Investigating Determinants of Richness in Ephemeral and Permanent Wetlands Using Linear Models in Shiny[a]

Introduction

Wetland hydroperiod is the pattern of water level fluctuations in a wetland. Some wetlands dry completely on an annual basis, and these are called ephemeral ponds, vernal pools, or simply temporary wetlands (Figure 1, Colburn 2004, Calhoun and DeMaynadier 2008). Ephemeral ponds tend to be small, hydrologically isolated (with no permanent outlet or inlet), and surrounded by forest (Colburn 2004). Other wetlands, which for the purposes of this activity are called "permanent", maintain water year-round although their water levels may fluctuate.

Ephemeral ponds are unique for many reasons. Because they dry completely during most years, they are fish-free. Without fish predation, amphibian larvae tend to have higher survival rates and so many amphibians use ephemeral ponds for breeding (Semlitsch and Skelly 2008). These amphibians include wood frogs, spring peepers, chorus frogs, and blue-spotted salamanders (Figure 2). Other fauna that inhabit these wetlands include fairy shrimp and fingernail clams (Figure 3). These invertebrates are able to tolerate desiccation (a prolonged period of drying) and benefit from the lack of fish predators in ephemeral ponds. There are still predators in the ponds, however. Macroinvertebrates like water tigers (Dytiscidae, Figure 3), the larval stage of predaceous diving beetles, are able to avoid predation and competition from fish by using ephemeral pond habitats. Although ephemeral ponds, or vernal pools, are most often of conservation interest as amphibian habitats, they are also home to a diversity of plant life. Annual plant species like *Bidens* spp. (beggars-ticks) and *Persicaria* spp. (smartweeds) grow quickly after water levels recede in late summer and avoid competition from perennials (Figure 4).

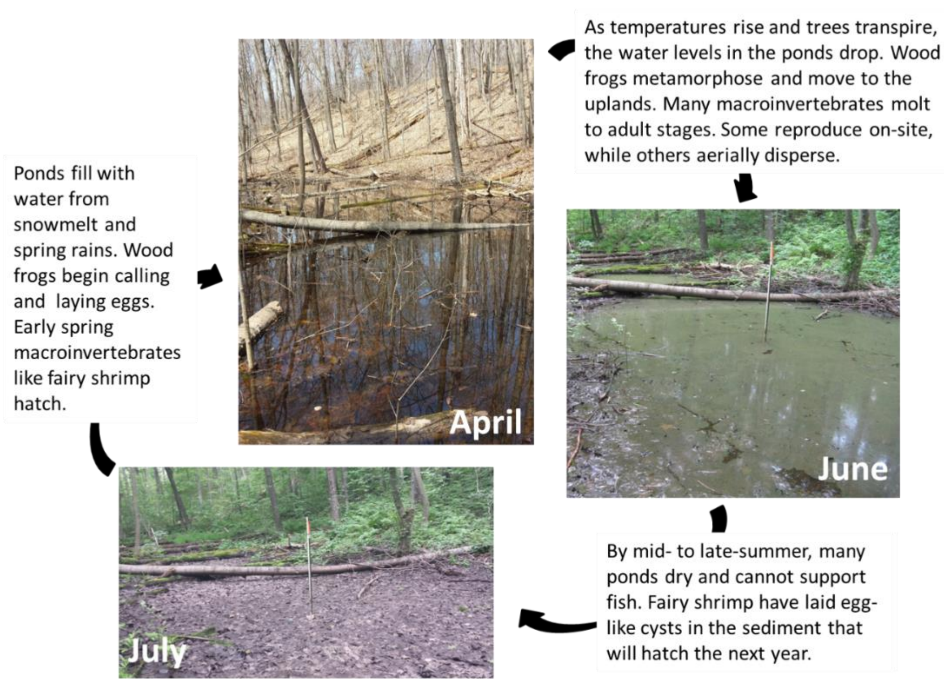

Figure 1. The life cycle of an ephemeral pond.[1]

Wood frogs, fairy shrimp, and blue-spotted salamanders are ephemeral pond specialists, but many of the other species also thrive in permanent wetlands. Permanent wetlands tend to be larger and provide a wider variety of microhabitats. They also have greater primary productivity due to more light availability (Figure 5). In this study, green frogs, leopard frogs, and newts are more common permanent wetland specialists. Larger macroinvertebrates like water tigers, water scavenger beetle larvae (Hydrophilidae), and giant water bugs find plentiful food resources in these larger systems (Figure

[a]Adapted from Little, A.M. (2018). Environment-richness relationships in ephemeral and permanent wetlands: Guided inquiry with graph interpretation. *Teaching Issues and Experiments in Ecology, 13,* online at http://tiee.esa.org/vol/v13/issues/data_sets/little/abstract.html

6). Permanent wetlands also tend to have more abundant vegetation due to greater light availability. Common groups in this study include various wetland sedges, cattails, reed canarygrass, and shrubs such as leatherleaf (Figure 7).

*Figure 2. Amphibians of ephemeral ponds, including wood frog (*Lithobates sylvaticus)[2] *, spring peeper (*Pseudacris crucifer*)*[3]*, boreal chorus frog (*Pseudacris maculate*)*[4]*, and blue-spotted salamander (*Ambystoma laterale*)*[5]

*Figure 3. Macroinvertebrates of ephemeral ponds. Fairy shrimp (*Eubranchipus*)*[6]*, fingernail clam (Sphaeriidae)*[7]*, and water tiger (Dytiscidae).*[8]

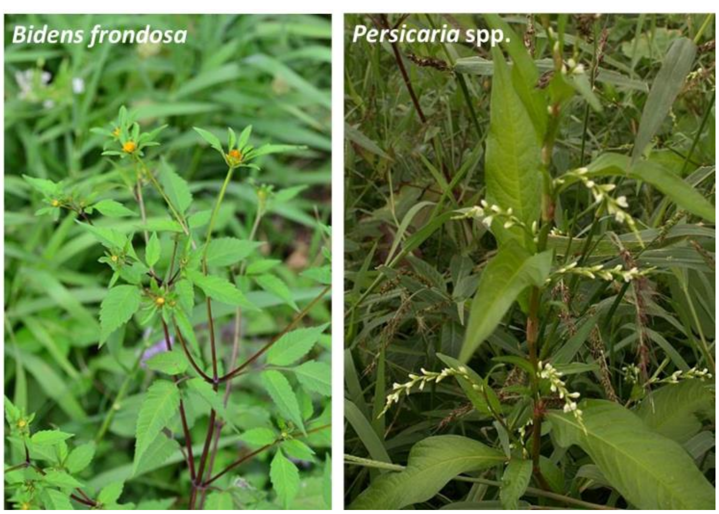

Figure 4. Common annual plants of ephemeral ponds, including Bidens frondosa *(devil beggar's ticks)*[9] *and* Persicaria spp. *(smartweed)*[10]*.*

Figure 5. Examples of permanent wetlands from this study. Sedge meadows (wetland P7A) are dominated by sedges (Carex spp.) and have shallower water depths than lacustrine fringe wetlands (wetland N2B), which consist of a narrow band of vegetation surrounding deeper water.[11]

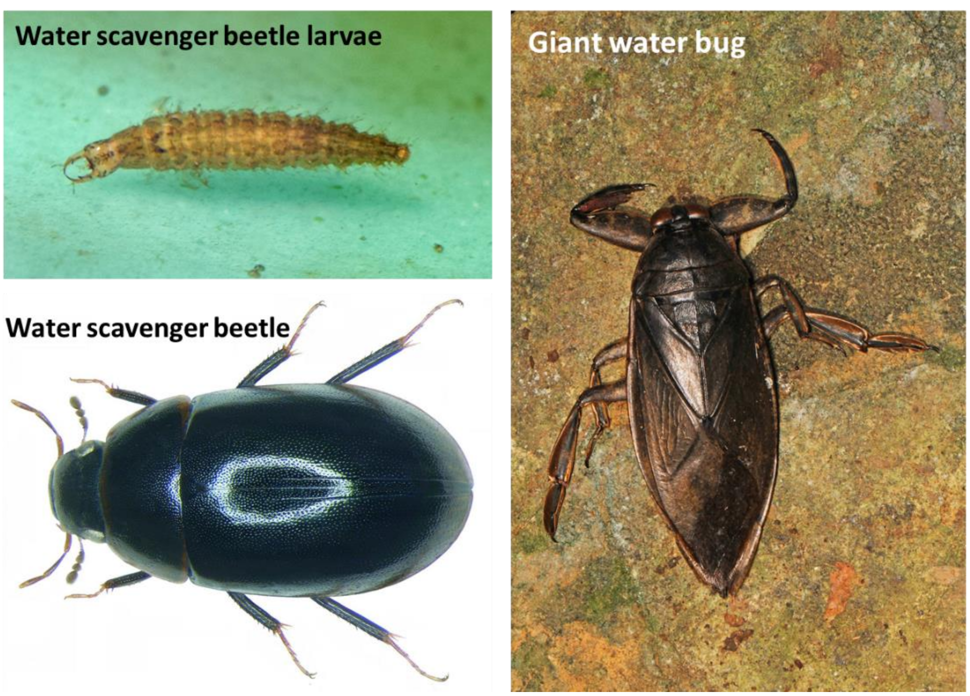

Figure 6. Examples of macroinvertebrate taxa found in permanent wetlands, including water scavenger beetles (Hydrophilidae)[12,13] *and giant water bugs (Belostomatidae)*[14]*.*

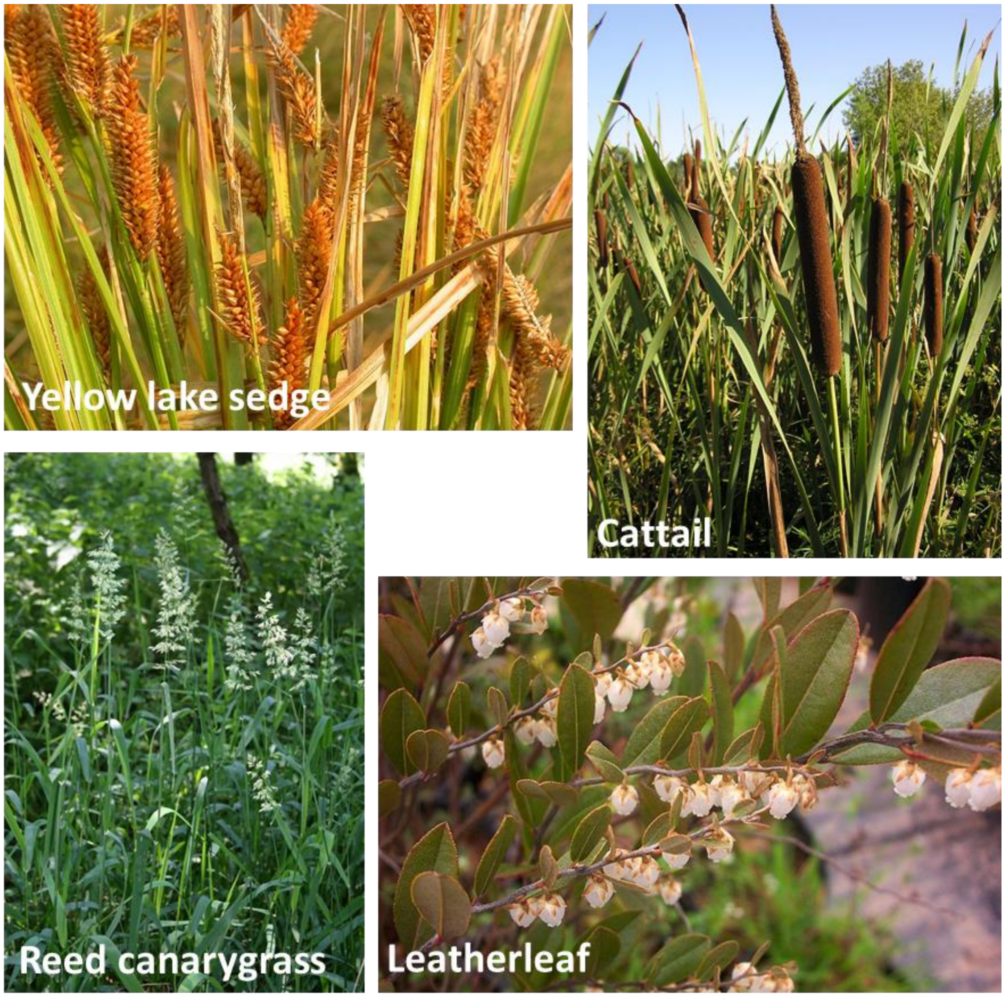

*Figure 7. Examples of plants common in permanent wetlands, including yellow lake sedge (*Carex utriculata*)*[15]*, broad-leaved cattail (*Typha latifolia*)*[16]*, reed canarygrass (*Phalaris arundinacea*)*[17]*, and leatherleaf (*Chamaedaphne calyculata*)*[18].

Species Richness and Community Composition

Species richness is the number of different species in a given area. It is typically considered a community-level attribute. A basic and much-discussed question in ecology is why some areas have more species than others. For conservation purposes, it is important to know which types of habitats support more species. Because hydrology (water level) is so important to wetland organisms, it is informative to evaluate how hydrologic fluctuations/extremes can affect the biotic and abiotic aspects of wetlands. **In this lab, we will assess whether the relationships between species richness and environmental factors differ between ephemeral and permanent wetlands and in which wetland type the relationship is stronger.**

Some common theories that ecologists have put forth for factors that control species richness include:

Theory of Island Biogeography: In general, the larger the area of an "island", the more species it will support (MacArthur & Wilson, 1967). There tend to be more resources, more heterogeneous habitats, and more sustainable population structures in larger areas. In addition, islands that are closer geographically to a large source mainland or other island may have more species because they are easier to colonize (MacArthur and Wilson 1963). In this study, each wetland site is considered to be an "island" in the surrounding upland.

Intermediate Disturbance Hypothesis: The level of disturbance, stress, and competition in the community. Generally, the higher level of stress or disturbance a community experiences, the lower the species richness. On the other extreme, areas with very low levels of stress or disturbance are associated with increased competition, which can also lead to lower species richness. As a result, intermediate levels of disturbance/stress can lead to higher levels of species richness (Connell, 1978) although there is some debate about the nature of this effect in the literature (Fox, 2013). In this study, the wetlands vary from fairly stable water levels in permanent wetlands to more variable hydroperiods in ephemeral ponds. Permanent wetlands could be considered less hydrologically "disturbed" than ephemeral wetlands.

Environmental Heterogeneity: Different species frequently have different requirements for survival and reproduction. The greater the variety of habitats that a wetland provides, the greater number of niches available for different species (Menge & Sutherland, 1976).

In this study, we do not measure any of these variables directly except wetland area. Rather, we measure specific environmental variables that reflect possible stress or resource levels. For example, water depth may act as a stressor variable for plants, in accordance with the intermediate disturbance hypothesis. Plants in wetlands with too little water may experience drought stress, while few plants may be able to survive in wetlands with very deep water levels. Definitions of the environmental variables we will explore in this study will be provided during the lab period, along with suggestions about how the affect resources and stress levels in the wetlands.

Although species richness is a commonly used measure of biodiversity in studies, ecologists may also be interested in whether the relative proportions of different species change across ecological gradients. In some cases, species richness (i.e. the total number of species) may not change very much, but the identity and proportions of species may change dramatically. Two wetlands, for example, may each have a species richness of 10, but the relative proportions (i.e. which species are common and rare) and identity of these species may be very different.

Linear Models

Many people think that a model has to be complicated or physical (such as a model plane) in nature. A scientific model is simply a description of how we think the world works and allows us to predict what might happen in the future. A linear model is a straight line that illustrates the relationship between two variables, typically represented by an equation (Figure 9). Sometimes a linear model is an appropriate representation of a relationship, but sometimes a non-linear model is a better fit. Today we will be exploring linear models, but that does not mean that all relationships can be modeled linearly.

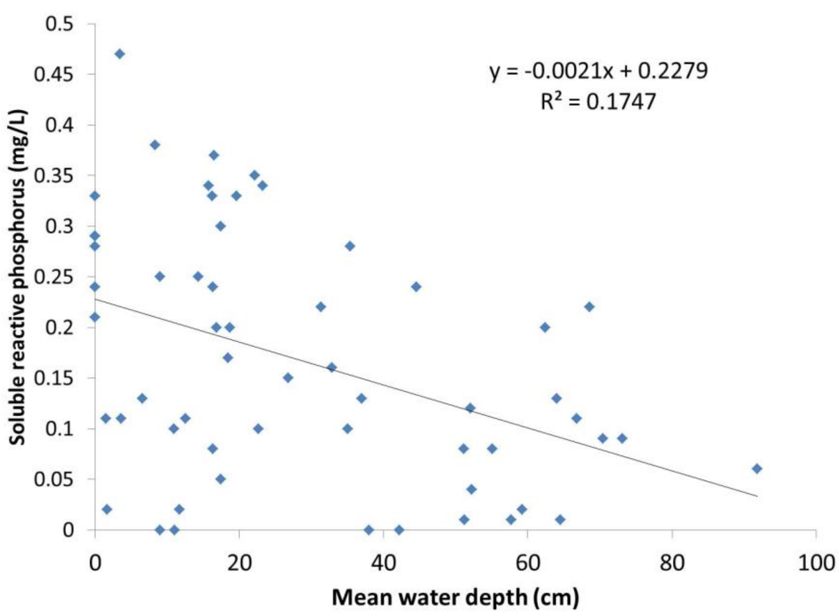

Figure 9. Linear model of the relationship between wetland water depth and soluble reactive phosphorus (SRP) concentrations. The equation describes the line and the R^2 value describes the scatter of points around the line.

A linear model has an equation in the form y = mx + b, where

- y = response variable value (also called dependent variable)
- x = explanatory variable value (also called predictor variable)
- m = slope of the line (i.e. how much average of y changes for a one-unit increase in x)
- b = y-intercept of the line (i.e. where the line crosses the y-axis, the average value of y when x = 0)

Slope (m): models how fast or in what direction y changes with every one unit change in x (Figure 10).

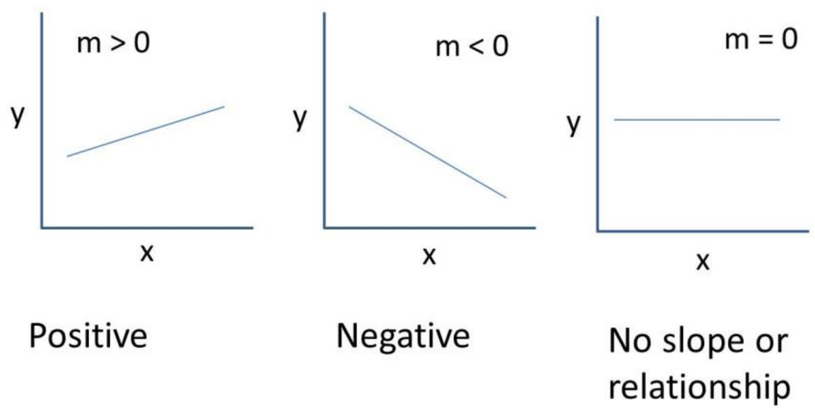

Figure 10. Positive relationship, negative relationship, and no relationship.

Intercept (b): models the value of y when x is zero (Figure 11).

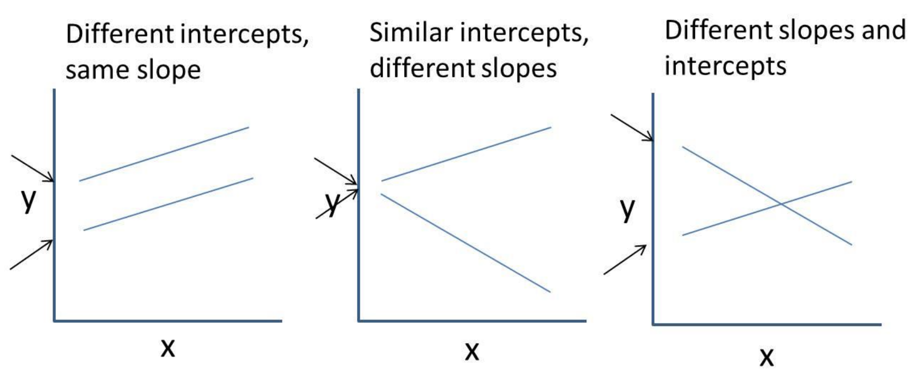

Figure 11. Illustration of linear models with different slopes and intercepts. Arrows indicate the approximate intercept locations.

R^2: models how well the linear model (line) fits the data points. In other words, how "spread" the data are away from the line. R^2 ranges from 0 to 1 and indicates the proportion of variation in y explained by x. In general, the higher R^2, the better the linear fit (Figure 12).

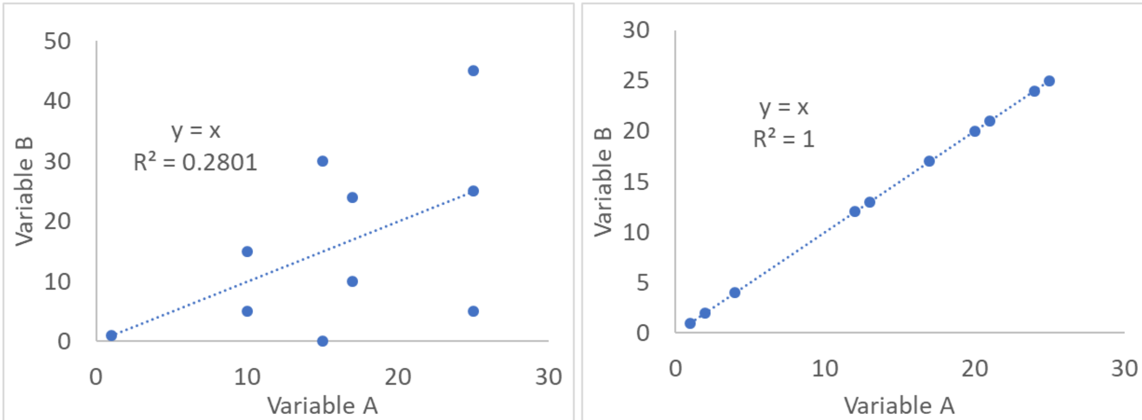

Figure 12. Linear model with a moderate R^2 (0.2801) showing poorer model fit and a high R^2 (1.0) showing ideal model fit with the data.

Linear models are typically tested statistically by determining whether the slope is significantly different from zero (a flat horizontal line). In the activity, we will be statistically assessing whether there is a significant effect of the predictor by examining a p-value for the slope. Recall that a rule of thumb for assessing statistical significance of a test is to compare the p-value to 0.05. If the p-value is less than 0.05 and in the direction that you hypothesized, then the evidence supports your hypothesis.

However, we will also be investigating whether a second predictor variable (wetland ephemerality) affects the relationship between species richness and the x-variable of interest. Statistically, this is known as an **interaction** between two independent variables. When an interaction is present, the effect of x on y is different at different values of a third variable, z. The figure below (Figure 13) shows figures that represent no interaction, a positive interaction, and a negative interaction between x and z.

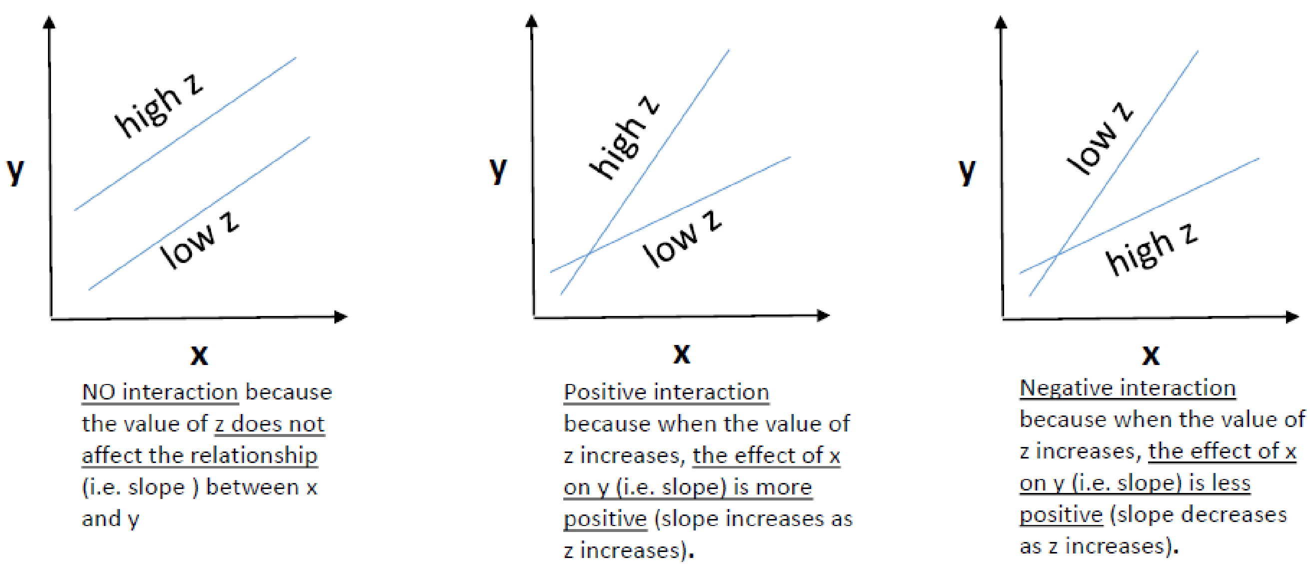

Figure 13. Examples of no interaction, a positive interaction, and a negative interaction between x and z and their effect on y

Photography Credits

1. Photographs are of wetland "Exile" from the study, by A.M. Little
2. Photo by Judy Gallagher, https://www.flickr.com/photos/52450054@N04/26705058872
3. Photo by Kevin Enge, https://www.flickr.com/photos/myfwc/14995946531
4. Photo by J.N. Stuart, https://www.flickr.com/photos/stuartwildlife/4669446198
5. Photo by Greg Schechter, https://commons.wikimedia.org/wiki/File:Blue-spotted_salamander_(Ambystoma_laterale)01.jpg
6. Photo by Christian Fischer, https://commons.wikimedia.org/wiki/File:EubranchipusGrubii1.jpg
7. Photo by Andrew Cannizzaro, https://commons.wikimedia.org/wiki/File:Fingernail_Clam_(Sphaeriidae)_(16938612779).jpg
8. Photo by Ingo Dehne, https://commons.wikimedia.org/wiki/File:Dytiscidae_larva.jpg
9. Photo by Radio Tonreg, https://commons.wikimedia.org/wiki/File:Bidens_frondosa_(7993113777).jpg
10. Photo by Aroche, https://commons.wikimedia.org/wiki/File:Polygonum_hydropiper1.jpg
11. Photos of wetlands P7A and N2B by A.M. Little
12. Photo by Fredlyfish4, https://commons.wikimedia.org/wiki/File:Tropisternus_lateralis_larva.jpg
13. Photo by Udo Schmidt, https://commons.wikimedia.org/wiki/File:Cymbiodyta_marginella_(Fabricius,_1792)_(3408978961).jpg
14. Photo by Judy Gallagher, https://www.flickr.com/photos/52450054@N04/13166303263
15. Photo by Matt Lavin, https://commons.wikimedia.org/wiki/File:Carex_utriculata_(4155807958).jpg
16. Photo by Le.Loup.Gris, https://commons.wikimedia.org/wiki/File:Typha_latifolia_(habitus)_2.jpg
17. Photo by Franz Xaver, https://commons.wikimedia.org/wiki/File:Phalaris_arundinacea_2.jpg
18. Photo by magnolia1000, https://commons.wikimedia.org/wiki/File:Chamaedaphne_calyculata_(2).jpg