Do plant patches within a bog conform to Island Biogeography Theory: A case study of Mud Lake Bog

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Abstract

Island Biogeography Theory (IBT) originally focused on marine islands but in the past few decades has been applied more broadly to varying ecosystems both terrestrial and marine based on the concept of patchiness. The application of Island Biogeography Theory to Mud Lake Bog is useful to assess both the distribution and patchiness of the habitat as well as IBT's applicability to systems of different spatial and temporal resolutions. Patches of plant growth were identified as islands and data were collected from each island. Islands were measured for their perimeter and distance from the shoreline. Species were identified and counted, and prominent plant groups (*Picea mariana* and *Chamaedaphne calyculata*) were measured for size in thickness and height, respectively. Species richness and plant size were analyzed in relation to island size and distance from the shoreline. The results of comparing species richness with island size and distance from the shoreline indicated a stronger correlation between patch size and species richness, rather than distance and richness , which is concurrent with IBT (species richness vs. perimeter: Multiple R-squared = 0.553, p-value < 0.001). Also, plant size increased as island size increased (*C. calyculata* vs. perimeter: Multiple R-squared = 0.4058, p-value = 0.008; *Picea mariana* vs. perimeter: Multiple R-squared = 0.495, p-value = 0.002). Our results are an indication that the heterogeneous patches of growth on the sphagnum mat in Mud Lake Bog can be considered isolated islands. Because Mud Lake Bog is heterogeneous and is a relatively undisturbed bog, we can conclude that a healthy bog will display heterogeneity with varying species richness as patch size changes.

Introduction

Island Biogeography Theory (IBT) describes the relationship between species richness and islands that are disconnected from the mainland. Islands that are larger in area, as well as islands located closer to the mainland, will likely have greater species richness compared to islands that are smaller in area and more distant from the mainland (MacArthur & Wilson, 1967). These predictions are formed around the isolation and dispersion of islands, or habitable zones, otherwise known as patchiness. Patchiness can refer to both spatial and temporal isolation. (Marquet et al. 1993). These factors influence immigration and emigration, therefore impacting species richness (Collins, Holt, & Foster 2009). Islands are in higher abundance and are smaller in area than other land masses and their habitats, so they are useful in learning about diversity trends. Due to the fact that islands have a greater degree of isolation, the complexity in studying variables that affect species richness in different habitats is reduced (MacArthur & Wilson, 1967).

IBT has also been applied to terrestrial systems that compare to islands. A large-scale study was conducted in Western Estonia that applied IBT to a bog ecosystem by comparing bog forests within a radius of 60km. Forest islands were grouped into four descriptions: 1-10 ha, >10 ha, small peninsular edge forests, and mainland forests. This study found a correlation between island size and species richness but found less diversity among the mainland than the islands on account of more disturbance (Liira, Jurjendal, & Paal, 2014). The idea of patchiness is what drives the application of IBT to terrestrial ecosystems; in any environment, there is likely to be isolation and changes in the distribution of both organisms and abiotic factors. This is true of any resolution of an ecosystem, both on a temporal and spatial scale (Marquet et al., 1993). Another study was conducted applying IBT to temporary (vernal) pools of varying volumes. This study found that pools of greater volume had more species richness, adhering to the trend that patch size has greater impact than patch distances (March & Bass 1995; MacArthur Wilson 1967).

This study operates on a smaller scope by testing the applicability of IBT in isolated groups within a single ecosystem—a bog—based on the premise of patchiness. Amongst the sphagnum mat in Mud Lake Bog, there is a clear distinction between small patches of plant growth that are separated by stretches of uncolonized sphagnum moss and sedges. These island patches are not isolated in the same way as ocean islands; in the bog patches, the moss mat "ocean" can be traversed by animals, so the impact of isolation was measured on plant species only. IBT has traditionally been applied to islands separated from the mainland by large bodies of water, but this study seeks to determine whether this same phenomenon can be observed among a bog mat.

Bogs represent a stage in the succession of an aquatic ecosystem that alters the habitable zone and can create isolated growth, similar to islands. Bogs are wetlands characterized by an abundance of peat and sphagnum moss that create acidic conditions (Jeglum, Boissonneau, & Haavisto, 1974). In a bog, a water body becomes infilled with mud, which is then overtaken by grasses, sedges, and sphagnum moss (Schwintzer & Williams 1974). The stage of the bog not only determines the stage of succession but also which plants are able to grow: sphagnum moss easily overtakes small aquatic plants and the thickness and acidity of the mat can only support the root systems of specific plants at different stages. Plants commonly found in the bogs of the Northern Lower Peninsula of Michigan include *Chamaedaphne calyculata, Picea mariana, Thuja occidentalis, Larix laricina, Sarracenia purpurea,* and a variety of different sedges. Near the middle stage of bog succession, bog habitats will become more populated by associations of Thuja and Chamaedaphne (Gates, 1942). However, while the plant associations are predictable, their dispersion among the mat is not. This study seeks to determine if this dispersion follows the patterns described by IBT. If island size and distance are related to species richness then islands that are smaller and farther away will be less rich than islands that are larger and closer to the mainland.

Methods

Experimental Design

The independent variables measured were island size as well as the island's distance from the established shoreline. Island status was determined by the following requirements: at the patch's center, the intersection of chords of its greatest length and width, is a distance of at least 10 m away from the shoreline, its edge is a distance of at least 30 cm from any other islands (otherwise it was counted as one island), and its total perimeter is at least 2 m. The shoreline was established where growth became dense enough that the moss mat no longer created any gaps larger than 30 cm between patches. The dependent variables being measured were the species richness and biodiversity of the plant community and plant health. Plant health was defined by size measurements of two abundant plant groups present (*Picea mariana* and *Chamaedaphne calyculata)* as an indirect measurement of that plots ability to support growth. Four mainland control plots were also measured. The mainland was defined as the area behind the established shoreline that approached the surrounding swamp.

Experimental Protocol

A perimeter of 18x30 m was established along the shoreline of the mainland, and 16 islands within that area were surveyed. The perimeter of each island was measured by laying an open-reel measuring tape along the island's outline. The distance from the center of the island to the closest point on the established shoreline was also measured with the open-reel measuring tape, running perpendicular to the shoreline. A sketch of each island's shape was recorded, as well (Figure 1). Plant species were identified and counted. Within each island and plot, the largest *P. mariana* was selected for measurement, if any individuals were found. In the one instance where *P. mariana* was not found, the measurement was entered as 0. Because many of the *P. mariana* were below breast height, the diameter at knee height in cm was taken instead using calipers. When *P. mariana* were under knee height, their diameters were recorded as 0 cm. The largest *C. calyculata* was selected for each island and plot and its height at the highest point was measured. In the mainland control group, four 1x1 m plots were randomly placed. Within each plot, as with the islands, plant species were identified and counted and the largest *P. mariana* and *C. calyculata* were measured.

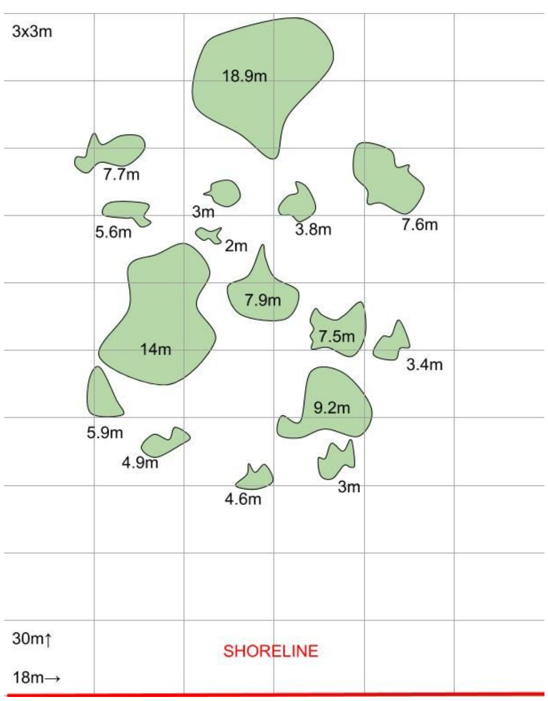


Figure 1. Approximate map of surveyed islands. Each grid represents an area of 3x3 m.

Data Analysis

Species richness was measured by a count of how many species were present on each island. On each dataset pairing (plot size vs. health, plot distance vs. health, plot size vs. species richness, plot distance vs. species richness) a linear regression analysis was run to test for correlation in each relationship. For these results, the multiple R-squared value was taken, since only one variable was tested. Then, a multiple regression analyses was run to factor in all of the effects of the independent variables on the dependent variables (plot size and distance vs. *P. mariana* thickness, plot size and distance vs. *C. calyculata* height, plot size and distance vs. species richness). For the multiple regressions, the adjusted R-squared was considered more accurate as multiple variables were being tested.

Results

A multiple regression analysis that compared species richness with island size and distance from shoreline yielded significant results (Adjusted R-squared = 0.4861, $F_{(2, 13, 0.05)} = 8.094$, p-value = 0.005; Figure 2). Comparing *C. calyculata* height with island size and distance from shoreline also yielded significant results (Adjusted R-squared = 0.589, $F_{(2, 13, 0.05)} = 11.73$, p-value = 0.001; Figure 3). A multiple regression analysis comparing *P. mariana* thickness with island perimeter and distance yielded significant results (Adjusted R-squared = 0.6526, $F_{(2, 13, 0.05)} = 16.09$, p-value < 0.001; Figure 4).

A linear regression analysis comparing species richness and distance from shoreline yielded insignificant results (Multiple R-squared = 0.06, $F_{(1, 14, 0.05)} = 0.9593$, p-value = 0.344; Figure 2, top). A linear regression analysis comparing species richness and island perimeter yielded significant results (Multiple R-squared = 0.5528, $F_{(1, 14, 0.05)} = 17.31$, p-value < 0.001; Figure 2, bottom).

A linear regression comparing *C calyculata* height and distance from shoreline yielded insignificant results (Multiple R-squared = 0.0393, $F_{(1, 14, 0.05)}$ = 0.5729, p-value = 0.462; Figure 3, top). A linear regression comparing *C calyculata* height and island perimeter yielded significant results (Multiple R-squared: 0.4058, $F_{(1, 14, 0.05)}$ = 9.561, p-value: 0.008; Figure 3; bottom).

A linear regression analysis comparing *P. mariana* thickness and distance from shoreline yielded insignificant results (Multiple R-squared: 0.0195, $F_{(1, 14, 0.05)}$ = .2785, p-value: 0.606; Figure 4, top). A linear regression comparing *P. mariana* thickness and island perimeter yielded significant results (Multiple R-squared: 0.4945, $F_{(1, 14, 0.05)}$ = 13.7, p-value: 0.002; Figure 4, bottom).

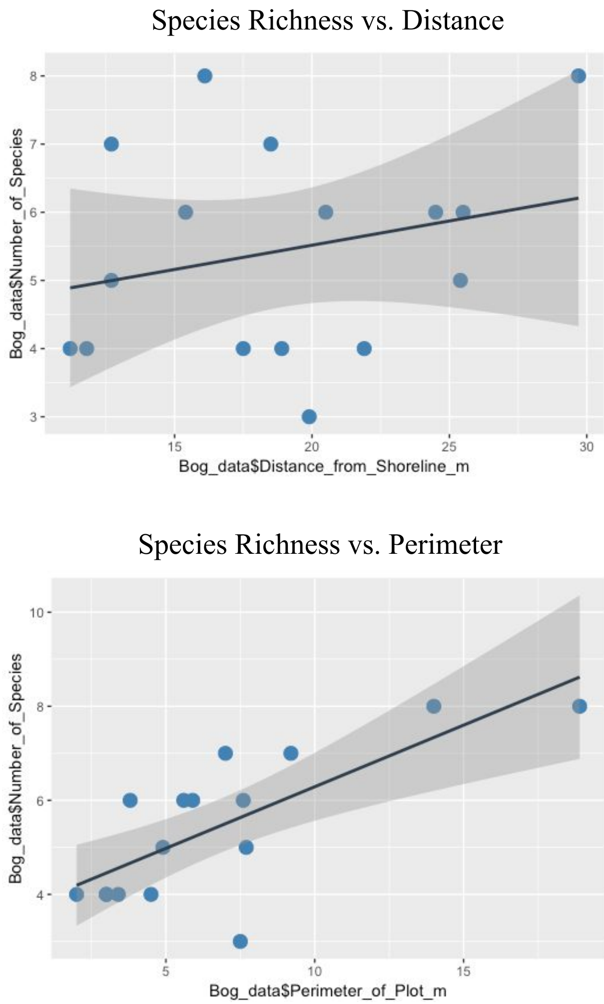


Figure 2. Top Panel: Linear regression comparing the number of species present (species richness) with the island distance from the shoreline. Bottom Panel: Linear regression comparing the species richness with the perimeter of the island plot. Each point represents an island measured. The shaded area represents the 95% confidence interval.

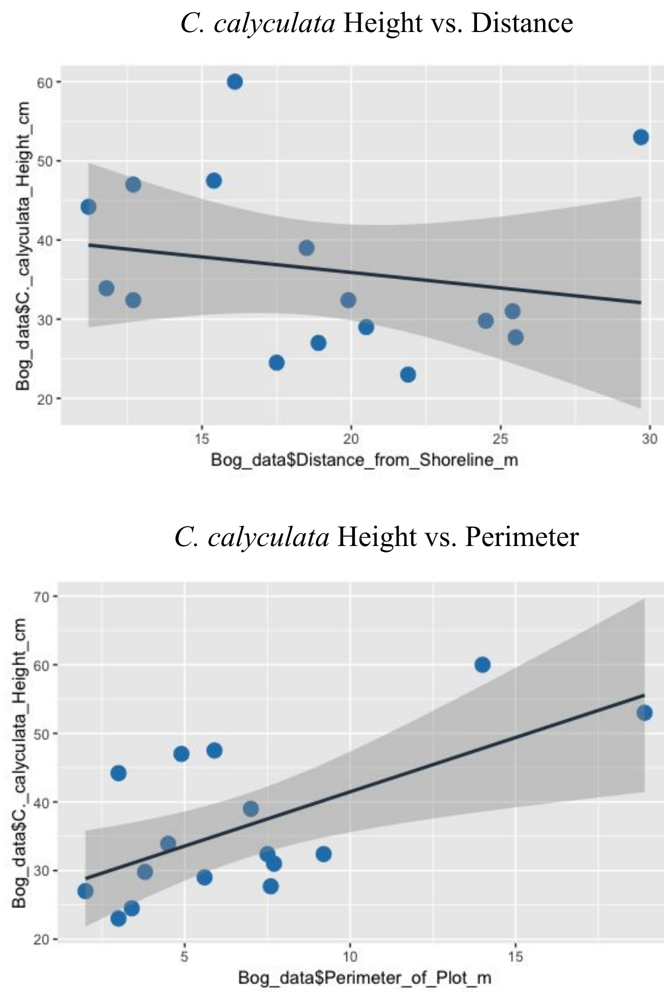
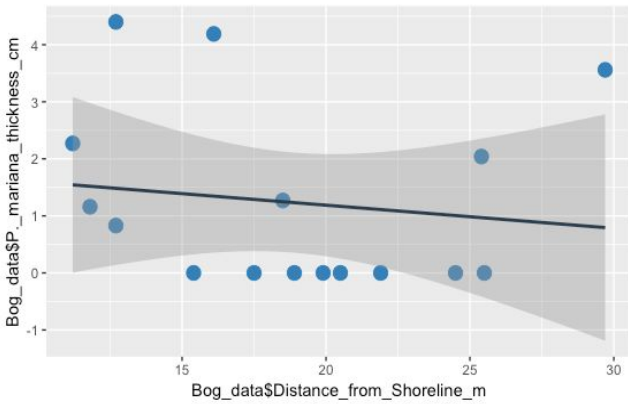


Figure 3. Top Panel: Linear regression comparing *C. calyculata* height to island distance from the shoreline. Bottom Panel: Linear regression comparing *C. calyculata* height to the perimeter of island plot. Each point represents an island where *C. calyculata* height was measured. The shaded area indicates the 95% confidence interval.

P. mariana Thickness vs. Distance



P. mariana Thickness vs. Perimeter

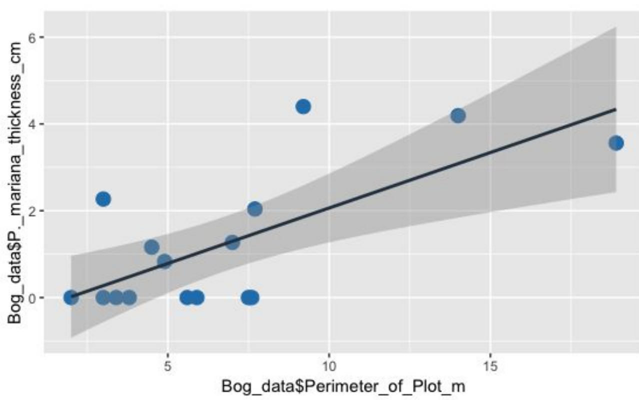


Figure 4. Top Panel: Linear regression comparing *P. mariana* thickness to island distance from the shoreline. Bottom Panel: Linear regression comparing *P. mariana* thickness to the perimeter of island plot. Each point represents an island where *P. mariana* thickness was measured. The shaded area indicates the 95% confidence interval.

Discussion

Linear regression analyses that were run on all of the data indicated a much stronger correlation between patch size and species richness than distance and species richness. When measuring species richness compared with island size and distance from the shoreline, the multiple linear regression analysis showed significant corollary results, but these results are not fully concurrent with IBT (Figure 2). There was a positive correlation between species richness of the bog islands and their distances from the shoreline, whereas IBT asserts there should be a negative correlation (McArthur & Wilson 1967). This positive correlation could be a result of a small sample size, the presence of outliers, or proximity issues. However, the results show a positive correlation between species richness and island size (Figure 2). These results align with the theory's assertion that island size has a greater impact on species richness than distance, since the linear regression for species richness and island size yielded more significant results (McArthur & Wilson 1967; Figure 2). With the coupling of a clear visual distinction between growth patches and the adherence of patch size to a trend in species richness, we can make the greater assertion that patch size has the larger impact on species richness and that this is applicable to Mud Lake Bog. Mud Lake Bog is, therefore, a heterogeneous ecosystem, and our results support the larger theory that patchiness exists at multiple resolutions of ecosystems (Marquet et al. 1993).

The measures of plant health (C. calyculata height, P. mariana thickness) indicated that larger islands supported larger plants (Figure 3, Bottom; Figure 4, Bottom). IBT specifically focuses on species richness as it changes according to island position and size, but these results suggest that the size of plants present are impacted by island size, as well. Further research into this relationship could potentially contribute to expanding the scope of IBT.

Studying isolated patches within systems allows us to gather more nuanced data by focusing on smaller areas. We may also draw firmer conclusions regarding the species richness and the spatial distribution of populations, of these different systems, when each microcosm is studied separately and results are drawn back to the whole to create an entire image (Caswell & Cohen 1991). If IBT is applicable to a habitat as small as a single bog, then we can continue to conclude that the distribution and heterogeneity of even small ecosystems have impacts on the approaches with which we study them (Simberloff & Abele 1976).

The way we study ecosystems is directly related to the results we obtain and how we interpret them; on too small of a scale we lose data, on too large of a scale we may overlook data. By studying ecosystems as heterogeneous, be it a single bog or a national park, we are able to focus on isolated areas and bring those foci into one final description, better understanding the nuances of an ecosystem in the process (Marquet et al. 1993). These nuances, such as where species are establishing themselves and where they thrive, are critical to understanding interactions and movement within a system, which becomes increasingly more important in the realm of conservation (Simberloff & Abele 1976). As we discover the application of IBT to more ecosystems, we also uncover the heterogeneous nature of these ecosystems and to the extent at which the patches are isolated (Liira, Jurjendal, & Paal, 2014; Boyd et al. 2016; Collins, Holt, & Foster 2009; Caswell & Cohen 1991; Marquet et. al 1993).

While isolation seems to be a common natural phenomenon, artificially fragmented ecosystems can have a negative impact, such as changes in plant distribution (Collins, Holt, & Foster 2009). These changes in distribution have the potential to impact herbivory, creating cascade effects that can disturb entire ecosystems. However, in the field of habitat conservation and restoration, there is debate between whether homogeneity or heterogeneity is more effective in sustaining populations (Donaldson, Wilson, and Maclean 2017). The most effective type of habitat for sustaining diversity often varies with the types of organisms present, such as generalists that may thrive in varying conditions, or edge species that benefit from fragmentation (Bender, Contreras, & Fahrig 1998).

The application of IBT becomes important in considering what size and spatial distribution in habitats are the most effective in preserving diversity. There is also the hypothesis that it is not the size and distribution of the habitats that impacts their diversity, but the quality of the habitats (Lawson et al. 2014). This quality is often influenced by the disturbance a habitat has experienced, such as noise pollution, hunting, and logging (Laurance 2008). Mud Lake Bog is a relatively undisturbed bog, and by observing the distribution of plant species a clearer image is formed not only of the heterogeneity of the habitat but also of what a ‘high quality,’ in this case meaning lacking disruption, wetland ecosystem may look like.

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