Bringing plants and soils to life through a simple role-playing activity

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Motivation

Biological interactions are one of the most common ways in which students learn about the ecological and evolutionary processes that shape biodiversity. For instance, food webs are commonly used to teach how reducing the interactions within a system can decrease diversity, possibly leading to species extinctions. However, most general biology textbooks primarily use animals, reptiles, or invertebrates as case studies to demonstrate the importance of interactions in nature (Uno, 1994; Schussler *et al.,* 2010; Link-Perez *et al.,* 2010). Moreover, many plant examples focus on herbivory, which plants experience only intermittently throughout their life. This contrasts with the fact that: (1) terrestrial plants are ubiquitous and students encounter them regularly in their daily lives, and (2) most interactions a plant experiences happen belowground.

Research on plant-soil interactions and their importance in ecology and evolution has blossomed in recent decades, yet there are exceptionally few examples that Biology students typically encounter (Wandersee & Schussler, 1999; 2001). One possibly reason for this is that plants (and especially soils) can be difficult to present in similarly exciting ways as more charismatic creatures. This leads many students to unintentionally cultivate a fauna-centric viewpoint of the natural world – a phenomenon known as ‘plant blindness’ (Wandersee & Schussler, 2001). If students rarely study plant and soil material, they may not recognize the importance of these critical elements for the functioning of natural systems and human existence (Wandersee & Schussler, 1999; 2001), which puts them at a disadvantage to make well-informed environmental decisions in the future (Balding & Williams, 2016). To avoid these issues, and to highlight the importance and relevance of relationships that form between plants and soils, we have devised a simple role-playing activity that is applicable for both classroom and lab settings.

Context

The American Association for the Advancement of Science's meeting report *Vision and Change in Undergraduate Biology Education* (AAAS, 2011) has called for a more widespread adoption of validated teaching practices in Biology classrooms. Research has indicated that the use of active learning in STEM courses, including group problem-solving, tutorials, in-class activities, and peer instruction, leads to increased understanding of course content (Freeman *et al*., 2007; Freeman *et al*., 2011) as well as a lower course failure rate (Springer *et al*., 1999; Freeman *et al*., 2014). In response, many university faculty members have incorporated learning activities, such as the one described here, into class sessions. We designed this activity as a way for students to engage with plant and soil concepts that are often overlooked or presented in lectures and readings.

Purpose

The purposes of the role-playing activity are: (1) to engage students in a more active interpretation and discussion of the interactions between plants and soils, and (2) to connect these interactions to the larger ecological concepts of drivers of biodiversity. The primary learning objective is for students to recognize how plant-soil interactions can impact patterns of plant community diversity. This learning objective is then assessed with targeted questions asking students to relate the strength and direction (positive or negative) of plant-soil interactions to total species richness or the abundance of specific plant species.

Activity description

The activity has two distinct modes, both of which simulate real-life interactions and outcomes of plant-soil relationships: "Negative" mode has rules to show how negative plant-soil interactions and feedbacks create and maintain diversity, and "Positive" mode has rules to show how positive plant-soil interactions and feedbacks are unstable and can result in monodominance, which limits diversity. With a class size of 30 students, the total activity (played in both negative and positive modes) should take approximately 30 minutes. The directions for the activity are as follows:

(1) Split the class so that half of the students are plants (different species represented as different shapes) and half are soils. Choose which mode (negative or positive) you wish to play, which will determine the type of interactions plant and soil players have (see below). Soil players each receive one soil card + paperclip and stand separate from plants (Fig. 1). Include a pile of extra shapes to serve as the plant species pool (3-4 times the amount of plant players per shape), as well as a discard pile for when plants die and are not returned to the species pool.

(2) Plant players randomly draw shapes from the species pool (one shape per student). Measure the diversity of the plant community this initial time point (T_0). Note: the game can be purposefully seeded with different levels of diversity at T_0.

(3) The game begins with the conditioning phase that simulates how plants change the physical, chemical, and biotic components of their soils based on traits related to their identity (i.e., species or genotype). Plants condition soils by giving them the same characteristics (shape) as the plant (Fig. 1). Plants hand their shape to soil players, and soil players paperclip the shape behind their soil card.

(4) Next, the plant players randomly draw another shape from the species pool and interact with a soil player (Fig. 2). It is important that plant players do not know the conditioned status of soil players before interacting with them, so it is best that soil players keep their conditioned statuses hidden. The outcome of the interaction (whether the plant survives or dies) depends on the rules established in the different negative or positive gameplay modes.

(5) Plants that survive remain standing next to their respective soil player (no other plant can interact with soils that are already matched with a plant). Plants that die discard their shape in a separate pile (do not put dead shapes back in the species pool), and randomly re-draw shapes from the species pool to interact with the remaining unmatched soil players. The gameplay continues until all plants are surviving and matched with a soil player. Pause the game to record the diversity of the community at this time step (T_1).

(6) Plants that survive condition soils based on their current identity (same as Step 3), such that soil players change their conditioned status (shape) on their cards before the next round by paper clipping the new shape on top of the old shape. Repeat Step 4-6 until you have measured diversity for multiple generations (T_0–T_4, or longer).

Negative mode

When the same plant species (shape) and soil properties (shape) are matched, the plant dies. Oppositely, plants survive when plants and conditioned soil shapes are mismatched. For example, if a plant with a diamond shape and a soil conditioned by a diamond plant are paired, the diamond plant would die (Fig. 2). This mode simulates negative frequency-dependent selection, an ecological process that maintains plant community diversity (Packer & Clay, 2000, Mangan *et al*., 2010; Fig. 3).

Positive mode

To play in positive mode, designate one plant species (one of the shapes) to have positive interactions, leaving all other plant species to continue playing in negative mode. The designated species survives in all soil types conditioned by all species (including its own), and no other plant species can survive in soils conditioned by the designated species (Fig. 2). For example, if plants with an X shape were designated to have positive interactions, they would survive in any soil no matter what plant shape conditioned that soil. In addition, plants with a circle shape would die if they interact with a circle-conditioned soil or an X-conditioned soil. This mode emphasizes a mechanism by which a single plant species can become monodominant in a community (e.g., invasive species; Fig. 3) by escaping their natural enemies (Klironomos, 2002) and cultivating inhospitable soil environments for heterospecific species (Bais *et al*., 2003).

Conclusions

We have designed an activity that will help students learn about plant-soil interactions as an important ecological process that influences biodiversity. Moreover, this activity is well-aligned with the benefits of interactive pedagogy, and can easily be implemented alongside recent examples from the primary literature in many different habitat types (see Packer & Clay, 2000, Bais *et al*., 2003, Klironomos, 2002, Mangan *et al*., 2010). We recommend that this activity may be most applicable for small class sizes (20-40 students), as it was successfully implemented in a class of 24 undergraduates (primarily 3rd and 4th year Ecology and Forestry students; Fig. 3).

However, in large classes (>100 students), this activity could be implemented as a demonstration in the front of class with student volunteers or during discussion/laboratory sections with teaching assistants. We recognize the value of having as many students engage in the activity as possible, and therefore recommend that the activity be implemented in laboratory or discussion sections of heavy-enrollment courses so that as many students can participate as possible. With an inexpensive, time-efficient, and engaging activity, we hope to enable teachers to encourage student thinking and conceptual understanding of important, overlooked ecological systems.

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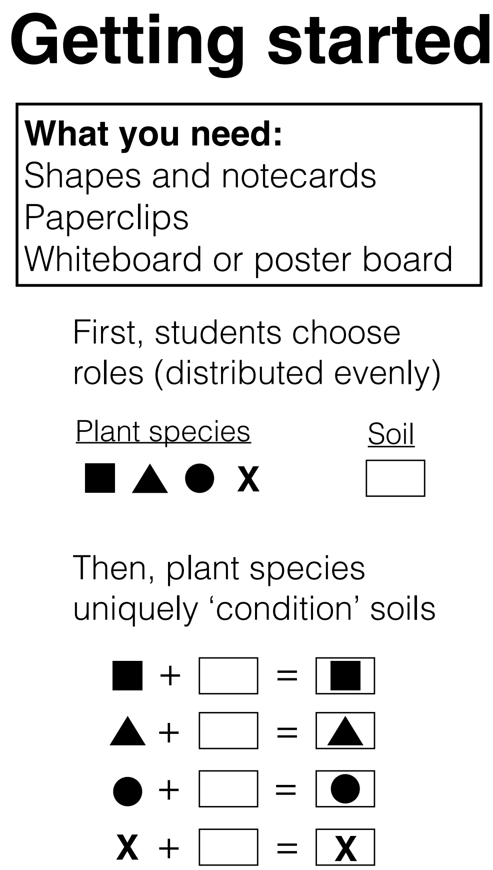

Figure 1. Setting up the activity. Split the class in half so that there are equal numbers of plant and soil players. Each player is either one plant species (shape), or a soil. The game is based on many random 1-on-1 interactions between plant and soil players. Once the players are established, plants condition soils based on their specific species identity by giving soils their shape card. After conditioning, plant players randomly draw a new shape from the species pool.

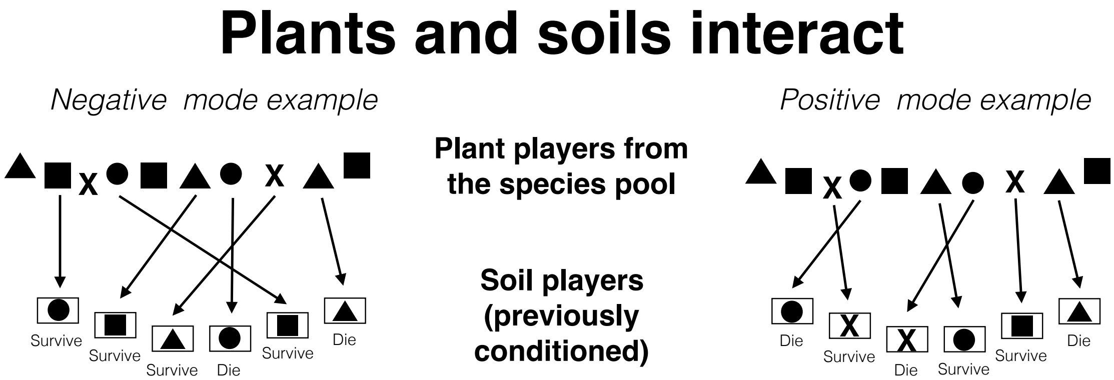

Figure 2. Role playing positive and negative plant-soil interactions. In negative mode, plants die when they interact with soils conditioned by the same species. Survival occurs when plants and soils are mismatched. In positive mode, select one plant species that will have positive interactions ("X" species above). This species survives in all soil types, and no other species can survive in "X"-conditioned soil. Dead plants do not get returned to the species pool. Keep playing until all soils are matched with a surviving plant, then measure the diversity of the community at this point. Plants condition soils based on their current species identity, and the interactions begin again until diversity has been measured 4-5 times. Arrows indicate potential interactions after the plant players obtain shapes from the species pool.

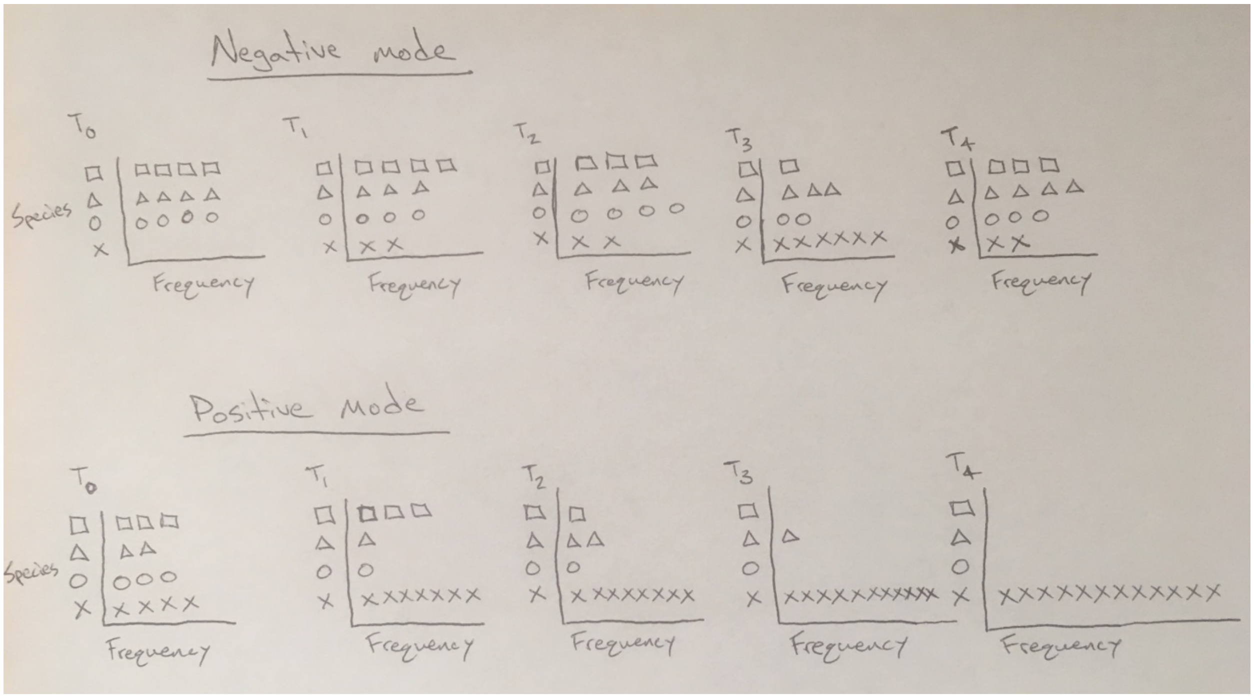

Figure 3. Example activity output from a class of 24 students. In negative mode, we purposefully set the plant community to have lower diversity (3 shapes) than the total number of species in the species pool (4 shapes). After one generation (T_0-T_1), students were able to see how negative plant-soil interactions increased plant diversity with the addition of the X-shaped species into the community. In positive mode, plant community diversity abruptly declined as X-shaped plant species began conditioning more soil players that allowed them to survive and inhibited the survival of other species. This output would be demonstrated on the board with the whole class at each time step and broad patterns discussed after the gameplay concludes.