Bee Survival: An Applied Network Analytical Strategy

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Abstract. In the interactive educational game, Pollinator Panic!, players learn crucial information about why pollinators are in peril, and actions to prevent community collapse. We will be presenting the many sophisticated threats to pollinator populations in the form of a game that will help players become more engaged and personally invested in existing conservation efforts. We hope to bridge the learning gap amongst differing learning styles through utilizing text, audio, and visual means of communicating these ideas in-game. The game will be publicly available online to promote ease of access and circulation via sharing on social media platforms. To accomplish this, we plan to utilize D3.js to build bipartite network models to most accurately illustrate how threats to a population can have severe ripple effects throughout a nested community structure. Players will have to overcome various environmental challenges defined by empirical research to win the game and save the pollinators.

Keywords: gamification · visualization · environmental.

1 Introduction

The ecological health of pollinators is a topic of global importance. Pollinator declines are part of a broader decline of terrestrial insects [5, 12, 8]. Key pollinating insects include butterflies, moths, beetles, flies, and bees [13]. Pollinators are essential in maintaining functioning terrestrial ecosystems and play a central role in agricultural production. The loss of bees, the main pollinator in many ecosystems, could affect many industrial sectors, including food production, cosmetics, and medicine [14]. Despite a great concern among scientists [19], the general publics understanding of pollinator declines and solutions is limited. We are developing a game called Pollinator Panic! [18], which promotes an understanding of this ecological community and the challenges it faces by focusing on maintaining a healthy ecosystem consisting of a sample network of prototypical bee types, generalists and specialists, connected to other species based on the overlapping plants they pollinate. Players are meant to develop a deeper understanding of the real-world threats and consequences pollinator community decline through overcoming challenges that affect the gameplay environment.

For a long time observational evidence has suggested that factors affecting the ecological health of pollinators were far more complex than simple random interactions between pollinator and plant species. [1, 11]. Research shows that pollinator species follow specific foraging patterns, often even coevolving in sync with specific flower species to mutually benefit one another. This is witnessed more frequently among specialist bees as they display preference for a few or even a single flower species and as such they develop adaptations specific to these flowers [20]. In contrast generalist bees form connections to many flower species. If species decline, especially those that play a large role in the community such as generalists, the entire pollinator system can collapse. Instead of seeing pollinator interactions as random, it is better and more complete to see them as a bipartite graph interaction, where bees have designated roles within their environment that can influence other pollinators, even indirectly.

1.1 Using Gamification as a Strategy

Communicating the significance behind the complex foraging patterns of pollinators often poses a challenge due to the many factors at play. We want to remove this obstacle by translating the pollinator network data into the format of a strategy game that enables players to understand the elements that most heavily affect these communities. By presenting complex concepts through the means of gameplay, users engage with the information presented in more dynamic ways, fostering improved understanding and critical insight. Current research shows the value of gamification, with benefits that include increased student participation, engagement, and retention of information [10]. Applications of "serious games" have been studied extensively in the past decade as a means of conveying statistical data [9]. It is understood that different varieties of graphical representation may impact students with certain learning styles differently [3]. The goal of crafting this information as a game would hopefully bridge multiple learning styles by allowing for tactile, visual and audio means of presenting concepts in-game.

1.2 Using Network Analytic as a Strategy

The links depicted between different species of pollinators are weighted based on how heavily two species interact with the same ecological network of plants, i.e. how many common flowers benefit from their pollination efforts. The focus on a network structure for this iteration of the game is vital because it allows for a more biologically realistic view of the factors that attribute stability to pollinator communities. Network analytics have elucidated many of the unique ecological qualities of pollinator communities that we hope to convey through this game. In this way, players will be able to see the ripple impact of an ecological challenge, understand the interactions, and see how the removal of a single flower or pollinator species may affect the entire community.

Social structures within a population can develop in many forms and provide insight into both basic and complex human-to-human communications and interactions. We are interested in expanding this paradigm in two specific forms: bee-to-flower (b-t-f) interactions and exploring sociometry [15] education in a game typesetting. Our work is a variation on the idea of Explorable Explanations [22], which allow users to navigate a variety of subjects through interactive visualizations. We suggest that when applied to a worldwide issue, such as pollinator conservation, these interactive platforms will more broadly communicate ideas across diverse learning styles, eliminating the need to further tailor information to match an individuals preferred learning format. We can engage the public more effectively to not only to yield a more accurate depiction of the root of the problem, but also provide a pathway to correct the issue at an individual and localized level.

2 Methodology

2.1 Bee-to-Flower Dynamics

The best way to think about this interaction is to assume that bees are community-blind, but consistent agents. That is to say, they do not consciously strategize or intermingle between species, but they do display strong and distinct preferences for specific flowers which may benefit other species possessing similar preferences. We categorize bees as one of two types of agents: specialist collectors and generalist collectors. Generalist collectors still display preference, but they interact with more species while specialist bees are more limited‘ and will collect pollen or nectar from only a few flower species. These specific roles create an interesting bipartite relationship between the bees based on the flowers they visit. Our game illustrates an optimal scenario through the depiction of a series of nested connections as observed within mutualistic pollinator network. For example when two bee species possess overlapping connections to a single flower, the flower proliferates doubly, increasing the abundance of this resource in the community and benefiting both associated pollinator species congruently. This illustration can remain accurate while discounting competition between species under the assumptions that the environment is able to sustain the increased volume of a continually growing population. Figure 1 provides an example network, where bees (labeled b*) interact with flowers (labeled f*). In Figure 1, both bee agent types are depicted, [b8, b9] as specialist collectors and [b1–b7] the generalist collectors.

2.2 Game Mechanics

Players take on the role of conservationists as they attempt to maintain a community under stress. In the game, the players face challenges based off the revised "5P‘s"(formerly "4P‘s" [4]) which are; pathogens, parasites, pesticides, poor nutrition, and pollution as it relates to global warming. Each challenge event will affect the network in a different manner resembling the real world ecological impact of each of the challenges discussed above. For example, pathogens may affect more species of closely related bees via contact transmission from the common flowers they pollinate. While pesticides could affect random species depending on whether multiple flower species reside in the area the pesticide was applied.

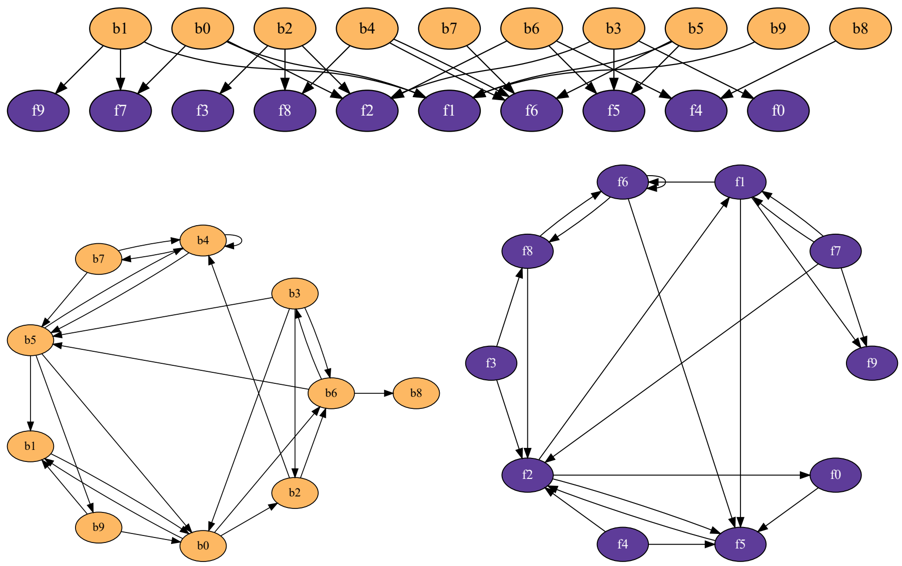

Fig. 1. The figure showcases an example network and understood complexity. The top figure shows an interaction between bees (b*) and flowers (f*). The figure on the bottom left the subsequent bee-network and the bottom-right the corresponding flower network.

Players will need to capitalize on three strategies derived from existing research to win. The first strategic initiative learned in-game is the value of a community with high species richness and abundance. For this reason, players are encouraged to fill their environment with multiple species and to ensure their population level stays consistently high. The second strategy learned is the importance of building a community network structure that demonstrates "modularity [16]." We represent this modularity in-game by the ability to "cluster" bees that share similar roles to strengthen the resilience of that group to challenge events. The final strategy is to place many generalist bees with overlapping function, in terms of the common plants they visit. This is creates the "nested structure" of pollinator communities. All three of these strategies must be mastered to "win" the game by maintaining a high "stability score."

2.3 Other strategic postulations

Based on these networks, species declines, when they do occur, are nonrandom and specialists are often the first to go (different vulnerability score attributed to bees with high connectivity vs low connectivity). There is also a direct relationship between bees and flowers, which can develop into an exponential decline simply because pollinator declines can drive plant declines and vice versa [19]. Pollinators and flowers form mutually beneficial communities where pollinator gain nutritional reward of nectar and pollen and immobile plants gain the benefit of outcrossing by pollinators who move their pollen to cospecifics. This nested mutualistic network structure makes the entire community more resistant to perturbation [17]. In this way Pollinator Panic! will help players to understand the concepts of species diversity, nestedness, and modularity which all contribute to the likelihood of surviving threats to the population.

3 Bee Survival Prototypes

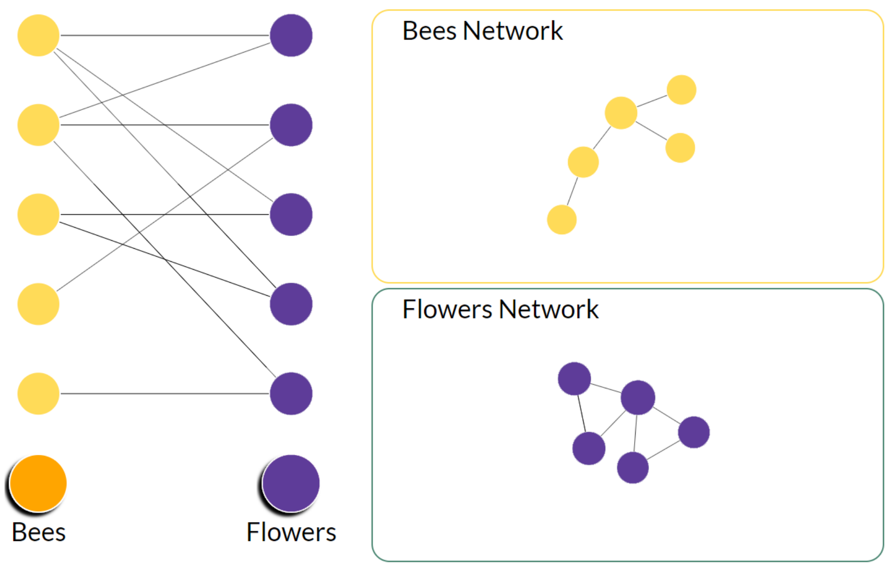

Fig. 2. The force-directed graph prototype. The bipartite graph highlighted to the left and subsequent force-directed graphs on the right.

One of the most important aspects of the project is projecting the bipartite graph structure in a way that is easy and intuitive to interpret. As bipartite graphs can suffer in their readability, based on edge–crossing [23, **?**]. Both prototypes are optimized to help alleviate this issue, using a force-directed graph and matrix to highlight connections. The designs were both developed using D3.js [2], as they create an interactive web-based interface that allows for smooth transitions between interactions, minimizing cognition issues associated with change blindness [21].

Shown in Figure 2, the force-directed graph shows an example bipartite graph (left) that allows for dynamically adding both nodes (circles) and edges. As connections generate, the force-directed graphs (right) also dynamically construct themselves to provide their individual (either bee or flower) networks. Also included, is a dynamic calculation of "degree-centrality [6]" to help highlight more central bees or flowers. The matrix variation, seen in Figure 3, again

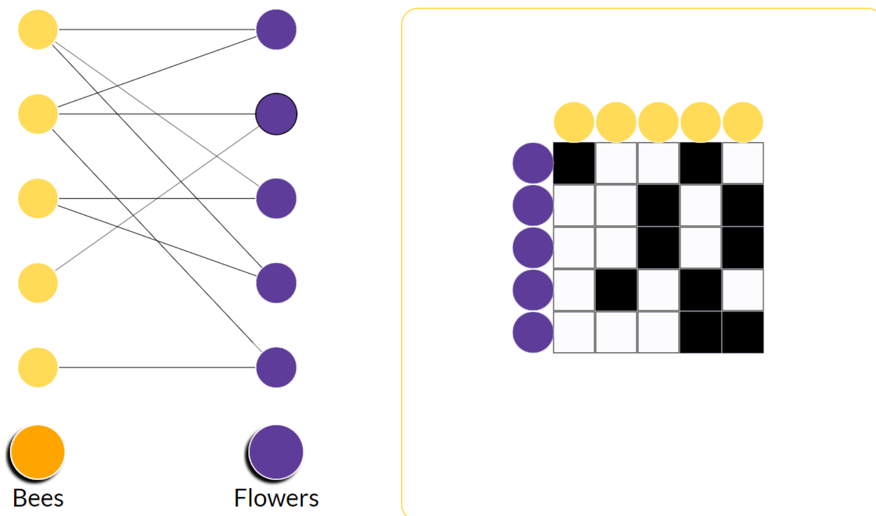

Fig. 3. The matrix prototype. The bipartite graph highlighted to the left and subsequent matrix on the right, where highlighted cells indicates a connection between a bee and flower.

has the bipartite graph (left), but the matrix representation of this network to the right. Highlighted cells indicate that there is a connection between bee and flower. The matrix prototype was also designed, as matrices can highlight both the nestedness and are easier to make use of by observers [7].

4 Conclusion and Future Work

There is great interest in understanding the sociology of gameplay as well as potential pedagogical utility in the classroom. We plan to design studies examining which aspects of the user interface best assist in comprehension of the learning concepts. To accomplish this we would need to know where players focus is directed throughout the gameplay experience by using technologies like eye tracking software, and administering assessments to better determine whether students understanding of the material is truly improved with this learning tool. The insight gained from these trials would allow for us to discern whether understanding and focus may be reliant on any specific game features that should be explored for future development.

The ability to input data collected from research directly into this simulation based game may also yield useful information advancing the field of study. While originally intended to benefit ecological researchers and their work in regards to pollinator health, this game has further purpose in different contexts including epidemiology. When considering disease surveillance this simulation technology could prove useful to observe patterns and model the efficacy of different mitigation efforts in order to better assess disease management methods relevant to human populations.

We believe that this endeavor can help shine a light on a current entomological issue. With a focus on education, we are trying to project these complex networks and concepts to make them more actionable at both a local and global level. As this project develops and is eventually distributed, we hope to incite the change necessary to preserve pollinators and the lush environment they build, for future generations to enjoy.

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