
Aphis.late %~% Rhyssomatus.late,
Aphis.late %~% Tetraopes.late,
  Aphis.late %~% Liriomyza.late,

## Tetraopes
tetraopes.presence.absence.early.urb_herb.toronto <- glm(
  Tetraopes.early ~ Distance,
  data = final.presence.absence.data,
  family = binomial(link = "logit")
  ),
tetraopes.presence.absence.late.urb_herb.toronto <- glm(
  Tetraopes.late ~ Distance + Danaus.early + Rhyssomatus.early + Aphis.early + Tetraopes.early + Liri
  data = final.presence.absence.data,
  family = binomial(link = "logit")
  ),

# Correlations
Tetraopes.early %~% Rhyssomatus.early,
Tetraopes.early %~% Liriomyza.early,
Tetraopes.late %~% Rhyssomatus.late,
  Tetraopes.late %~% Liriomyza.late,

## Liriomyza
liriomyza.presence.absence.early.urb_herb.toronto <- glm(
  Liriomyza.early ~ Distance,
  data = final.presence.absence.data,
  family = binomial(link = "logit")
  ),
liriomyza.presence.absence.late.urb_herb.toronto <- glm(
  Liriomyza.late ~ Distance + Danaus.early + Rhyssomatus.early + Aphis.early + Tetraopes.early + Liri
  data = final.presence.absence.data,
  family = binomial(link = "logit"),
  )
)
```

```
## pSEM summary
urbanization.herbivore.pSEM.presence.absence.summary <- summary(
    urbanization.herbivore.pSEM.presence.absence,
    conserve = TRUE
    )

## Test of directed separation
urbanization.herbivore.pSEM.presence.absence.directed.separation <- dSep(
    urbanization.herbivore.pSEM.presence.absence,
    conserve = TRUE
    )

## Get Fisher's C statistics of model fit
fisherC(urbanization.herbivore.pSEM.presence.absence, conserve = TRUE)
# Fisher's C < 0.001, df = 8, P = 0.999

## R-squared values for endogenous variables
urbanization.herbivore.pSEM.presence.absence.R.squared <- rsquared(
    urbanization.herbivore.pSEM.presence.absence
    )

## Standardized coefficients
urbanization.herbivore.pSEM.presence.absence.path.coefficients <- coefs(
    urbanization.herbivore.pSEM.presence.absence,
    standardize.type = "latent.linear"
    )
```

Table 24: Path coefficients for each causal and correlational pathway in the urbanization and herbivore interactions pSEM (presence-absence). Global model fit: Fisher's $C = 0, df = 8, P = 0.999$; AICc = 219.760. R^2 values for endogenous variables: $Danaus_{early} = 0.04, Danaus_{late} = 1, Rhyssomatus_{early} = 0.09, Rhyssomatus_{late} = 1, Aphis_{early} = 0.01, Aphis_{late} = 1, Tetraopes_{early} = 0.01, Tetraopes_{late} = 1, Liriomyza_{early} = 0.01, Liriomyza_{late} = 0.1$.

Response	Predictor	Estimate	Std.Error	DF	Crit.Value	P.Value	Std.Estimate
Danaus.early	Distance	-0.035	0.025	65	-1.394	0.163	-0.220
Danaus.late	Distance	-0.035	0.025	65	-1.394	0.163	-0.220
Rhyssomatus.early	Distance	0.059	0.036	65	1.634	0.102	0.351
Rhyssomatus.late	Distance	0.059	0.036	65	1.634	0.102	0.351
Aphis.early	Distance	-0.026	0.070	65	-0.378	0.706	-0.167
Aphis.late	Distance	-0.026	0.070	65	-0.378	0.706	-0.167
Tetraopes.early	Distance	0.011	0.021	65	0.501	0.616	0.069
Tetraopes.late	Distance	0.011	0.021	65	0.501	0.616	0.069
Liriomyza.early	Distance	-0.021	0.033	65	-0.631	0.528	-0.133
Liriomyza.late	Distance	-0.021	0.033	65	-0.631	0.528	-0.133

pSEM Comparisons (Presence-Absence)

Table 25: Summary of hypothesize pSEMs model fits and information theoretic comparisons using presence-absence data. We report the model name (pSEM 1 = urbanization, pSEM 2 = herbivore interactions, and pSEM 3 = urbanization and herbivore interactions), Fisher's C statistic of goodness-of-fit, degrees of freedom in the pSEM (df), P-value associated with pSEM goodness-of-fit test (P), Akaike's information criteria with a sample size correction (AIC_c), difference in AIC_c between the candidate pSEM and the best-supported pSEM (ΔAIC_c), and the number of parameters fitted in the model (K).

Model	Fisher's C	df	P	AIC_c	ΔAIC_c	K
pSEM 2	0	8	0.999	87.100	0	26
pSEM 1	62.180	90	0.989	148.827	85.102	20
pSEM 3	0	8	0.999	219.760	132.681	41

Appendix

Estimated marginal means and contrasts were analyzed using the `emmeans` package. Predictions were weighted by cell frequency, and P-values were adjusted using the false discovery rate (FDR).

Marginal Means: Abundance, Richness, & Diversity (Toronto)

Toronto Abundance

```
## emmeans
# Season
toronto.abundance.emmeans.season <- emmeans(
    toronto.abundance.ANCOVA,
    specs = pairwise ~ Season,
    weights = "cells",
    adjust = "fdr"
)

# Distance x Season
toronto.abundance.emmeans.distance_season <- emmeans(
    toronto.abundance.ANCOVA,
    specs = pairwise ~ Season | Distance,
    weights = "cells",
    adjust = "fdr"
)
```

Table 26: Estimated marginal means of the main effect of Season in the Toronto Abundance ANCOVA.

Season	estimate	std.error	df	statistic	p.value
Early	2.775	0.104	Inf	26.647	0
Late	2.823	0.108	Inf	26.206	0

Table 27: Estimated marginal means of the two-way interaction between Distance and Season in the Toronto Abundance ANCOVA.

Season	Distance	estimate	std.error	df	statistic	p.value
Early	17.977	2.775	0.104	Inf	26.647	0
Late	17.977	2.823	0.108	Inf	26.206	0

Toronto Richness

```
## emmeans
# Season
toronto.richness.emmeans.season <- emmeans(
    toronto.richness.ANCOVA,
    specs = pairwise ~ Season,
    weights = "cells",
    adjust = "fdr"
)

# Distance x Season
toronto.richness.emmeans.distance_season <- emmeans(
    toronto.richness.ANCOVA,
    specs = pairwise ~ Season | Distance,
    weights = "cells",
    adjust = "fdr"
)
```

Table 28: Estimated marginal means of the main effect of Season in the Toronto Richness ANCOVA.

Season	estimate	std.error	df	statistic	p.value
Early	0.798	0.079	Inf	10.093	0
Late	0.851	0.080	Inf	10.648	0

Table 29: Estimated marginal means of the two-way interaction between Distance and Season in the Toronto Richness ANCOVA.

Season	Distance	estimate	std.error	df	statistic	p.value
Early	17.977	0.798	0.079	Inf	10.093	0
Late	17.977	0.851	0.080	Inf	10.648	0

Toronto Diversity

```
## emmeans
# Season
toronto.diversity.emmeans.season <- emmeans(
    toronto.diversity.ANCOVA,
    specs = pairwise ~ Season,
    weights = "cells",
    adjust = "fdr"
)

# Distance x Season
toronto.diversity.emmeans.distance_season <- emmeans(
    toronto.diversity.ANCOVA,
    specs = pairwise ~ Season | Distance,
    weights = "cells",
    adjust = "fdr"
)
```

Table 30: Estimated marginal means of the main effect of Season in the Toronto Diversity ANCOVA.

Season	estimate	std.error	df	statistic	p.value
Early	0.538	0.042	135	12.764	0
Late	0.570	0.044	135	13.049	0

Table 31: Estimated marginal means of the two-way interaction between Distance and Season in the Toronto Diversity ANCOVA.

Season	Distance	estimate	std.error	df	statistic	p.value
Early	17.977	0.538	0.042	135	12.764	0
Late	17.977	0.570	0.044	135	13.049	0

Marginal Means: Abundance, Richness, & Diversity (5 Cities)

5 Cities Abundance

```
## emmeans
# City
five.cities.abundance.emmeans.city <- emmeans(
    five.cities.abundance.ANOVA,
    specs = pairwise ~ City,
    weights = "cells",
    adjust = "fdr"
)

# Habitat
five.cities.abundance.emmeans.habitat <- emmeans(
    five.cities.abundance.ANOVA,
    specs = pairwise ~ Habitat,
    weights = "cells",
    adjust = "fdr"
)

# Season
five.cities.abundance.emmeans.season <- emmeans(
    five.cities.abundance.ANOVA,
    specs = pairwise ~ Season,
    weights = "cells",
    adjust = "fdr"
)
```

```
## emmeans
# City x Habitat
five.cities.abundance.emmeans.city_habitat <- emmeans(
    five.cities.abundance.ANOVA,
    specs = pairwise ~ City:Habitat,
    weights = "cells",
    adjust = "fdr"
)

# City x Season
five.cities.abundance.emmeans.city_season <- emmeans(
    five.cities.abundance.ANOVA,
    specs = pairwise ~ City:Season,
    weights = "cells",
    adjust = "fdr"
)

# Habitat x Season
five.cities.abundance.emmeans.habitat_season <- emmeans(
    five.cities.abundance.ANOVA,
    specs = pairwise ~ Habitat:Season,
    weights = "cells",
    adjust = "fdr"
```

```
)
```

```
## emmeans
# City x Habitat x Season
five.cities.abundance.emmeans.city_habitat_season <- emmeans(
    five.cities.abundance.ANOVA,
    specs = pairwise ~ City:Habitat:Season,
    weights = "cells",
    adjust = "fdr"
)
```

Table 32: Estimated marginal means of the main effect of City in the 5 Cities Abundance ANOVA.

City	estimate	std.error	df	statistic	p.value
Brantford	3.555	0.331	Inf	10.741	0
Guelph	3.208	0.330	Inf	9.728	0
Kitchener	4.932	0.325	Inf	15.184	0
London	2.025	0.341	Inf	5.942	0
St_Catharines	2.321	0.349	Inf	6.645	0

Table 33: Estimated marginal means of the main effect of Habitat in the 5 Cities Abundance ANOVA.

Habitat	estimate	std.error	df	statistic	p.value
Rural	2.928	0.216	Inf	13.557	0
Urban	3.509	0.208	Inf	16.880	0

Table 34: Estimated marginal means of the main effect of Season in the 5 Cities Abundance ANOVA.

Season	estimate	std.error	df	statistic	p.value
Early	2.621	0.210	Inf	12.485	0
Late	3.846	0.214	Inf	17.989	0

Table 35: Estimated marginal means of the two-way interaction between City and Habitat in the 5 Cities Abundance ANOVA.

City	Habitat	estimate	std.error	df	statistic	p.value
Brantford	Rural	2.013	0.481	Inf	4.183	0.000
Guelph	Rural	2.533	0.467	Inf	5.422	0.000
Kitchener	Rural	6.139	0.453	Inf	13.539	0.000
London	Rural	1.551	0.496	Inf	3.127	0.002
St_Catharines	Rural	2.300	0.521	Inf	4.416	0.000
Brantford	Urban	5.098	0.455	Inf	11.212	0.000
Guelph	Urban	3.883	0.466	Inf	8.340	0.000
Kitchener	Urban	3.725	0.465	Inf	8.006	0.000
London	Urban	2.499	0.467	Inf	5.347	0.000
St_Catharines	Urban	2.339	0.471	Inf	4.967	0.000

Table 36: Estimated marginal means of the two-way interaction between City and Season in the 5 Cities Abundance ANOVA.

City	Season	estimate	std.error	df	statistic	p.value
Brantford	Early	3.204	0.461	Inf	6.949	0
Guelph	Early	2.141	0.474	Inf	4.516	0
Kitchener	Early	3.278	0.466	Inf	7.039	0
London	Early	2.303	0.471	Inf	4.891	0
St_Catharines	Early	2.180	0.475	Inf	4.585	0
Brantford	Late	3.907	0.475	Inf	8.224	0
Guelph	Late	4.276	0.459	Inf	9.322	0
Kitchener	Late	6.585	0.453	Inf	14.542	0
London	Late	1.747	0.493	Inf	3.545	0
St_Catharines	Late	2.491	0.515	Inf	4.838	0

Table 37: Estimated marginal means of the two-way interaction between Habitat and Season in the 5 Cities Abundance ANOVA.

Habitat	Season	estimate	std.error	df	statistic	p.value
Rural	Early	2.667	0.297	Inf	8.971	0
Urban	Early	2.576	0.297	Inf	8.686	0
Rural	Late	3.208	0.314	Inf	10.211	0
Urban	Late	4.442	0.291	Inf	15.245	0

5 Cities Richness

```
## emmeans
# City
five.cities.richness.emmeans.city <- emmeans(
    five.cities.richness.ANOVA,
    specs = pairwise ~ City,
    weights = "cells",
    adjust = "fdr"
)

# Habitat
five.cities.richness.emmeans.habitat <- emmeans(
    five.cities.richness.ANOVA,
    specs = pairwise ~ Habitat,
    weights = "cells",
    adjust = "fdr"
)

# Season
five.cities.richness.emmeans.season <- emmeans(
    five.cities.richness.ANOVA,
    specs = pairwise ~ Season,
    weights = "cells",
    adjust = "fdr"
)
```

```
## emmeans
# City x Habitat
five.cities.richness.emmeans.city_habitat <- emmeans(
    five.cities.richness.ANOVA,
    specs = pairwise ~ City:Habitat,
    weights = "cells",
    adjust = "fdr"
)

# City x Season
five.cities.richness.emmeans.city_season <- emmeans(
    five.cities.richness.ANOVA,
    specs = pairwise ~ City:Season,
    weights = "cells",
    adjust = "fdr"
)

# Habitat x Season
five.cities.richness.emmeans.habitat_season <- emmeans(
    five.cities.richness.ANOVA,
    specs = pairwise ~ Habitat:Season,
    weights = "cells",
    adjust = "fdr"
)
```

```
## emmeans
# City x Habitat x Season
five.cities.richness.emmeans.city_habitat_season <- emmeans(
    five.cities.richness.ANOVA,
    specs = pairwise ~ City:Habitat:Season,
    weights = "cells",
    adjust = "fdr"
)
```

Table 38: Estimated marginal means of the main effect of City in the 5 Cities Richness ANOVA.

City	estimate	std.error	df	statistic	p.value
Brantford	2.000	0.252	39	7.921	0
Guelph	2.083	0.252	39	8.251	0
Kitchener	2.667	0.252	39	10.562	0
London	2.417	0.252	39	9.572	0
St_Catharines	2.000	0.264	39	7.584	0

Table 39: Estimated marginal means of the main effect of Habitat in the 5 Cities Richness ANOVA.

Habitat	estimate	std.error	df	statistic	p.value
Rural	2.448	0.162	39	15.074	0
Urban	2.033	0.160	39	12.734	0

Table 40: Estimated marginal means of the main effect of Season in the 5 Cities Richness ANOVA.

Season	estimate	std.error	df	statistic	p.value
Early	2.633	0.160	39	16.491	0
Late	1.828	0.162	39	11.253	0

Table 41: Estimated marginal means of the two-way interaction between City and Habitat in the 5 Cities Richness ANOVA.

City	Habitat	estimate	std.error	df	statistic	p.value
Brantford	Rural	2.000	0.357	39	5.601	0
Guelph	Rural	2.167	0.357	39	6.068	0
Kitchener	Rural	3.167	0.357	39	8.869	0
London	Rural	2.500	0.357	39	7.002	0
St_Catharines	Rural	2.400	0.391	39	6.136	0
Brantford	Urban	2.000	0.357	39	5.601	0
Guelph	Urban	2.000	0.357	39	5.601	0
Kitchener	Urban	2.167	0.357	39	6.068	0
London	Urban	2.333	0.357	39	6.535	0
St_Catharines	Urban	1.667	0.357	39	4.668	0

Table 42: Estimated marginal means of the two-way interaction between City and Season in the 5 Cities Richness ANOVA.

City	Season	estimate	std.error	df	statistic	p.value
Brantford	Early	2.833	0.357	39	7.935	0.000
Guelph	Early	2.500	0.357	39	7.002	0.000
Kitchener	Early	3.000	0.357	39	8.402	0.000
London	Early	2.500	0.357	39	7.002	0.000
St_Catharines	Early	2.333	0.357	39	6.535	0.000
Brantford	Late	1.167	0.357	39	3.267	0.002
Guelph	Late	1.667	0.357	39	4.668	0.000
Kitchener	Late	2.333	0.357	39	6.535	0.000
London	Late	2.333	0.357	39	6.535	0.000
St_Catharines	Late	1.600	0.391	39	4.091	0.000

Table 43: Estimated marginal means of the two-way interaction between Habitat and Season in the 5 Cities Richness ANOVA.

Habitat	Season	estimate	std.error	df	statistic	p.value
Rural	Early	2.867	0.226	39	12.694	0
Urban	Early	2.400	0.226	39	10.628	0
Rural	Late	2.000	0.234	39	8.556	0
Urban	Late	1.667	0.226	39	7.380	0

5 Cities Diversity

```
## emmeans
# City
five.cities.diversity.emmeans.city <- emmeans(
    five.cities.diversity.ANOVA,
    specs = pairwise ~ City,
    weights = "cells",
    adjust = "fdr"
)

# Habitat
five.cities.diversity.emmeans.habitat <- emmeans(
    five.cities.diversity.ANOVA,
    specs = pairwise ~ Habitat,
    weights = "cells",
    adjust = "fdr"
)

# Season
five.cities.diversity.emmeans.season <- emmeans(
    five.cities.diversity.ANOVA,
    specs = pairwise ~ Season,
    weights = "cells",
    adjust = "fdr"
)
```

```
## emmeans
# City x Habitat
five.cities.diversity.emmeans.city_habitat <- emmeans(
    five.cities.diversity.ANOVA,
    specs = pairwise ~ City:Habitat,
    weights = "cells",
    adjust = "fdr"
)

# City x Season
five.cities.diversity.emmeans.city_season <- emmeans(
    five.cities.diversity.ANOVA,
    specs = pairwise ~ City:Season,
    weights = "cells",
    adjust = "fdr"
)

# Habitat x Season
five.cities.diversity.emmeans.habitat_season <- emmeans(
    five.cities.diversity.ANOVA,
    specs = pairwise ~ Habitat:Season,
    weights = "cells",
    adjust = "fdr"
)
```

```
## emmeans
# City x Habitat x Season
five.cities.diversity.emmeans.city_habitat_season <- emmeans(
    five.cities.diversity.ANOVA,
    specs = pairwise ~ City:Habitat:Season,
    weights = "cells",
    adjust = "fdr"
)
```

Table 44: Estimated marginal means of the main effect of City in the 5 Cities Diversity ANOVA.

City	estimate	std.error	df	statistic	p.value
Brantford	0.486	0.114	39	4.246	0.000
Guelph	0.529	0.114	39	4.626	0.000
Kitchener	0.530	0.114	39	4.630	0.000
London	0.725	0.114	39	6.333	0.000
St_Catharines	0.404	0.119	39	3.379	0.002

Table 45: Estimated marginal means of the main effect of Habitat in the 5 Cities Diversity ANOVA.

Habitat	estimate	std.error	df	statistic	p.value
Rural	0.634	0.074	39	8.619	0
Urban	0.443	0.072	39	6.117	0

Table 46: Estimated marginal means of the main effect of Season in the 5 Cities Diversity ANOVA.

Season	estimate	std.error	df	statistic	p.value
Early	0.769	0.072	39	10.635	0
Late	0.296	0.074	39	4.024	0

Table 47: Estimated marginal means of the two-way interaction between City and Habitat in the 5 Cities Diversity ANOVA.

City	Habitat	estimate	std.error	df	statistic	p.value
Brantford	Rural	0.566	0.162	39	3.496	0.001
Guelph	Rural	0.654	0.162	39	4.044	0.000
Kitchener	Rural	0.609	0.162	39	3.761	0.001
London	Rural	0.793	0.162	39	4.899	0.000
St_Catharines	Rural	0.533	0.177	39	3.010	0.005
Brantford	Urban	0.406	0.162	39	2.509	0.016
Guelph	Urban	0.404	0.162	39	2.497	0.017
Kitchener	Urban	0.451	0.162	39	2.786	0.008
London	Urban	0.656	0.162	39	4.057	0.000
St_Catharines	Urban	0.296	0.162	39	1.828	0.075

Table 48: Estimated marginal means of the two-way interaction between City and Season in the 5 Cities Diversity ANOVA.

City	Season	estimate	std.error	df	statistic	p.value
Brantford	Early	0.869	0.162	39	5.370	0.000
Guelph	Early	0.755	0.162	39	4.664	0.000
Kitchener	Early	0.806	0.162	39	4.983	0.000
London	Early	0.782	0.162	39	4.831	0.000
St_Catharines	Early	0.636	0.162	39	3.933	0.000
Brantford	Late	0.103	0.162	39	0.634	0.530
Guelph	Late	0.304	0.162	39	1.878	0.068
Kitchener	Late	0.253	0.162	39	1.565	0.126
London	Late	0.667	0.162	39	4.125	0.000
St_Catharines	Late	0.125	0.177	39	0.704	0.485

Table 49: Estimated marginal means of the two-way interaction between Habitat and Season in the 5 Cities Diversity ANOVA.

Habitat	Season	estimate	std.error	df	statistic	p.value
Rural	Early	0.882	0.102	39	8.620	0.000
Urban	Early	0.657	0.102	39	6.419	0.000
Rural	Late	0.369	0.106	39	3.481	0.001
Urban	Late	0.228	0.102	39	2.231	0.031

Marginal Means: Leaf Herbivory (Toronto)

```
## emmeans
# Season
toronto.leaf.herbivory.emmeans.season <- emmeans(
    toronto.leaf.herbivory.LMM,
    specs = pairwise ~ Season,
    weights = "cells",
    adjust = "fdr"
)

# Distance x Season
toronto.leaf.herbivory.emmeans.distance_season <- emmeans(
    toronto.leaf.herbivory.LMM,
    specs = pairwise ~ Season | Distance,
    weights = "cells",
    adjust = "fdr"
)
```

Table 50: Estimated marginal means of the main effect of Season in the Toronto Leaf Herbivory ANCOVA.

Season	estimate	std.error	df	statistic	p.value
Early	1.102	0.079	66.417	13.927	0
Late	1.989	0.101	63.014	19.771	0

Table 51: Estimated marginal means of the two-way interaction between Distance and Season in the Toronto Leaf Herbivory ANCOVA.

Season	Distance	estimate	std.error	df	statistic	p.value
Early	18.748	1.102	0.079	66.417	13.927	0
Late	18.748	1.989	0.101	63.014	19.771	0

Marginal Means: Leaf Herbivory (5 Cities)

```
## emmeans
# City
five.cities.leaf.herbivory.emmeans.city <- emmeans(
    five.cities.leaf.herbivory.LMM,
    specs = pairwise ~ City,
    weights = "cells",
    adjust = "fdr"
)

# Habitat
five.cities.leaf.herbivory.emmeans.habitat <- emmeans(
    five.cities.leaf.herbivory.LMM,
    specs = pairwise ~ Habitat,
    weights = "cells",
    adjust = "fdr"
)

# Season
five.cities.leaf.herbivory.emmeans.season <- emmeans(
    five.cities.leaf.herbivory.LMM,
    specs = pairwise ~ Season,
    weights = "cells",
    adjust = "fdr"
)
```

```
## emmeans
# City x Habitat
five.cities.leaf.herbivory.emmeans.city_habitat <- emmeans(
    five.cities.leaf.herbivory.LMM,
    specs = pairwise ~ City:Habitat,
    weights = "cells",
    adjust = "fdr"
)

# City x Season
five.cities.leaf.herbivory.emmeans.city_season <- emmeans(
    five.cities.leaf.herbivory.LMM,
    specs = pairwise ~ City:Season,
    weights = "cells",
    adjust = "fdr"
)

# Habitat x Season
five.cities.leaf.herbivory.emmeans.habitat_season <- emmeans(
    five.cities.leaf.herbivory.LMM,
    specs = pairwise ~ Habitat:Season,
    weights = "cells",
    adjust = "fdr"
)
```

```r
## emmeans
# City x Habitat x Season
five.cities.leaf.herbivory.emmeans.city_habitat_season <- emmeans(
    five.cities.leaf.herbivory.LMM,
    specs = pairwise ~ City:Habitat:Season,
    weights = "cells",
    adjust = "fdr"
)
```

Table 52: Estimated marginal means of the main effect of City in the 5 Cities Leaf Herbivory ANOVA.

City	estimate	std.error	df	statistic	p.value
Brantford	1.307	0.153	34.057	8.539	0
Guelph	1.042	0.150	38.535	6.954	0
Kitchner	0.989	0.150	38.015	6.577	0
London	1.291	0.156	34.472	8.278	0
St_Catharines	0.836	0.154	33.719	5.421	0

Table 53: Estimated marginal means of the main effect of Habitat in the 5 Cities Leaf Herbivory ANOVA.

Habitat	estimate	std.error	df	statistic	p.value
Rural	1.295	0.102	34.641	12.749	0
Urban	0.904	0.102	32.027	8.888	0

Table 54: Estimated marginal means of the main effect of Season in the 5 Cities Leaf Herbivory ANOVA.

Season	estimate	std.error	df	statistic	p.value
Early	0.165	0.095	31.953	1.748	0.09
Late	2.070	0.097	31.171	21.304	0.00

Table 55: Estimated marginal means of the two-way interaction between City and Habitat in the 5 Cities Leaf Herbivory ANOVA.

City	Habitat	estimate	std.error	df	statistic	p.value
Brantford	Rural	1.675	0.194	45.271	8.621	0.000
Guelph	Rural	1.192	0.185	66.560	6.434	0.000
Kitchner	Rural	1.461	0.191	55.439	7.639	0.000
London	Rural	1.304	0.209	42.455	6.241	0.000
St_Catharines	Rural	0.753	0.224	38.313	3.366	0.002
Brantford	Urban	0.939	0.196	46.132	4.794	0.000
Guelph	Urban	0.893	0.195	71.537	4.573	0.000
Kitchner	Urban	0.518	0.183	67.992	2.825	0.006
London	Urban	1.279	0.222	37.273	5.774	0.000
St_Catharines	Urban	0.906	0.213	30.729	4.258	0.000

Table 56: Estimated marginal means of the two-way interaction between City and Season in the 5 Cities Leaf Herbivory ANOVA.

City	Season	estimate	std.error	df	statistic	p.value
Brantford	Early	0.197	0.198	47.700	0.994	0.325
Guelph	Early	0.149	0.197	50.760	0.754	0.454
Kitchner	Early	0.078	0.197	51.118	0.396	0.694
London	Early	0.269	0.207	38.164	1.300	0.201
St_Catharines	Early	0.138	0.213	30.729	0.649	0.521
Brantford	Late	2.418	0.205	39.117	11.812	0.000
Guelph	Late	1.936	0.197	50.036	9.818	0.000
Kitchner	Late	1.901	0.198	49.514	9.616	0.000
London	Late	2.390	0.201	52.822	11.867	0.000
St_Catharines	Late	1.674	0.224	38.313	7.485	0.000

Table 57: Estimated marginal means of the two-way interaction between Habitat and Season in the 5 Cities Leaf Herbivory ANOVA.

Habitat	Season	estimate	std.error	df	statistic	p.value
Rural	Early	0.285	0.126	41.618	2.267	0.029
Urban	Early	0.044	0.127	41.498	0.348	0.730
Rural	Late	2.425	0.129	47.551	18.788	0.000
Urban	Late	1.753	0.123	45.076	14.212	0.000

Contrasts: Abundance, Richness, & Diversity (Toronto)

Toronto Abundance

Table 58: Post-hoc comparisons of the main effect of Season in the Toronto Abundance ANCOVA.

Term	Contrast	Null Value	Estimate	SE	df	statistic	P_fdr
Season	Early - Late	0	-0.048	0.15	Inf	-0.322	0.747

Table 59: Post-hoc comparisons of the two-way interaction between Distance and Season in the Toronto Abundance ANCOVA.

Distance (emmean)	Term	Contrast	Null Value	Estimate	SE	df	statistic	P_fdr
17.977	Season	Early - Late	0	-0.048	0.15	Inf	-0.322	0.747

Toronto Richness

Table 60: Post-hoc comparisons of the main effect of Season in the Toronto Richness ANCOVA.

Term	Contrast	Null Value	Estimate	SE	df	statistic	P_fdr
Season	Early - Late	0	-0.052	0.112	Inf	-0.466	0.641

Table 61: Post-hoc comparisons of the two-way interaction between Distance and Season in the Toronto Richness ANCOVA.

Distance (emmean)	Term	Contrast	Null Value	Estimate	SE	df	statistic	P_fdr
17.977	Season	Early - Late	0	-0.052	0.112	Inf	-0.466	0.641

Toronto Diversity

Table 62: Post-hoc comparisons of the main effect of Season in the Toronto Diversity ANCOVA.

Term	Contrast	Null Value	Estimate	SE	df	statistic	P_fdr
Season	Early - Late	0	-0.032	0.061	135	-0.53	0.597

Table 63: Post-hoc comparisons of the two-way interaction between Distance and Season in the Toronto Diversity ANCOVA.

Distance (emmean)	Term	Contrast	Null Value	Estimate	SE	df	statistic	P_fdr
17.977	Season	Early - Late	0	-0.032	0.061	135	-0.53	0.597

Contrasts: Abundance, Richness, & Diversity (5 Cities)

5 Cities Abundance

Table 64: Post-hoc comparisons of the main effect of City in the 5 Cities Abundance ANOVA.

Term	Contrast	Null Value	Estimate	SE	df	statistic	P_fdr
City	Brantford - Guelph	0	0.347	0.467	Inf	0.743	0.508
City	Brantford - Kitchener	0	-1.377	0.464	Inf	-2.968	0.006
City	Brantford - London	0	1.531	0.475	Inf	3.223	0.003
City	Brantford - St_Catharines	0	1.234	0.481	Inf	2.565	0.017
City	Guelph - Kitchener	0	-1.724	0.463	Inf	-3.724	0.001
City	Guelph - London	0	1.184	0.474	Inf	2.496	0.018
City	Guelph - St_Catharines	0	0.887	0.480	Inf	1.846	0.081
City	Kitchener - London	0	2.907	0.471	Inf	6.176	0.000
City	Kitchener - St_Catharines	0	2.611	0.477	Inf	5.473	0.000
City	London - St_Catharines	0	-0.297	0.488	Inf	-0.608	0.543

Table 65: Post-hoc comparisons of the main effect of Habitat in the 5 Cities Abundance ANOVA.

Term	Contrast	Null Value	Estimate	SE	df	statistic	P_fdr
Habitat	Rural - Urban	0	-0.581	0.3	Inf	-1.938	0.053

Table 66: Post-hoc comparisons of the main effect of Season in the 5 Cities Abundance ANOVA.

Term	Contrast	Null Value	Estimate	SE	df	statistic	P_fdr
Season	Early - Late	0	-1.225	0.3	Inf	-4.089	0

Table 67: Post-hoc comparisons of the two-way interaction between City and Habitat in the 5 Cities Abundance ANOVA.

Term	Contrast	Null Value	Estimate	SE	df	statistic	P_fdr
City*Habitat	Brantford Rural - Guelph Rural	0	-0.520	0.671	Inf	-0.775	0.580
City*Habitat	Brantford Rural - Kitchener Rural	0	-4.126	0.661	Inf	-6.242	0.000
City*Habitat	Brantford Rural - London Rural	0	0.462	0.691	Inf	0.669	0.630
City*Habitat	Brantford Rural - St_Catharines Rural	0	-0.287	0.709	Inf	-0.405	0.812
City*Habitat	Brantford Rural - Brantford Urban	0	-3.085	0.662	Inf	-4.661	0.000
City*Habitat	Brantford Rural - Guelph Urban	0	-1.871	0.670	Inf	-2.794	0.014
City*Habitat	Brantford Rural - Kitchener Urban	0	-1.712	0.669	Inf	-2.558	0.026
City*Habitat	Brantford Rural - London Urban	0	-0.486	0.671	Inf	-0.724	0.603
City*Habitat	Brantford Rural - St_Catharines Urban	0	-0.326	0.673	Inf	-0.485	0.764
City*Habitat	Guelph Rural - Kitchener Rural	0	-3.606	0.651	Inf	-5.540	0.000
City*Habitat	Guelph Rural - London Rural	0	0.982	0.681	Inf	1.442	0.224
City*Habitat	Guelph Rural - St_Catharines Rural	0	0.233	0.700	Inf	0.333	0.848
City*Habitat	Guelph Rural - Brantford Urban	0	-2.565	0.652	Inf	-3.935	0.000
City*Habitat	Guelph Rural - Guelph Urban	0	-1.351	0.660	Inf	-2.048	0.074
City*Habitat	Guelph Rural - Kitchener Urban	0	-1.192	0.659	Inf	-1.808	0.113
City*Habitat	Guelph Rural - London Urban	0	0.034	0.661	Inf	0.052	0.959
City*Habitat	Guelph Rural - St_Catharines Urban	0	0.194	0.663	Inf	0.292	0.848
City*Habitat	Kitchener Rural - London Rural	0	4.589	0.672	Inf	6.829	0.000
City*Habitat	Kitchener Rural - St_Catharines Rural	0	3.839	0.691	Inf	5.560	0.000
City*Habitat	Kitchener Rural - Brantford Urban	0	1.041	0.642	Inf	1.621	0.163
City*Habitat	Kitchener Rural - Guelph Urban	0	2.256	0.650	Inf	3.470	0.002
City*Habitat	Kitchener Rural - Kitchener Urban	0	2.415	0.650	Inf	3.717	0.001
City*Habitat	Kitchener Rural - London Urban	0	3.641	0.651	Inf	5.591	0.000
City*Habitat	Kitchener Rural - St_Catharines Urban	0	3.800	0.654	Inf	5.813	0.000
City*Habitat	London Rural - St_Catharines Rural	0	-0.749	0.719	Inf	-1.042	0.406
City*Habitat	London Rural - Brantford Urban	0	-3.547	0.673	Inf	-5.272	0.000
City*Habitat	London Rural - Guelph Urban	0	-2.333	0.680	Inf	-3.429	0.002
City*Habitat	London Rural - Kitchener Urban	0	-2.174	0.680	Inf	-3.197	0.004
City*Habitat	London Rural - London Urban	0	-0.948	0.681	Inf	-1.391	0.238
City*Habitat	London Rural - St_Catharines Urban	0	-0.788	0.684	Inf	-1.153	0.350
City*Habitat	St_Catharines Rural - Brantford Urban	0	-2.798	0.691	Inf	-4.047	0.000
City*Habitat	St_Catharines Rural - Guelph Urban	0	-1.584	0.699	Inf	-2.267	0.053
City*Habitat	St_Catharines Rural - Kitchener Urban	0	-1.425	0.698	Inf	-2.040	0.074
City*Habitat	St_Catharines Rural - London Urban	0	-0.199	0.700	Inf	-0.284	0.848
City*Habitat	St_Catharines Rural - St_Catharines Urban	0	-0.039	0.702	Inf	-0.056	0.959
City*Habitat	Brantford Urban - Guelph Urban	0	1.214	0.651	Inf	1.866	0.105
City*Habitat	Brantford Urban - Kitchener Urban	0	1.373	0.651	Inf	2.111	0.071
City*Habitat	Brantford Urban - London Urban	0	2.599	0.652	Inf	3.987	0.000
City*Habitat	Brantford Urban - St_Catharines Urban	0	2.759	0.655	Inf	4.215	0.000
City*Habitat	Guelph Urban - Kitchener Urban	0	0.159	0.658	Inf	0.241	0.848
City*Habitat	Guelph Urban - London Urban	0	1.385	0.660	Inf	2.099	0.071
City*Habitat	Guelph Urban - St_Catharines Urban	0	1.544	0.662	Inf	2.332	0.047
City*Habitat	Kitchener Urban - London Urban	0	1.226	0.659	Inf	1.859	0.105
City*Habitat	Kitchener Urban - St_Catharines Urban	0	1.386	0.662	Inf	2.093	0.071
City*Habitat	London Urban - St_Catharines Urban	0	0.160	0.663	Inf	0.241	0.848

Table 68: Post-hoc comparisons of the two-way interaction between City and Season in the 5 Cities Abundance ANOVA.

Term	Contrast	Null Value	Estimate	SE	df	statistic	P_fdr
City*Season	Brantford Early - Guelph Early	0	1.063	0.661	Inf	1.608	0.194
City*Season	Brantford Early - Kitchener Early	0	-0.074	0.655	Inf	-0.114	0.930
City*Season	Brantford Early - London Early	0	0.901	0.659	Inf	1.368	0.266
City*Season	Brantford Early - St_Catharines Early	0	1.024	0.662	Inf	1.547	0.211
City*Season	Brantford Early - Brantford Late	0	-0.703	0.662	Inf	-1.061	0.412
City*Season	Brantford Early - Guelph Late	0	-1.072	0.650	Inf	-1.648	0.186
City*Season	Brantford Early - Kitchener Late	0	-3.381	0.646	Inf	-5.232	0.000
City*Season	Brantford Early - London Late	0	1.457	0.675	Inf	2.160	0.069
City*Season	Brantford Early - St_Catharines Late	0	0.713	0.691	Inf	1.032	0.412
City*Season	Guelph Early - Kitchener Early	0	-1.138	0.665	Inf	-1.712	0.178
City*Season	Guelph Early - London Early	0	-0.162	0.668	Inf	-0.242	0.866
City*Season	Guelph Early - St_Catharines Early	0	-0.039	0.671	Inf	-0.058	0.954
City*Season	Guelph Early - Brantford Late	0	-1.766	0.671	Inf	-2.632	0.025
City*Season	Guelph Early - Guelph Late	0	-2.135	0.660	Inf	-3.237	0.005
City*Season	Guelph Early - Kitchener Late	0	-4.445	0.656	Inf	-6.780	0.000
City*Season	Guelph Early - London Late	0	0.394	0.684	Inf	0.576	0.683
City*Season	Guelph Early - St_Catharines Late	0	-0.350	0.700	Inf	-0.501	0.712
City*Season	Kitchener Early - London Early	0	0.976	0.662	Inf	1.473	0.226
City*Season	Kitchener Early - St_Catharines Early	0	1.099	0.666	Inf	1.651	0.186
City*Season	Kitchener Early - Brantford Late	0	-0.628	0.665	Inf	-0.944	0.457
City*Season	Kitchener Early - Guelph Late	0	-0.997	0.654	Inf	-1.525	0.212
City*Season	Kitchener Early - Kitchener Late	0	-3.307	0.650	Inf	-5.091	0.000
City*Season	Kitchener Early - London Late	0	1.532	0.678	Inf	2.259	0.056
City*Season	Kitchener Early - St_Catharines Late	0	0.787	0.694	Inf	1.134	0.385
City*Season	London Early - St_Catharines Early	0	0.123	0.669	Inf	0.184	0.894
City*Season	London Early - Brantford Late	0	-1.604	0.669	Inf	-2.398	0.041
City*Season	London Early - Guelph Late	0	-1.973	0.657	Inf	-3.002	0.009
City*Season	London Early - Kitchener Late	0	-4.283	0.653	Inf	-6.556	0.000
City*Season	London Early - London Late	0	0.556	0.681	Inf	0.816	0.533
City*Season	London Early - St_Catharines Late	0	-0.188	0.698	Inf	-0.270	0.864
City*Season	St_Catharines Early - Brantford Late	0	-1.727	0.672	Inf	-2.570	0.027
City*Season	St_Catharines Early - Guelph Late	0	-2.096	0.661	Inf	-3.173	0.006
City*Season	St_Catharines Early - Kitchener Late	0	-4.406	0.657	Inf	-6.710	0.000
City*Season	St_Catharines Early - London Late	0	0.433	0.685	Inf	0.633	0.659
City*Season	St_Catharines Early - St_Catharines Late	0	-0.311	0.701	Inf	-0.444	0.739
City*Season	Brantford Late - Guelph Late	0	-0.369	0.660	Inf	-0.559	0.683
City*Season	Brantford Late - Kitchener Late	0	-2.679	0.656	Inf	-4.081	0.000
City*Season	Brantford Late - London Late	0	2.160	0.684	Inf	3.156	0.006
City*Season	Brantford Late - St_Catharines Late	0	1.416	0.701	Inf	2.021	0.093
City*Season	Guelph Late - Kitchener Late	0	-2.310	0.645	Inf	-3.583	0.002
City*Season	Guelph Late - London Late	0	2.529	0.673	Inf	3.757	0.001
City*Season	Guelph Late - St_Catharines Late	0	1.785	0.690	Inf	2.588	0.027
City*Season	Kitchener Late - London Late	0	4.839	0.669	Inf	7.231	0.000
City*Season	Kitchener Late - St_Catharines Late	0	4.094	0.686	Inf	5.971	0.000
City*Season	London Late - St_Catharines Late	0	-0.744	0.713	Inf	-1.045	0.412

Table 69: Post-hoc comparisons of the two-way interaction between Habitat and Season in the 5 Cities Abundance ANOVA.

Term	Contrast	Null Value	Estimate	SE	df	statistic	P_fdr
Habitat*Season	Rural Early - Urban Early	0	0.091	0.420	Inf	0.217	0.828
Habitat*Season	Rural Early - Rural Late	0	-0.541	0.433	Inf	-1.252	0.253
Habitat*Season	Rural Early - Urban Late	0	-1.775	0.416	Inf	-4.265	0.000
Habitat*Season	Urban Early - Rural Late	0	-0.632	0.432	Inf	-1.464	0.215
Habitat*Season	Urban Early - Urban Late	0	-1.866	0.416	Inf	-4.489	0.000
Habitat*Season	Rural Late - Urban Late	0	-1.234	0.428	Inf	-2.880	0.008

5 Cities Richness

Table 70: Post-hoc comparisons of the main effect of City in the 5 Cities Richness ANOVA.

Term	Contrast	Null Value	Estimate	SE	df	statistic	P_fdr
City	Brantford - Guelph	0	-0.083	0.357	39	-0.233	0.912
City	Brantford - Kitchener	0	-0.667	0.357	39	-1.867	0.368
City	Brantford - London	0	-0.417	0.357	39	-1.167	0.521
City	Brantford - St_Catharines	0	0.000	0.365	39	0.000	1.000
City	Guelph - Kitchener	0	-0.583	0.357	39	-1.634	0.368
City	Guelph - London	0	-0.333	0.357	39	-0.934	0.594
City	Guelph - St_Catharines	0	0.083	0.365	39	0.228	0.912
City	Kitchener - London	0	0.250	0.357	39	0.700	0.697
City	Kitchener - St_Catharines	0	0.667	0.365	39	1.826	0.368
City	London - St_Catharines	0	0.417	0.365	39	1.141	0.521

Table 71: Post-hoc comparisons of the main effect of Habitat in the 5 Cities Richness ANOVA.

Term	Contrast	Null Value	Estimate	SE	df	statistic	P_fdr
Habitat	Rural - Urban	0	0.415	0.228	39	1.822	0.076

Table 72: Post-hoc comparisons of the main effect of Season in the 5 Cities Richness ANOVA.

Term	Contrast	Null Value	Estimate	SE	df	statistic	P_fdr
Season	Early - Late	0	0.806	0.228	39	3.538	0.001

Table 73: Post-hoc comparisons of the two-way interaction between City and Habitat in the 5 Cities Richness ANOVA.

Term	Contrast	Null Value	Estimate	SE	df	statistic	P_fdr
City*Habitat	Brantford Rural - Guelph Rural	0	-0.167	0.505	39	-0.330	0.857
City*Habitat	Brantford Rural - Kitchener Rural	0	-1.167	0.505	39	-2.310	0.295
City*Habitat	Brantford Rural - London Rural	0	-0.500	0.505	39	-0.990	0.825
City*Habitat	Brantford Rural - St_Catharines Rural	0	-0.400	0.530	39	-0.755	0.825
City*Habitat	Brantford Rural - Brantford Urban	0	0.000	0.505	39	0.000	1.000
City*Habitat	Brantford Rural - Guelph Urban	0	0.000	0.505	39	0.000	1.000
City*Habitat	Brantford Rural - Kitchener Urban	0	-0.167	0.505	39	-0.330	0.857
City*Habitat	Brantford Rural - London Urban	0	-0.333	0.505	39	-0.660	0.825
City*Habitat	Brantford Rural - St_Catharines Urban	0	0.333	0.505	39	0.660	0.825
City*Habitat	Guelph Rural - Kitchener Rural	0	-1.000	0.505	39	-1.980	0.411
City*Habitat	Guelph Rural - London Rural	0	-0.333	0.505	39	-0.660	0.825
City*Habitat	Guelph Rural - St_Catharines Rural	0	-0.233	0.530	39	-0.441	0.857
City*Habitat	Guelph Rural - Brantford Urban	0	0.167	0.505	39	0.330	0.857
City*Habitat	Guelph Rural - Guelph Urban	0	0.167	0.505	39	0.330	0.857
City*Habitat	Guelph Rural - Kitchener Urban	0	0.000	0.505	39	0.000	1.000
City*Habitat	Guelph Rural - London Urban	0	-0.167	0.505	39	-0.330	0.857
City*Habitat	Guelph Rural - St_Catharines Urban	0	0.500	0.505	39	0.990	0.825
City*Habitat	Kitchener Rural - London Rural	0	0.667	0.505	39	1.320	0.729
City*Habitat	Kitchener Rural - St_Catharines Rural	0	0.767	0.530	39	1.448	0.729
City*Habitat	Kitchener Rural - Brantford Urban	0	1.167	0.505	39	2.310	0.295
City*Habitat	Kitchener Rural - Guelph Urban	0	1.167	0.505	39	2.310	0.295
City*Habitat	Kitchener Rural - Kitchener Urban	0	1.000	0.505	39	1.980	0.411
City*Habitat	Kitchener Rural - London Urban	0	0.833	0.505	39	1.650	0.601
City*Habitat	Kitchener Rural - St_Catharines Urban	0	1.500	0.505	39	2.971	0.228
City*Habitat	London Rural - St_Catharines Rural	0	0.100	0.530	39	0.189	0.958
City*Habitat	London Rural - Brantford Urban	0	0.500	0.505	39	0.990	0.825
City*Habitat	London Rural - Guelph Urban	0	0.500	0.505	39	0.990	0.825
City*Habitat	London Rural - Kitchener Urban	0	0.333	0.505	39	0.660	0.825
City*Habitat	London Rural - London Urban	0	0.167	0.505	39	0.330	0.857
City*Habitat	London Rural - St_Catharines Urban	0	0.833	0.505	39	1.650	0.601
City*Habitat	St_Catharines Rural - Brantford Urban	0	0.400	0.530	39	0.755	0.825
City*Habitat	St_Catharines Rural - Guelph Urban	0	0.400	0.530	39	0.755	0.825
City*Habitat	St_Catharines Rural - Kitchener Urban	0	0.233	0.530	39	0.441	0.857
City*Habitat	St_Catharines Rural - London Urban	0	0.067	0.530	39	0.126	0.988
City*Habitat	St_Catharines Rural - St_Catharines Urban	0	0.733	0.530	39	1.385	0.729
City*Habitat	Brantford Urban - Guelph Urban	0	0.000	0.505	39	0.000	1.000
City*Habitat	Brantford Urban - Kitchener Urban	0	-0.167	0.505	39	-0.330	0.857
City*Habitat	Brantford Urban - London Urban	0	-0.333	0.505	39	-0.660	0.825
City*Habitat	Brantford Urban - St_Catharines Urban	0	0.333	0.505	39	0.660	0.825
City*Habitat	Guelph Urban - Kitchener Urban	0	-0.167	0.505	39	-0.330	0.857
City*Habitat	Guelph Urban - London Urban	0	-0.333	0.505	39	-0.660	0.825
City*Habitat	Guelph Urban - St_Catharines Urban	0	0.333	0.505	39	0.660	0.825
City*Habitat	Kitchener Urban - London Urban	0	-0.167	0.505	39	-0.330	0.857
City*Habitat	Kitchener Urban - St_Catharines Urban	0	0.500	0.505	39	0.990	0.825
City*Habitat	London Urban - St_Catharines Urban	0	0.667	0.505	39	1.320	0.729

Table 74: Post-hoc comparisons of the two-way interaction between City and Season in the 5 Cities Richness ANOVA.

Term	Contrast	Null Value	Estimate	SE	df	statistic	P_fdr
City*Season	Brantford Early - Guelph Early	0	0.333	0.505	39	0.660	0.700
City*Season	Brantford Early - Kitchener Early	0	-0.167	0.505	39	-0.330	0.836
City*Season	Brantford Early - London Early	0	0.333	0.505	39	0.660	0.700
City*Season	Brantford Early - St_Catharines Early	0	0.500	0.505	39	0.990	0.492
City*Season	Brantford Early - Brantford Late	0	1.667	0.505	39	3.301	0.047
City*Season	Brantford Early - Guelph Late	0	1.167	0.505	39	2.310	0.107
City*Season	Brantford Early - Kitchener Late	0	0.500	0.505	39	0.990	0.492
City*Season	Brantford Early - London Late	0	0.500	0.505	39	0.990	0.492
City*Season	Brantford Early - St_Catharines Late	0	1.233	0.530	39	2.329	0.107
City*Season	Guelph Early - Kitchener Early	0	-0.500	0.505	39	-0.990	0.492
City*Season	Guelph Early - London Early	0	0.000	0.505	39	0.000	1.000
City*Season	Guelph Early - St_Catharines Early	0	0.167	0.505	39	0.330	0.836
City*Season	Guelph Early - Brantford Late	0	1.333	0.505	39	2.640	0.089
City*Season	Guelph Early - Guelph Late	0	0.833	0.505	39	1.650	0.321
City*Season	Guelph Early - Kitchener Late	0	0.167	0.505	39	0.330	0.836
City*Season	Guelph Early - London Late	0	0.167	0.505	39	0.330	0.836
City*Season	Guelph Early - St_Catharines Late	0	0.900	0.530	39	1.699	0.321
City*Season	Kitchener Early - London Early	0	0.500	0.505	39	0.990	0.492
City*Season	Kitchener Early - St_Catharines Early	0	0.667	0.505	39	1.320	0.365
City*Season	Kitchener Early - Brantford Late	0	1.833	0.505	39	3.631	0.037
City*Season	Kitchener Early - Guelph Late	0	1.333	0.505	39	2.640	0.089
City*Season	Kitchener Early - Kitchener Late	0	0.667	0.505	39	1.320	0.365
City*Season	Kitchener Early - London Late	0	0.667	0.505	39	1.320	0.365
City*Season	Kitchener Early - St_Catharines Late	0	1.400	0.530	39	2.643	0.089
City*Season	London Early - St_Catharines Early	0	0.167	0.505	39	0.330	0.836
City*Season	London Early - Brantford Late	0	1.333	0.505	39	2.640	0.089
City*Season	London Early - Guelph Late	0	0.833	0.505	39	1.650	0.321
City*Season	London Early - Kitchener Late	0	0.167	0.505	39	0.330	0.836
City*Season	London Early - London Late	0	0.167	0.505	39	0.330	0.836
City*Season	London Early - St_Catharines Late	0	0.900	0.530	39	1.699	0.321
City*Season	St_Catharines Early - Brantford Late	0	1.167	0.505	39	2.310	0.107
City*Season	St_Catharines Early - Guelph Late	0	0.667	0.505	39	1.320	0.365
City*Season	St_Catharines Early - Kitchener Late	0	0.000	0.505	39	0.000	1.000
City*Season	St_Catharines Early - London Late	0	0.000	0.505	39	0.000	1.000
City*Season	St_Catharines Early - St_Catharines Late	0	0.733	0.530	39	1.385	0.365
City*Season	Brantford Late - Guelph Late	0	-0.500	0.505	39	-0.990	0.492
City*Season	Brantford Late - Kitchener Late	0	-1.167	0.505	39	-2.310	0.107
City*Season	Brantford Late - London Late	0	-1.167	0.505	39	-2.310	0.107
City*Season	Brantford Late - St_Catharines Late	0	-0.433	0.530	39	-0.818	0.607
City*Season	Guelph Late - Kitchener Late	0	-0.667	0.505	39	-1.320	0.365
City*Season	Guelph Late - London Late	0	-0.667	0.505	39	-1.320	0.365
City*Season	Guelph Late - St_Catharines Late	0	0.067	0.530	39	0.126	0.988
City*Season	Kitchener Late - London Late	0	0.000	0.505	39	0.000	1.000
City*Season	Kitchener Late - St_Catharines Late	0	0.733	0.530	39	1.385	0.365
City*Season	London Late - St_Catharines Late	0	0.733	0.530	39	1.385	0.365

Table 75: Post-hoc comparisons of the two-way interaction between Habitat and Season in the 5 Cities Richness ANOVA.

Term	Contrast	Null Value	Estimate	SE	df	statistic	P_fdr
Habitat*Season	Rural Early - Urban Early	0	0.467	0.319	39	1.461	0.228
Habitat*Season	Rural Early - Rural Late	0	0.867	0.325	39	2.667	0.033
Habitat*Season	Rural Early - Urban Late	0	1.200	0.319	39	3.757	0.003
Habitat*Season	Urban Early - Rural Late	0	0.400	0.325	39	1.231	0.271
Habitat*Season	Urban Early - Urban Late	0	0.733	0.319	39	2.296	0.054
Habitat*Season	Rural Late - Urban Late	0	0.333	0.325	39	1.026	0.311

5 Cities Diversity

Table 76: Post-hoc comparisons of the main effect of City in the 5 Cities Diversity ANOVA.

Term	Contrast	Null Value	Estimate	SE	df	statistic	P_fdr
City	Brantford - Guelph	0	-0.043	0.162	39	-0.269	0.877
City	Brantford - Kitchener	0	-0.044	0.162	39	-0.272	0.877
City	Brantford - London	0	-0.239	0.162	39	-1.476	0.589
City	Brantford - St_Catharines	0	0.082	0.165	39	0.495	0.877
City	Guelph - Kitchener	0	0.000	0.162	39	-0.003	0.998
City	Guelph - London	0	-0.195	0.162	39	-1.207	0.589
City	Guelph - St_Catharines	0	0.125	0.165	39	0.758	0.755
City	Kitchener - London	0	-0.195	0.162	39	-1.204	0.589
City	Kitchener - St_Catharines	0	0.126	0.165	39	0.761	0.755
City	London - St_Catharines	0	0.321	0.165	39	1.939	0.589

Table 77: Post-hoc comparisons of the main effect of Habitat in the 5 Cities Diversity ANOVA.

Term	Contrast	Null Value	Estimate	SE	df	statistic	P_fdr
Habitat	Rural - Urban	0	0.192	0.103	39	1.857	0.071

Table 78: Post-hoc comparisons of the main effect of Season in the 5 Cities Diversity ANOVA.

Term	Contrast	Null Value	Estimate	SE	df	statistic	P_fdr
Season	Early - Late	0	0.473	0.103	39	4.587	0

Table 79: Post-hoc comparisons of the two-way interaction between City and Habitat in the 5 Cities Diversity ANOVA.

Term	Contrast	Null Value	Estimate	SE	df	statistic	P_fdr
City*Habitat	Brantford Rural - Guelph Rural	0	-0.089	0.229	39	-0.388	0.900
City*Habitat	Brantford Rural - Kitchener Rural	0	-0.043	0.229	39	-0.188	0.913
City*Habitat	Brantford Rural - London Rural	0	-0.227	0.229	39	-0.993	0.871
City*Habitat	Brantford Rural - St_Catharines Rural	0	0.032	0.240	39	0.134	0.936
City*Habitat	Brantford Rural - Brantford Urban	0	0.160	0.229	39	0.698	0.871
City*Habitat	Brantford Rural - Guelph Urban	0	0.161	0.229	39	0.706	0.871
City*Habitat	Brantford Rural - Kitchener Urban	0	0.115	0.229	39	0.501	0.871
City*Habitat	Brantford Rural - London Urban	0	-0.091	0.229	39	-0.397	0.900
City*Habitat	Brantford Rural - St_Catharines Urban	0	0.270	0.229	39	1.179	0.871
City*Habitat	Guelph Rural - Kitchener Rural	0	0.046	0.229	39	0.200	0.913
City*Habitat	Guelph Rural - London Rural	0	-0.138	0.229	39	-0.604	0.871
City*Habitat	Guelph Rural - St_Catharines Rural	0	0.121	0.240	39	0.504	0.871
City*Habitat	Guelph Rural - Brantford Urban	0	0.248	0.229	39	1.086	0.871
City*Habitat	Guelph Rural - Guelph Urban	0	0.250	0.229	39	1.094	0.871
City*Habitat	Guelph Rural - Kitchener Urban	0	0.204	0.229	39	0.890	0.871
City*Habitat	Guelph Rural - London Urban	0	-0.002	0.229	39	-0.009	0.994
City*Habitat	Guelph Rural - St_Catharines Urban	0	0.359	0.229	39	1.567	0.871
City*Habitat	Kitchener Rural - London Rural	0	-0.184	0.229	39	-0.804	0.871
City*Habitat	Kitchener Rural - St_Catharines Rural	0	0.075	0.240	39	0.313	0.913
City*Habitat	Kitchener Rural - Brantford Urban	0	0.203	0.229	39	0.886	0.871
City*Habitat	Kitchener Rural - Guelph Urban	0	0.205	0.229	39	0.894	0.871
City*Habitat	Kitchener Rural - Kitchener Urban	0	0.158	0.229	39	0.690	0.871
City*Habitat	Kitchener Rural - London Urban	0	-0.048	0.229	39	-0.209	0.913
City*Habitat	Kitchener Rural - St_Catharines Urban	0	0.313	0.229	39	1.367	0.871
City*Habitat	London Rural - St_Catharines Rural	0	0.259	0.240	39	1.080	0.871
City*Habitat	London Rural - Brantford Urban	0	0.387	0.229	39	1.690	0.871
City*Habitat	London Rural - Guelph Urban	0	0.389	0.229	39	1.698	0.871
City*Habitat	London Rural - Kitchener Urban	0	0.342	0.229	39	1.494	0.871
City*Habitat	London Rural - London Urban	0	0.136	0.229	39	0.596	0.871
City*Habitat	London Rural - St_Catharines Urban	0	0.497	0.229	39	2.171	0.871
City*Habitat	St_Catharines Rural - Brantford Urban	0	0.127	0.240	39	0.531	0.871
City*Habitat	St_Catharines Rural - Guelph Urban	0	0.129	0.240	39	0.539	0.871
City*Habitat	St_Catharines Rural - Kitchener Urban	0	0.083	0.240	39	0.344	0.913
City*Habitat	St_Catharines Rural - London Urban	0	-0.123	0.240	39	-0.513	0.871
City*Habitat	St_Catharines Rural - St_Catharines Urban	0	0.238	0.240	39	0.990	0.871
City*Habitat	Brantford Urban - Guelph Urban	0	0.002	0.229	39	0.008	0.994
City*Habitat	Brantford Urban - Kitchener Urban	0	-0.045	0.229	39	-0.196	0.913
City*Habitat	Brantford Urban - London Urban	0	-0.250	0.229	39	-1.095	0.871
City*Habitat	Brantford Urban - St_Catharines Urban	0	0.110	0.229	39	0.481	0.871
City*Habitat	Guelph Urban - Kitchener Urban	0	-0.047	0.229	39	-0.204	0.913
City*Habitat	Guelph Urban - London Urban	0	-0.252	0.229	39	-1.103	0.871
City*Habitat	Guelph Urban - St_Catharines Urban	0	0.108	0.229	39	0.473	0.871
City*Habitat	Kitchener Urban - London Urban	0	-0.206	0.229	39	-0.898	0.871
City*Habitat	Kitchener Urban - St_Catharines Urban	0	0.155	0.229	39	0.677	0.871
City*Habitat	London Urban - St_Catharines Urban	0	0.361	0.229	39	1.576	0.871

Table 80: Post-hoc comparisons of the two-way interaction between City and Season in the 5 Cities Diversity ANOVA.

Term	Contrast	Null Value	Estimate	SE	df	statistic	P_fdr
City*Season	Brantford Early - Guelph Early	0	0.114	0.229	39	0.500	0.776
City*Season	Brantford Early - Kitchener Early	0	0.063	0.229	39	0.274	0.906
City*Season	Brantford Early - London Early	0	0.087	0.229	39	0.381	0.836
City*Season	Brantford Early - St_Catharines Early	0	0.233	0.229	39	1.016	0.568
City*Season	Brantford Early - Brantford Late	0	0.766	0.229	39	3.349	0.054
City*Season	Brantford Early - Guelph Late	0	0.565	0.229	39	2.469	0.074
City*Season	Brantford Early - Kitchener Late	0	0.616	0.229	39	2.691	0.059
City*Season	Brantford Early - London Late	0	0.201	0.229	39	0.880	0.641
City*Season	Brantford Early - St_Catharines Late	0	0.744	0.240	39	3.100	0.054
City*Season	Guelph Early - Kitchener Early	0	-0.052	0.229	39	-0.226	0.906
City*Season	Guelph Early - London Early	0	-0.027	0.229	39	-0.118	0.927
City*Season	Guelph Early - St_Catharines Early	0	0.118	0.229	39	0.517	0.776
City*Season	Guelph Early - Brantford Late	0	0.652	0.229	39	2.849	0.054
City*Season	Guelph Early - Guelph Late	0	0.451	0.229	39	1.969	0.126
City*Season	Guelph Early - Kitchener Late	0	0.501	0.229	39	2.191	0.091
City*Season	Guelph Early - London Late	0	0.087	0.229	39	0.380	0.836
City*Season	Guelph Early - St_Catharines Late	0	0.630	0.240	39	2.624	0.062
City*Season	Kitchener Early - London Early	0	0.025	0.229	39	0.107	0.927
City*Season	Kitchener Early - St_Catharines Early	0	0.170	0.229	39	0.742	0.717
City*Season	Kitchener Early - Brantford Late	0	0.704	0.229	39	3.075	0.054
City*Season	Kitchener Early - Guelph Late	0	0.502	0.229	39	2.195	0.091
City*Season	Kitchener Early - Kitchener Late	0	0.553	0.229	39	2.417	0.077
City*Season	Kitchener Early - London Late	0	0.139	0.229	39	0.606	0.771
City*Season	Kitchener Early - St_Catharines Late	0	0.681	0.240	39	2.839	0.054
City*Season	London Early - St_Catharines Early	0	0.145	0.229	39	0.635	0.768
City*Season	London Early - Brantford Late	0	0.679	0.229	39	2.967	0.054
City*Season	London Early - Guelph Late	0	0.478	0.229	39	2.088	0.103
City*Season	London Early - Kitchener Late	0	0.528	0.229	39	2.309	0.085
City*Season	London Early - London Late	0	0.114	0.229	39	0.499	0.776
City*Season	London Early - St_Catharines Late	0	0.657	0.240	39	2.737	0.059
City*Season	St_Catharines Early - Brantford Late	0	0.534	0.229	39	2.332	0.085
City*Season	St_Catharines Early - Guelph Late	0	0.332	0.229	39	1.453	0.289
City*Season	St_Catharines Early - Kitchener Late	0	0.383	0.229	39	1.674	0.209
City*Season	St_Catharines Early - London Late	0	-0.031	0.229	39	-0.136	0.927
City*Season	St_Catharines Early - St_Catharines Late	0	0.511	0.240	39	2.131	0.099
City*Season	Brantford Late - Guelph Late	0	-0.201	0.229	39	-0.880	0.641
City*Season	Brantford Late - Kitchener Late	0	-0.151	0.229	39	-0.658	0.768
City*Season	Brantford Late - London Late	0	-0.565	0.229	39	-2.469	0.074
City*Season	Brantford Late - St_Catharines Late	0	-0.022	0.240	39	-0.093	0.927
City*Season	Guelph Late - Kitchener Late	0	0.051	0.229	39	0.222	0.906
City*Season	Guelph Late - London Late	0	-0.364	0.229	39	-1.589	0.235
City*Season	Guelph Late - St_Catharines Late	0	0.179	0.240	39	0.746	0.717
City*Season	Kitchener Late - London Late	0	-0.414	0.229	39	-1.810	0.167
City*Season	Kitchener Late - St_Catharines Late	0	0.128	0.240	39	0.535	0.776
City*Season	London Late - St_Catharines Late	0	0.543	0.240	39	2.261	0.088

Table 81: Post-hoc comparisons of the two-way interaction between Habitat and Season in the 5 Cities Diversity ANOVA.

Term	Contrast	Null Value	Estimate	SE	df	statistic	P_fdr
Habitat*Season	Rural Early - Urban Early	0	0.225	0.145	39	1.556	0.153
Habitat*Season	Rural Early - Rural Late	0	0.513	0.147	39	3.486	0.004
Habitat*Season	Rural Early - Urban Late	0	0.654	0.145	39	4.518	0.000
Habitat*Season	Urban Early - Rural Late	0	0.288	0.147	39	1.956	0.086
Habitat*Season	Urban Early - Urban Late	0	0.429	0.145	39	2.961	0.010
Habitat*Season	Rural Late - Urban Late	0	0.140	0.147	39	0.953	0.346

Contrasts: Leaf Herbivory (Toronto)

Table 82: Post-hoc comparisons of the main effect of Season in the Toronto Leaf Herbivory ANCOVA.

Term	Contrast	Null Value	Estimate	SE	df	statistic	P_fdr
Season	Early - Late	0	-0.888	0.107	63.374	-8.283	0

Table 83: Post-hoc comparisons of the two-way interaction between Distance and Season in the Toronto Leaf Herbivory ANCOVA.

Distance (emmean)	Term	Contrast	Null Value	Estimate	SE	df	statistic	P_fdr
18.748	Season	Early - Late	0	-0.888	0.107	63.374	-8.283	0

Contrasts: Leaf Herbivory (5 Cities)

Table 84: Post-hoc comparisons of the main effect of City in the 5 Cities Leaf Herbivory ANOVA.

Term	Contrast	Null Value	Estimate	SE	df	statistic	P_fdr
City	Brantford - Guelph	0	0.265	0.175	72.777	1.516	0.285
City	Brantford - Kitchner	0	0.318	0.213	40.532	1.496	0.285
City	Brantford - London	0	0.016	0.219	34.716	0.074	0.942
City	Brantford - St_Catharines	0	0.471	0.217	33.899	2.168	0.186
City	Guelph - Kitchner	0	0.053	0.173	82.097	0.307	0.844
City	Guelph - London	0	-0.249	0.214	39.888	-1.160	0.421
City	Guelph - St_Catharines	0	0.206	0.215	36.060	0.959	0.492
City	Kitchner - London	0	-0.302	0.180	64.014	-1.673	0.285
City	Kitchner - St_Catharines	0	0.153	0.214	38.440	0.717	0.597
City	London - St_Catharines	0	0.455	0.179	58.847	2.538	0.138

Table 85: Post-hoc comparisons of the main effect of Habitat in the 5 Cities Leaf Herbivory ANOVA.

Term	Contrast	Null Value	Estimate	SE	df	statistic	P_fdr
Habitat	Rural - Urban	0	0.39	0.112	98.457	3.494	0.001

Table 86: Post-hoc comparisons of the main effect of Season in the 5 Cities Leaf Herbivory ANOVA.

Term	Contrast	Null Value	Estimate	SE	df	statistic	P_fdr
Season	Early - Late	0	-1.905	0.089	141.428	-21.45	0

Table 87: Post-hoc comparisons of the two-way interaction between City and Habitat in the 5 Cities Leaf Herbivory ANOVA.

Term	Contrast	Null Value	Estimate	SE	df	statistic	P_fdr
City*Habitat	Brantford Rural - Guelph Rural	0	0.484	0.247	75.461	1.956	0.180
City*Habitat	Brantford Rural - Kitchner Rural	0	0.215	0.271	54.160	0.792	0.571
City*Habitat	Brantford Rural - London Rural	0	0.371	0.285	44.232	1.300	0.348
City*Habitat	Brantford Rural - St_Catharines Rural	0	0.922	0.296	41.126	3.114	0.022
City*Habitat	Brantford Rural - Brantford Urban	0	0.736	0.242	79.614	3.041	0.022
City*Habitat	Brantford Rural - Guelph Urban	0	0.782	0.253	79.291	3.092	0.022
City*Habitat	Brantford Rural - Kitchner Urban	0	1.157	0.266	57.736	4.351	0.001
City*Habitat	Brantford Rural - London Urban	0	0.396	0.295	40.591	1.345	0.348
City*Habitat	Brantford Rural - St_Catharines Urban	0	0.770	0.288	36.346	2.672	0.056
City*Habitat	Guelph Rural - Kitchner Rural	0	-0.269	0.222	144.506	-1.212	0.361
City*Habitat	Guelph Rural - London Rural	0	-0.113	0.277	57.048	-0.408	0.770
City*Habitat	Guelph Rural - St_Catharines Rural	0	0.439	0.290	47.462	1.511	0.309
City*Habitat	Guelph Rural - Brantford Urban	0	0.252	0.226	124.882	1.118	0.386
City*Habitat	Guelph Rural - Guelph Urban	0	0.298	0.235	222.875	1.272	0.348
City*Habitat	Guelph Rural - Kitchner Urban	0	0.674	0.238	109.054	2.825	0.032
City*Habitat	Guelph Rural - London Urban	0	-0.087	0.289	47.778	-0.303	0.838
City*Habitat	Guelph Rural - St_Catharines Urban	0	0.286	0.282	41.530	1.014	0.445
City*Habitat	Kitchner Rural - London Rural	0	0.156	0.247	63.851	0.631	0.649
City*Habitat	Kitchner Rural - St_Catharines Rural	0	0.708	0.294	45.908	2.408	0.082
City*Habitat	Kitchner Rural - Brantford Urban	0	0.521	0.272	57.610	1.918	0.180
City*Habitat	Kitchner Rural - Guelph Urban	0	0.567	0.241	138.605	2.353	0.082
City*Habitat	Kitchner Rural - Kitchner Urban	0	0.943	0.223	179.076	4.220	0.001
City*Habitat	Kitchner Rural - London Urban	0	0.182	0.289	51.292	0.628	0.649
City*Habitat	Kitchner Rural - St_Catharines Urban	0	0.555	0.286	39.210	1.941	0.180
City*Habitat	London Rural - St_Catharines Rural	0	0.552	0.305	41.697	1.806	0.220
City*Habitat	London Rural - Brantford Urban	0	0.365	0.286	44.912	1.275	0.348
City*Habitat	London Rural - Guelph Urban	0	0.411	0.283	59.722	1.453	0.325
City*Habitat	London Rural - Kitchner Urban	0	0.786	0.257	74.357	3.060	0.022
City*Habitat	London Rural - London Urban	0	0.026	0.298	46.410	0.086	0.953
City*Habitat	London Rural - St_Catharines Urban	0	0.399	0.231	80.803	1.725	0.234
City*Habitat	St_Catharines Rural - Brantford Urban	0	-0.187	0.297	41.477	-0.627	0.649
City*Habitat	St_Catharines Rural - Guelph Urban	0	-0.140	0.297	49.438	-0.473	0.737
City*Habitat	St_Catharines Rural - Kitchner Urban	0	0.235	0.284	57.456	0.827	0.561
City*Habitat	St_Catharines Rural - London Urban	0	-0.526	0.267	59.171	-1.970	0.180
City*Habitat	St_Catharines Rural - St_Catharines Urban	0	-0.153	0.309	34.399	-0.495	0.737
City*Habitat	Brantford Urban - Guelph Urban	0	0.046	0.244	122.998	0.189	0.911
City*Habitat	Brantford Urban - Kitchner Urban	0	0.421	0.267	60.579	1.580	0.299
City*Habitat	Brantford Urban - London Urban	0	-0.340	0.296	40.984	-1.148	0.386
City*Habitat	Brantford Urban - St_Catharines Urban	0	0.034	0.289	36.671	0.117	0.950
City*Habitat	Guelph Urban - Kitchner Urban	0	0.375	0.244	113.895	1.535	0.302
City*Habitat	Guelph Urban - London Urban	0	-0.386	0.295	49.867	-1.307	0.348
City*Habitat	Guelph Urban - St_Catharines Urban	0	-0.012	0.289	43.491	-0.043	0.966
City*Habitat	Kitchner Urban - London Urban	0	-0.761	0.240	102.441	-3.175	0.022
City*Habitat	Kitchner Urban - St_Catharines Urban	0	-0.388	0.281	41.701	-1.380	0.348
City*Habitat	London Urban - St_Catharines Urban	0	0.373	0.307	33.888	1.216	0.361

Table 88: Post-hoc comparisons of the two-way interaction between City and Season in the 5 Cities Leaf Herbivory ANOVA.

Term	Contrast	Null Value	Estimate	SE	df	statistic	P_fdr
City*Season	Brantford Early - Guelph Early	0	0.048	0.268	68.885	0.179	0.920
City*Season	Brantford Early - Kitchner Early	0	0.119	0.279	52.072	0.427	0.823
City*Season	Brantford Early - London Early	0	-0.072	0.286	42.400	-0.251	0.920
City*Season	Brantford Early - St_Catharines Early	0	0.059	0.290	37.244	0.202	0.920
City*Season	Brantford Early - Brantford Late	0	-2.221	0.261	61.710	-8.494	0.000
City*Season	Brantford Early - Guelph Late	0	-1.739	0.173	264.558	-10.066	0.000
City*Season	Brantford Early - Kitchner Late	0	-1.704	0.275	61.416	-6.206	0.000
City*Season	Brantford Early - London Late	0	-2.193	0.282	51.822	-7.772	0.000
City*Season	Brantford Early - St_Catharines Late	0	-1.477	0.299	42.099	-4.946	0.000
City*Season	Guelph Early - Kitchner Early	0	0.071	0.267	72.901	0.265	0.920
City*Season	Guelph Early - London Early	0	-0.120	0.286	44.077	-0.420	0.823
City*Season	Guelph Early - St_Catharines Early	0	0.011	0.290	38.162	0.037	0.971
City*Season	Guelph Early - Brantford Late	0	-2.269	0.283	47.456	-8.023	0.000
City*Season	Guelph Early - Guelph Late	0	-1.787	0.256	77.068	-6.974	0.000
City*Season	Guelph Early - Kitchner Late	0	-1.752	0.173	263.611	-10.147	0.000
City*Season	Guelph Early - London Late	0	-2.241	0.277	64.965	-8.103	0.000
City*Season	Guelph Early - St_Catharines Late	0	-1.525	0.298	43.449	-5.115	0.000
City*Season	Kitchner Early - London Early	0	-0.191	0.274	58.326	-0.695	0.648
City*Season	Kitchner Early - St_Catharines Early	0	-0.060	0.290	38.258	-0.208	0.920
City*Season	Kitchner Early - Brantford Late	0	-2.340	0.284	44.765	-8.240	0.000
City*Season	Kitchner Early - Guelph Late	0	-1.858	0.277	54.902	-6.702	0.000
City*Season	Kitchner Early - Kitchner Late	0	-1.823	0.255	79.122	-7.141	0.000
City*Season	Kitchner Early - London Late	0	-2.312	0.180	269.651	-12.816	0.000
City*Season	Kitchner Early - St_Catharines Late	0	-1.596	0.292	52.264	-5.457	0.000
City*Season	London Early - St_Catharines Early	0	0.130	0.296	34.038	0.440	0.823
City*Season	London Early - Brantford Late	0	-2.149	0.291	38.642	-7.391	0.000
City*Season	London Early - Guelph Late	0	-1.667	0.286	43.344	-5.839	0.000
City*Season	London Early - Kitchner Late	0	-1.632	0.286	43.955	-5.711	0.000
City*Season	London Early - London Late	0	-2.121	0.263	66.023	-8.055	0.000
City*Season	London Early - St_Catharines Late	0	-1.405	0.179	260.651	-7.869	0.000
City*Season	St_Catharines Early - Brantford Late	0	-2.280	0.295	34.382	-7.724	0.000
City*Season	St_Catharines Early - Guelph Late	0	-1.798	0.290	37.945	-6.199	0.000
City*Season	St_Catharines Early - Kitchner Late	0	-1.762	0.290	37.800	-6.071	0.000
City*Season	St_Catharines Early - London Late	0	-2.252	0.293	39.026	-7.688	0.000
City*Season	St_Catharines Early - St_Catharines Late	0	-1.536	0.309	34.399	-4.976	0.000
City*Season	Brantford Late - Guelph Late	0	0.482	0.273	59.419	1.766	0.124
City*Season	Brantford Late - Kitchner Late	0	0.517	0.284	45.798	1.821	0.117
City*Season	Brantford Late - London Late	0	0.028	0.287	45.397	0.098	0.943
City*Season	Brantford Late - St_Catharines Late	0	0.744	0.303	38.682	2.454	0.031
City*Season	Guelph Late - Kitchner Late	0	0.035	0.268	69.674	0.132	0.937
City*Season	Guelph Late - London Late	0	-0.454	0.281	54.057	-1.613	0.163
City*Season	Guelph Late - St_Catharines Late	0	0.262	0.298	42.939	0.879	0.540
City*Season	Kitchner Late - London Late	0	-0.489	0.271	70.268	-1.805	0.117
City*Season	Kitchner Late - St_Catharines Late	0	0.227	0.298	43.231	0.760	0.615
City*Season	London Late - St_Catharines Late	0	0.716	0.288	58.753	2.484	0.027

Table 89: Post-hoc comparisons of the two-way interaction between Habitat and Season in the 5 Cities Leaf Herbivory ANOVA.

Term	Contrast	Null Value	Estimate	SE	df	statistic	P_fdr
Habitat*Season	Rural Early - Urban Early	0	0.241	0.167	61.254	1.438	0.156
Habitat*Season	Rural Early - Rural Late	0	-2.140	0.154	73.215	-13.931	0.000
Habitat*Season	Rural Early - Urban Late	0	-1.468	0.137	134.984	-10.743	0.000
Habitat*Season	Urban Early - Rural Late	0	-2.381	0.149	97.245	-15.979	0.000
Habitat*Season	Urban Early - Urban Late	0	-1.709	0.146	87.984	-11.729	0.000
Habitat*Season	Rural Late - Urban Late	0	0.672	0.161	95.726	4.175	0.000

R Session Information

Table 90: Packages for data management and analyses.

Package	Loaded Version	Date
bayestestR	0.11.5	2021-10-30
broom	0.7.12	2022-01-28
car	3.0-12	2021-11-06
carData	3.0-5	2022-01-06
correlation	0.8.0	2022-02-14
datawizard	0.3.0	2022-03-03
dplyr	1.0.8	2022-02-08
easystats	0.4.3	2021-11-07
effectsize	0.6.0.1	2022-01-26
emmeans	1.7.2	2022-01-04
forcats	0.5.1	2021-01-27
ggplot2	3.3.5	2021-06-25
insight	0.16.0	2022-02-17
kableExtra	1.3.4	2021-02-20
knitr	1.37	2021-12-16
lattice	0.20-45	2021-09-22
lme4	1.1-28	2022-02-05
lmerTest	3.1-3	2020-10-23
MASS	7.3-55	2022-01-13
Matrix	1.4-0	2021-12-08
modelbased	0.7.2	2022-02-28
mvabund	4.2.1	2022-02-16
parameters	0.17.0	2022-03-10
performance	0.8.0	2021-10-01
permute	0.9-7	2022-01-27
piecewiseSEM	2.1.2	2020-12-09
purrr	0.3.4	2020-04-17
readr	2.1.2	2022-01-30
report	0.5.1	2022-02-22
see	0.6.9	2022-02-15
stringr	1.4.0	2019-02-10
tibble	3.1.6	2021-11-07
tidyr	1.2.0	2022-02-01
tidyverse	1.3.1	2021-04-15
vegan	2.5-7	2020-11-28