**Exotic Plant Invasion and Natural Habitat Loss:**



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*How these global change factors can influence the biodiversity, abundance, and functional diversity of pollinators in a subtropical landscape*

*A QUBES lesson by Maxcy Hill*

**Learning Objectives and Prerequisites:**

This lesson is designed to introduce students to exotic plant invasion, natural habitat loss, biodiversity, and general linear models. At the end of this lesson, students should be able to identify the damages that exotic plants can have on ecosystems and recognize how these foreign plant invasions can impact pollinator diversity and abundance. Students will also analyze the relationship between exotic plant invasion and natural habitat loss and be able to recognize the impacts that these global changes stressors have on ecosystems. This lesson will teach students how to use Pearson’s correlation coefficient to analyze relationships between two variables, and general linear models to analyze count data that does not follow a normal distribution.

This lesson is intended for students who are already familiar with statistics and have a basic working knowledge of R and R-Studio. In the case that students are not able to access or operate R, graphics, and output will be provided. Students will be expected to analyze and interpret the output and graphs provided with adequate quantitative analysis.

**Exotic Plant Invasion:**

Any organism that is introduced into a foreign ecosystem that causes harm or causes ecological, environmental, or economic damage is considered an invasive species. Exotic plant invasion can happen because of anthropogenic activity; however, introduction can be either intentional or accidental. These plants can either hitchhike into an ecosystem through transportation or can be brought in as ornamental horticulture and then take over.

A close-up of some flowers

Description automatically generated with low confidenceInvasive species take advantage of disturbed areas such as forest edges, or areas where natural habitat has been fragmented or destroyed. The removal and fragmentation of habitat for agricultural purposes is a common cause for natural habitat loss. The introduction of exotic plant species can drastically alter the functionality of ecosystems. These invasions are considered one of the leading causes in the loss of biodiversity (Stout & Tiedeken, 2017).

Invasive plant species typically outcompete native flora for limited resources such as space, water, nutrients, and sunlight (Bartomeus et al., 2008). In addition to outcompeting for resources, exotic plant invasion can create monospecific stands if left unchecked, because there are no natural predators. If there is no herbivory on the plant, the energy entering the ecosystem stops at the primary level, drastically altering the energy flux within the ecosystem.

**Pollinators:**

 In the early 2000s, pollinator numbers began drastically declining (Nowierski, 2021). Several factors have contributed to this decline, including pollutants, pesticides, and habitat loss (Nowierski, 2021). In addition to these, and many other anthropogenic factors, the invasion of exotic plant species might also be driving this decline in pollinator numbers. Although the relationship between pollinators and exotic plants is not fully understood, there is evidence to suggest that the exotic plants benefit from this interaction while the native pollinators do not (Stout & Tiedeken, 2017). The functional diversity of a species is an important piece of biodiversity, and communities with higher functional diversity typically tend to be more stable (Grass et al., 2014). Functional diversity can be defined as “the diversity of species’ properties that can influence their individual performances” (Grass et al., 2014). Functional diversity is thought to heavily influence the positive relationship between species richness and pollinator processes (Grass et al., 2014).

**The Problem:**

Anthropogenic activity has caused the introduction of exotic plant species and natural habitat loss. The mutualisms between plants and pollinators are ecosystem functions that are threatened by the invasion of exotic plant species (Hanna et al., 2013). Native pollinators exhibit variation in behavioral or morphological traits that are complementary to the native plants within their ecosystem that can increase the reproductive output and crop yield of the plants (Grass et al., 2014). Although the pollinator might still be attracted to an invasive plant, they may not possess the appropriate phenology or behavior to accurately pollinate or feed from the plant, causing more work for less benefit for the pollinator (Stout & Tiedeken, 2017). As the abundance of flowering exotic species increases, the number of co-flowering native species decreases (Stout & Tiedeken, 2017).



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**The Focal Paper:**

Text

Description automatically generated This lesson is based off the 2014 Grass et al. study *Natural habitat loss and exotic plants reduce the functional diversity of flower visitors in a heterogeneous subtropical landscape*. Tropical and subtropical plant species are particularly dependent on animal pollinators for reproduction but are being heavily threatened by exotic plant invasion (Grass et al., 2014). This study was designed to analyze the effects of natural habitat loss and exotic plant invasion on the functional diversity of pollinator communities. Grass et al. established 17 study sites with varying degrees of habitat loss and exotic invasion and observed insect visitation on native and exotic plants. The researchers measured three different functional traits of the flower visitors, probiscis length, probiscis diameter, and body length. Functional dispersion, which “measures the mean distance of species’ trait values to the centroid of all species in trait space”, was used to quantify the functional diversity of flower visitor assemblage (Grass et al., 2014).

***Synergistic effect:*** when the combined outcome of two or more processes is greater than the cumulative effect of the individual processes

The researchers found that both natural habitat loss and exotic plant abundance had a negative effect on the multivariate functional diversity of flower visitors. The researchers expected to see a synergistic relationship between natural habitat loss and exotic plant invasion, but the data showed otherwise. There was not a strong interaction between natural habitat loss and exotic plant abundance regarding the functional diversity of pollinators.

**The Data:**



[This Photo](https://www.scientia.global/pollinator-decline-implications-for-food-security-environment/) by Unknown Author is licensed under [CC BY](https://creativecommons.org/licenses/by/3.0/)

The data for this study was obtained from the Dryad database. The available data includes four different tables. The first is a list of flower visitors and flower visitor traits. This includes mean trait values and abundance for each of the 131 different species. The measurements for probiscis length, probiscis diameter, and body length are all found in this table. The second list is the list of plants and plant traits, including native or exotic status and potential floral traits that may impact visitor functional diversity. The plant-flower visitor interaction network is also included in the available dataset. This offers data for each of the 17 sites, listing which species of pollinators and which plant species were observed in each site. The authors of the focal paper used each of these data tables to create a functional dispersion cloud to measure multivariate functional diversity of pollinators in relation to natural habitat loss and relative exotic abundance.

The final table of data available is the environmental data. This includes amount of natural habitat loss and relative exotic abundance, as well as other site information. We will be using this dataset for our lesson. This dataset has been modified to include the total number of visits to each site as well as the total number of species that visited each site, and any irrelevant information has been removed.

**The Lesson:**

For this lesson, students will test two hypotheses. First, students will analyze the relationship between natural habitat loss and relative exotic abundance. Because exotic plant species excel in disturbed areas, we expect that as natural habitat loss increases, relative exotic abundance will also increase. We also expect that exotic plant species abundance will negatively influence pollinator biodiversity and abundance. \*\*If R is not available for the students, plots, and output will be provided\*\*

***Hypotheses:***

1. As natural habitat loss increases, so will relative exotic abundance
2. As relative exotic abundance increases, pollinator biodiversity and abundance will decrease

 To begin this lesson, we will first start by loading all necessary packages. See [this](https://www.statmethods.net/interface/packages.html) tutorial if you need help. Before we begin our analysis, we will read in our dataset and make sure that there are no errors.

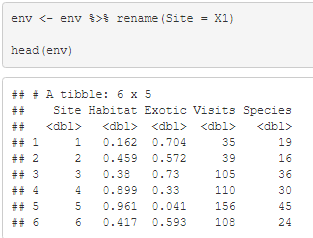
Table

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**QUESTION 1:** What is wrong with our R output?

Our first column reads “X1”. This does not give us any useful information. It should read “Site”, so that we know what data correlates with each site.

If you need to download R and RStudio, click [here](https://www.rstudio.com/products/rstudio/download/)!

Before we begin our analysis, lets change our first column name to ‘Site’ instead of X1, so that it has a useful title.

Now that all our columns have a descriptive title, we can continue with our lesson.

To test our first hypothesis, we will plot relative exotic abundance as a function of natural habitat loss. We will use the Pearson’s correlation coefficient to analyze this relationship, which measures the strength of the correlation between two variables.

Chart, line chart

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To learn more about Pearson’s correlation coefficient, check [this](https://www.statisticshowto.com/probability-and-statistics/correlation-coefficient-formula/) out.

**QUESTION 2:** Why are we plotting relative exotic abundance as a function of natural habitat loss and not the other way around?

Because exotic plants take advantage of disturbed sites, we want to see how natural habitat loss effects the abundance of exotic plants, not how the abundance of exotic plants effects natural habitat loss.

**QUESTION 3:** What are the results of this analysis? Do these findings support our first hypothesis? Why might this contradict findings from previous studies?

Our p-value is 0.017, so this suggests that natural habitat loss does have a significant effect on relative exotic abundance, however our correlation coefficient, R is -0.57, suggesting a moderate negative correlation between the natural habitat loss and relative exotic abundance. This means that as the amount of natural habitat loss increases, the relative abundance of exotic plants decreases. These findings do not support our hypothesis that relative exotic abundance will increase as natural habitat loss decreases. There can be any number of reasons as to why we are getting this result. The study site chosen by these authors are grasslands and scarp forests that have been heavily modified by sugarcane farms and other agricultural factors, so this might explain this discrepancy.

For the next portion of our lesson, we will analyze the relationship between the total number of pollinator visits, the total number of species visits, and relative exotic abundance. Here we are testing our second hypothesis, that as relative exotic abundance increases, pollinator species diversity and abundance will decrease. Before we run our analyses, lets take a look at our data to see if it is normally distributed.

Chart, histogram

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Chart, histogram

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**QUESTION 4:** Are our data normally distributed? Why or why not?

No, our data do not follow the typical “bell-curve” normal distribution.

Because our data are not normally distributed, we cannot run a regular linear model. When data are not normally distributed, general linear models can be used. It is very rare that count data are normally distributed, so general linear models are the best choice to analyze these types of data.

There are three important properties to a general linear model: the error structure, the linear predictor, and the link function. The family directive that is used in your model defines your error structure in the general linear model. The family directives that can be used in these models include Poisson errors, which can be used with count data, binomial errors, which can be used for proportion data, gamma errors, which can be used for data showing a constant coefficient variation, or exponential errors, which can be used for survival analysis data. For this analysis, we will be using the Poisson error directive. The sum of the effects of one or more variables is your linear predictor. The link function relates the mean value of *y* to its linear predictor. For Poisson errors, the link function used is log link.

Count data have certain properties that can be easily accounted for when using general linear models. First, count data cannot be less than zero, so the data are bounded below. The variance increases with the mean, so it is not constant. Errors are not normally distributed, and all the data are whole numbers, which effects the error distribution.

Now that we have a better grasp on what a general linear model entails, lets test our hypotheses.

For more information on general linear models, check [this](https://www.educba.com/glm-in-r/) out!

First, we want to see how relative exotic abundance influences pollinator biodiversity. To do this, we will run a general linear model with total species visits as a function of relative exotic abundance.

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**QUESTION 5:** Interpret the model. Do these findings support our hypothesis that as relative exotic abundance increases, pollinator biodiversity will decrease?

Our p-value is 0.483, which suggests that an increase in relative exotic abundance does not have a significant influence pollinator biodiversity. Our coefficient estimate is -0.12421, which suggests a weak, negative relationship between relative exotic abundance and pollinator diversity.

No, as relative exotic abundance increases, pollinator biodiversity does not significantly decrease, so this model does not support our hypothesis.

Now that we have interpreted our general linear model, it is helpful to visualize the data to see the trend. We will use ggplot2, a data visualization package to create this graph.

Chart, scatter chart

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Here, we can see the slight downward trend in total pollinator biodiversity as relative exotic abundance increases.

Recall that we wanted to know if relative exotic abundance influenced both pollinator biodiversity and pollinator abundance. We can run another general linear model that analyzes pollinator abundance as a function of relative exotic abundance.

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**QUESTION 6:** Interpret the model. Do these findings support our hypothesis that as relative exotic abundance increases, pollinator abundance will decrease?

Our p-value is extremely small, 2.67e-14, which suggests that relative exotic abundance does have a significant influence on pollinator abundance. Our coefficient estimate is -0.74346, which suggests a relatively strong negative relationship between our variables.

Yes, as relative exotic abundance increases, pollinator abundance drops significantly, so this model supports our hypothesis.

To learn more about ggplot2 and other R graphics, click [here](https://r-graph-gallery.com/ggplot2-package.html)!

Check out [this](http://sape.inf.usi.ch/quick-reference/ggplot2/colour) link to see the amazing color palette that R offers!

Let’s create another visualization for this model so that we can better understand our results.

Chart, scatter chart

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Here, we can see the significant downward trend in pollinator abundance as relative exotic abundance increases.

**Question 7:** Think critically. What does this mean for future research? How can these results help inform management practices?

It is clear that exotic plant invasion has a negative impact on our pollinator abundance, however there is no effect on pollinator biodiversity. Future research trends within this field might include repercussions of the loss of pollinator biodiversity and abundance, energy flux alterations, or biogeochemical cycling alterations in response to these exotic species invasions.

Managers and policy makers can use the knowledge gained from this study to limit or prevent the sale of exotic species in hopes of preventing invasion. Agriculture and other land use changes should be closely monitored to prevent unnecessary habitat loss or other ecological disturbances.

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Images:

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