2019

Investigating the Role of Recreational Trails in Plant Invasion in Southeastern Connecticut

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2018-2019

Introduction

The spread of invasive plant species poses a significant threat to the future of native ecosystems. An invasive plant species is a species which is both non-native and harmful to the environment it inhabits. The most vigorous invasive plants often grow quickly, are tolerant of many habitat conditions, and disperse seeds in great numbers and at high frequencies (Bewick et al., 2017). These factors allow invasive plants to reproduce and spread rapidly into a variety of habitat types. Rapidly spreading invasive plants are able to outmatch native plants in competition for resources such as light, water, and soil nutrients. Due to the interconnectedness of ecosystems, the effect of invasion on one native species could affect the success of many other native species. The perpetuation of plant invasion is a threat to the habitats of native plants world-wide (Mack, 2002).

A thorough understanding of historical and environmental conditions that promote plant invasion is very important. It can be observed in a forest that some areas are heavily invaded, while some have no presence of invasive plants. While it was commonly thought that developed, undisturbed forests could exclude plant invasion, studies on invasion show significant plant invasion in the forests of south eastern Connecticut. By gaining knowledge of the characteristics of habitats that promote invasion, efforts in invasive plant management can be more focused. This sort of knowledge will provide insight into likely locations for high levels of invasion, which can support efforts to manage and remove invasive plants (Kuhman et al., 2010). Knowledge of invasion-promoting environmental factors could also affect the way humans interact with areas sensitive to invasion. For example, an area with invasion-promoting qualities could be restricted to limited human use, as an effort to negate the spread of seeds.

The disturbance of the forest can leave areas vulnerable to invasion (Kuhman et al, 2010). A prominent disturbance for forests that are recreationally visited are roads and trails. Many studies have found a heightened level of plant invasion near roads and trails (Ballantyne and Pickering, 2015). The clearing of forest for trails also opens the canopy to allow light, which is often taken advantage of by invasive plants (Peknicová and Berchová-Bímová, 2016). The spread of seeds, facilitated by the passing of people, animals, and vehicles can also pose a threat (Ansong and Pickering, 2014). Song et al. found that damage to the canopy facilitated the spread of an invasive plant (Song et al., 2017). Huebner et al. identified trails as potential corridors for invasion, but did not find significant influence of canopy openness on plant invasion in the Allegheny National Forest of Pennsylvania (Huebner et al, 2009). In discussing the reasons for increased invasion along haul roads in Michigan forests, Buckley et al. proposed that differences in soil moisture, light, and species richness along trails could be major factors (Buckley et al, 2003).

It’s possible that the size of trails and roads may influence the ability of invasive plants to inhabit the area. In Queensland, Australia, wider trails were found to potentially alter plant composition, while narrow and informal trails appeared to impact along-trail vegetation less (Pickering and Norman, 2017). Woziwoda et al. took note of the potential for dispersal of propagules via birds and rodents along small forest roads (Woziwoda et al, 2018). Ballantyne and Pickering, in a review of relevant literature, call for more investigation into narrow recreational trails, noting the focus on large formal trails in most relevant literature (Ballantyne and Pickering, 2015).

The age of forests could also influence the ability of invasive plants to enter. Flory and Kay (2009) found increased plant invasion in younger forest and along roads. This study isolated the tendency for invasive plants to grow along roads and in younger forest. In this study, I aim to explore these variables both individually and in relation to each other, asking the question of if the presence of trails has greater influence on plant invasion in younger or older forests.

Alston and Richardson (2006) found a relationship between plant invasion and the proximity to anthropogenic areas of disturbance in Cape Peninsula, South Africa. They also found greater invasive presence closer to areas of anthropogenic disturbance, suggesting that these areas may be the source from which invasive plants spread in the region.

Weiss et. al (2018) found that recreational trailheads could be a starting point for invasion deeper into forests, advising that trailheads of popular bike paths be cleared of invasive plants. This finding suggests that trailheads could be an entry point for plant invasion in natural areas.

Since their introduction to this country through such plant exploration, invasive plants have established populations across the region of south eastern Connecticut. This spread of invasive plants introduces threats to native plant populations, but also facilitates the study of plant invasion. There are a variety of habitat types in the forests of Connecticut. A wide array of environmental qualities brings differing presence and abundance of native and non-native plant species.

The Barn Island Wildlife Management Area is a natural area open to recreational human use. Across these three sites, activities such as biking, swimming, walking, horse riding, and paddling are possible. Limited motor vehicle use is also carried out on trails by officials of these sites. The open access to these sites allows for meaningful exploration of south eastern Connecticut's flora, fauna, geography and geology. However, this open access can also facilitate a higher abundance of invasive plant species. In exploring the role of trails in plant invasion I take into account factors of distance from trail, canopy openness, forest age, trail width, distance from edge of forest, and distance from trailhead. From previous research at Barn Island Wildlife Management Area in 2014, a positive correlation was found between proximity to trails and abundance of invasive species. I plan to study this relationship further and to gain a more complex understanding of factors which may influence it.

For my honors thesis within the botany major, I investigate the relationship between plant invasion and trail proximity at the Barn Island Wildlife Management Area. I study the factors which influence this relationship by examining variables of forest age, trail size, distance from trailheads, distance from forest edge, and canopy cover. I plan to examine how factors of forest age, distance from forest edge, and trail width may be related to the amount of invasive plants directly along trails. By measuring invasion both along trails and deeper into forests, I hope to assess how factors of forest age, distance from forest edge, distance from trailheads might influence the distribution of invasive plants from along the trail to 20m deeper into the forest. Taking into account the distribution of invasive plants as you go deeper into a forest will act as a way of assessing how these variables may be related to the penetrability of a forest. I will also use measurements of canopy openness to assess how it might be related to invasion along trails and deeper into forests.

Methods

Barn Island Wildlife Management Area is a ~1,000 acre natural area in Stonington, Connecticut. While the site contains many habitat types, the focus of this study is on forested areas. Forests within Barn Island primarily consist of mixed hardwood trees (Dreyer et al., 2015). Much of Barn Island Wildlife Management Area is inhabited by plants invasive to Connecticut. The most common invasive plants found throughout Barn Island Wildlife Management Area are *Lonicera japonica, Rosa multiflora*, *Celastrus orbiculatus,* and *Lonicera morrowii*.

2018 study

This section of the study was performed in the late summer and autumn of 2018. In order to assess the distribution of invasive plants in relation to distance from walking trails, I used measuring tapes to section off sets of plots in which I counted the number of individual invasive stems. I initially selected the location of plots by observing the presence of invasive plants along the trail. All plots were also located in a forested area. Plots were established every 100m along a trail. Once a plot location was selected, a 2 x 20m plot would be established parallel to the trail. Another 2 x 20m plot would be established 10m deep into the forest parallel to the first plot, and a third 2 x 20m plot would be established 20m deep into the forest, parallel to its counterparts. Additionally, the canopy openness of each sub-plot was measured using a Sigma hemispherical camera lens of the canopy at the mid-point of each plot, at each respective distance from the trail. A total of 32 sets of 3 sub-plots were observed and analyzed. Using GapLightAnalyzer, these photos were used to estimate canopy at different distances from the trail. These methods were applied to a variety of areas of Barn Island Wildlife Management area, including wide and thin trails. Trails considered to be wide were dirt trails with the approximate width of a one lane road. They allow for maintenance and fire access, but are not open to the public and are rarely used. Narrow trails were smaller footpaths which were approximately the width of one person.

2014 study

This study also uses data related to invasion and forest age, trail width, and distance from forest edge from a 2014 study by Dr. Chad Jones at the Barn Island Wildlife Management Area on the presence of invasive plants along trails. 1 x 100m plots were established parallel to trails and invasive individuals were counted in each plot. Plots were established adjacent to each other along trails. This study included 109 plots.

Analysis

ArcGIS was used to analyze metrics of distance from forest edge, distance from trailhead, forest age, and trail width. Forest age is determined based on a binary metric of "young" or "old", depending on whether an area was forested in a 1934 aerial photograph of Barn Island Wildlife Management Area.

For several variables I assess the distribution of invasive plants between plots 0m from the trail, 10m from the trail, and 20m from the trail. I do this by calculating what percentage of the invasion at plots 0m from the trail are represented in their corresponding plots 10m and 20m from the trail. This provides a measure of how invaded the forest is off the trails relative to the amount of invasion at the nearby trail. I then compare this distribution to variables such as forest age, distance from the edge of the forest, and distance from the edge of the trailhead to examine how these factors might influence the spread of invasive plants from along the trail, into the forest. My measure of distance from forest edge is a straight line distance, whereas my measure of distance to the nearest trailhead is a distance along the trail.

Statistical Analysis:

For assessing the significance of linear regressions, I used IBM SPSS. For variables I explored with T-Tests and Analysis of Variance I used IBM SPSS and Excel. I used linear regressions for observing relationships between invasion and distance to the forest edge, distance to the trailhead. I also used linear regressions to compare the percentages of invasion that 10m and 20m from trail plots took of their corresponding 0m from trail plots to variables of distance from forest edge and distance from trailheads. I also used linear regressions to assess the relationships between invasion and canopy openness at different depths into the forest.

I used ANOVA tests for the relationships between invasion and distance from trail and the relationships between canopy openness and distance from trail. I applied T-tests to the relationships between trail width and invasion along trails, forest age and invasion 0m from the trail, and forest age and the percentages of invasion that plots 10m and 20m from trails contained of their corresponding plots 0m from the trail.

Results

Distance from trail:

Invasive plants heavily inhabited areas directly adjacent to the trail in comparison to deeper into the forest (P=0.000114)(Fig. 1).

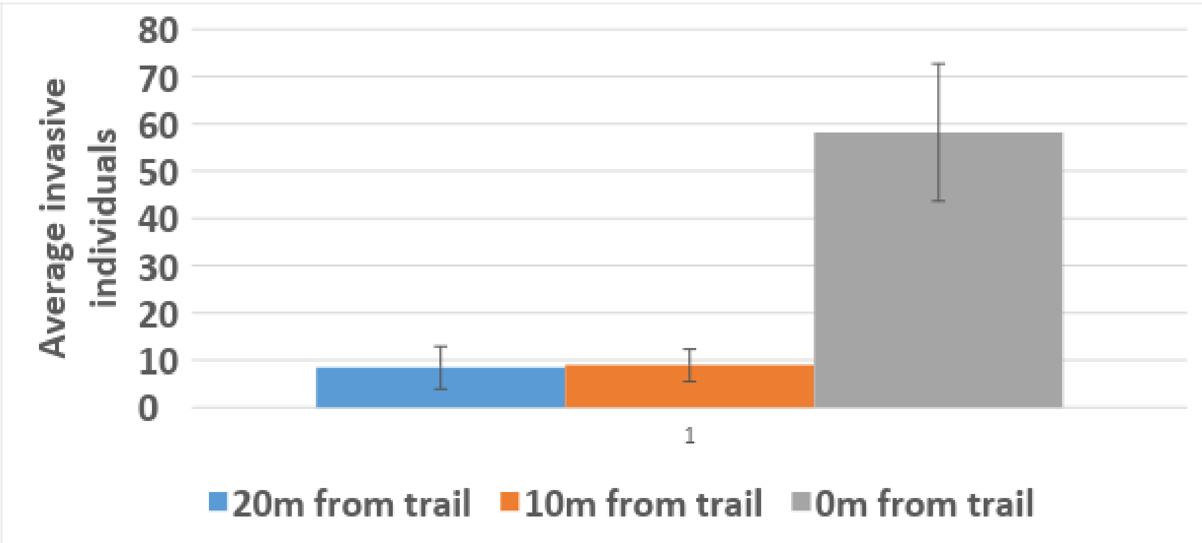

Fig. 1 Invasive plants at different distances from trail. Data from 2018 study. The error bars represent 1 standard error.

Canopy openness:

When comparing average canopy openness between plots 0m, 10m, and 20m from trails, there is minimal difference (Fig. 2). While there was considerable variation in canopy openness readings (ranging from 9.95% canopy openness to 24.18% canopy openness), ultimately, plots didn't vary in canopy openness based on their closeness to the trail.

There was also found to be no significant difference between the average canopy cover of plots 0m, 10m, or 20m from the trail (P=0.776). There were no significant trends found between the number of invasive individuals and the amount of canopy openness at plots 0m (P=0.397), 10m (P=0.593), or 20m (P=0.558).

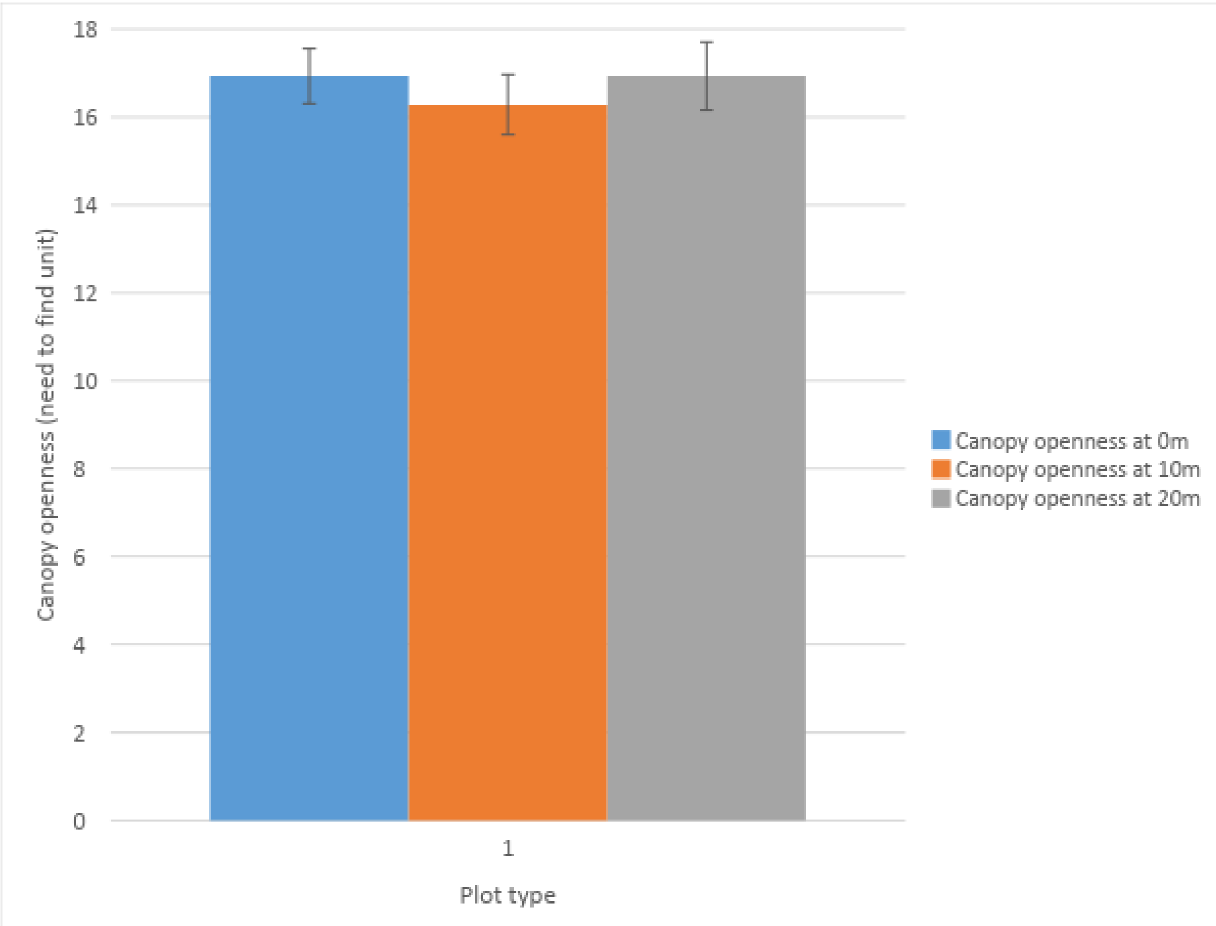

Fig. 2: Canopy openness compared across plots at different distances from the trail

Trail width:

Based on the 2014 study of invasion along trails, invasive plants were over 6 times more common adjacent to wide trails than narrow trails. The average invasive individual count on wide trails was 129.8, while the average invasive individual count on narrow trails was 18.6. (P=0.000) (Fig. 3). Based on the 2018 study, there was no significant difference found between invasion at plots 0m from the trail on wide vs. narrow trails. This insignificance is likely because plots in the 2018 study were selected on the basis of having invasive plants in them, reducing the potential difference between the invasive plants present in wide vs. narrow trails.

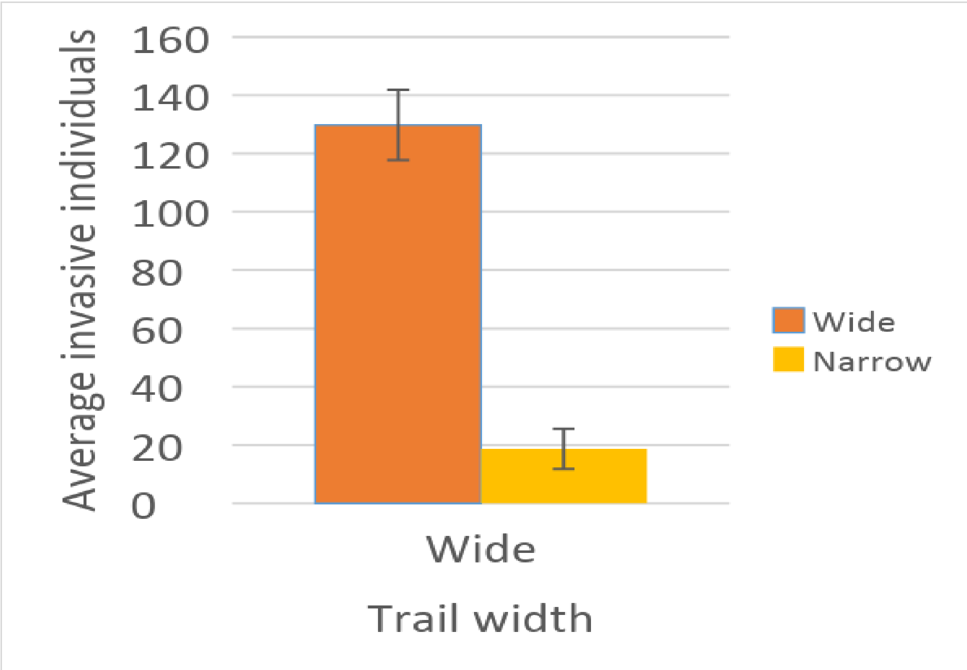

Fig. 3: 2014 data shows the average number of invasive individuals in plots along trails. Error bars show standard error.

Forest age:

Invasion in plots 0m (P=0.343), 10m (P=0.103), and 20m (P=0.343) from the trail had a weak trend of more invasive individuals in young forest than in corresponding plots found in old forest; however the difference was not significant (Fig. 4). As such, it can be said that plots in young forest are proportionally increased in invasion for all sub-plots.

Invasion at 10m from trails was found to take up a larger percentage of invasion at its corresponding plots 0m from the trail in old forest when compared to young forest. In old forest, plots 10m from trails also had a higher average percentage of invasion at corresponding plots 0m from trails than the corresponding value for plots 20m from trails. Invasion at 20m from trails was found to take up a smaller percentage of invasion of its corresponding plots at 0m from the trail in old forest when compared to young forest. In young forest, the average percentage of invasion at 0m is comparable for both 10m and 20m plots. The differences between these average percentages were not significant (Fig. 5).

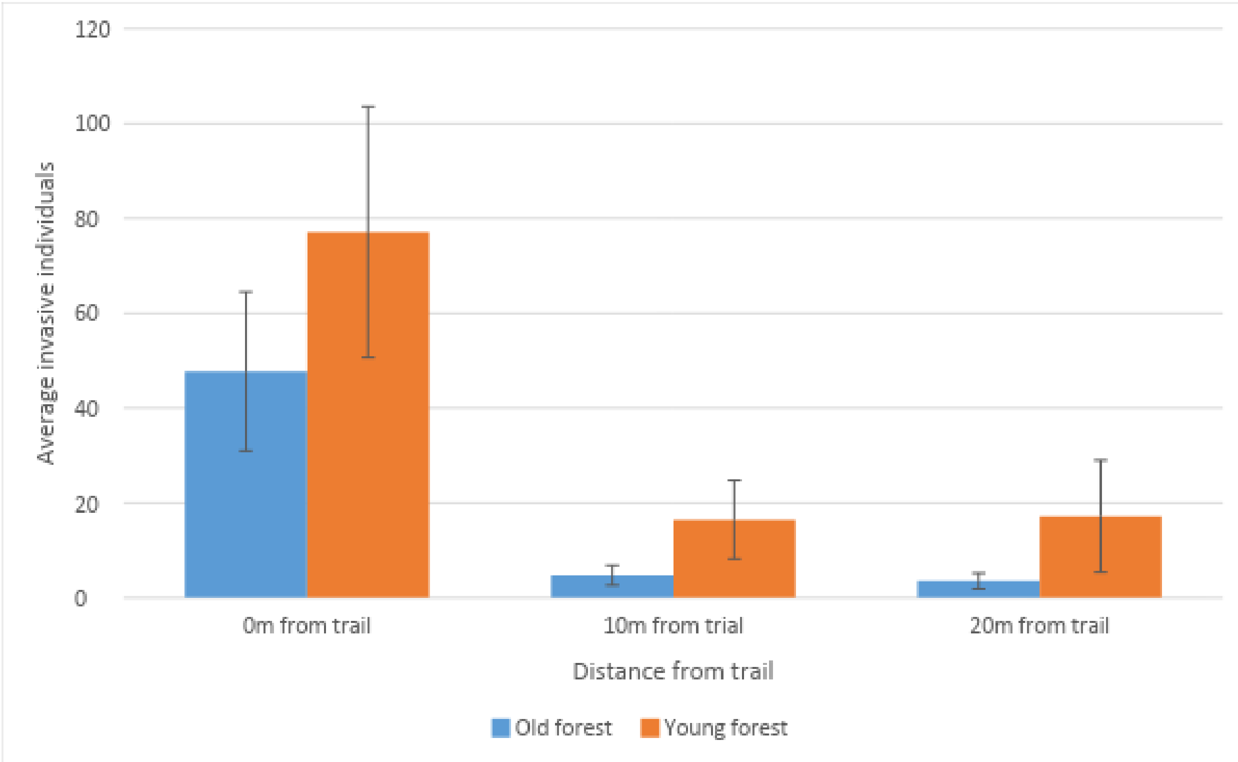

Fig. 4: 2018 data shows average invasive individuals for plots 0m, 10m, and 20m from the forest in both young and old forests. Error bars represent 1 standard error.

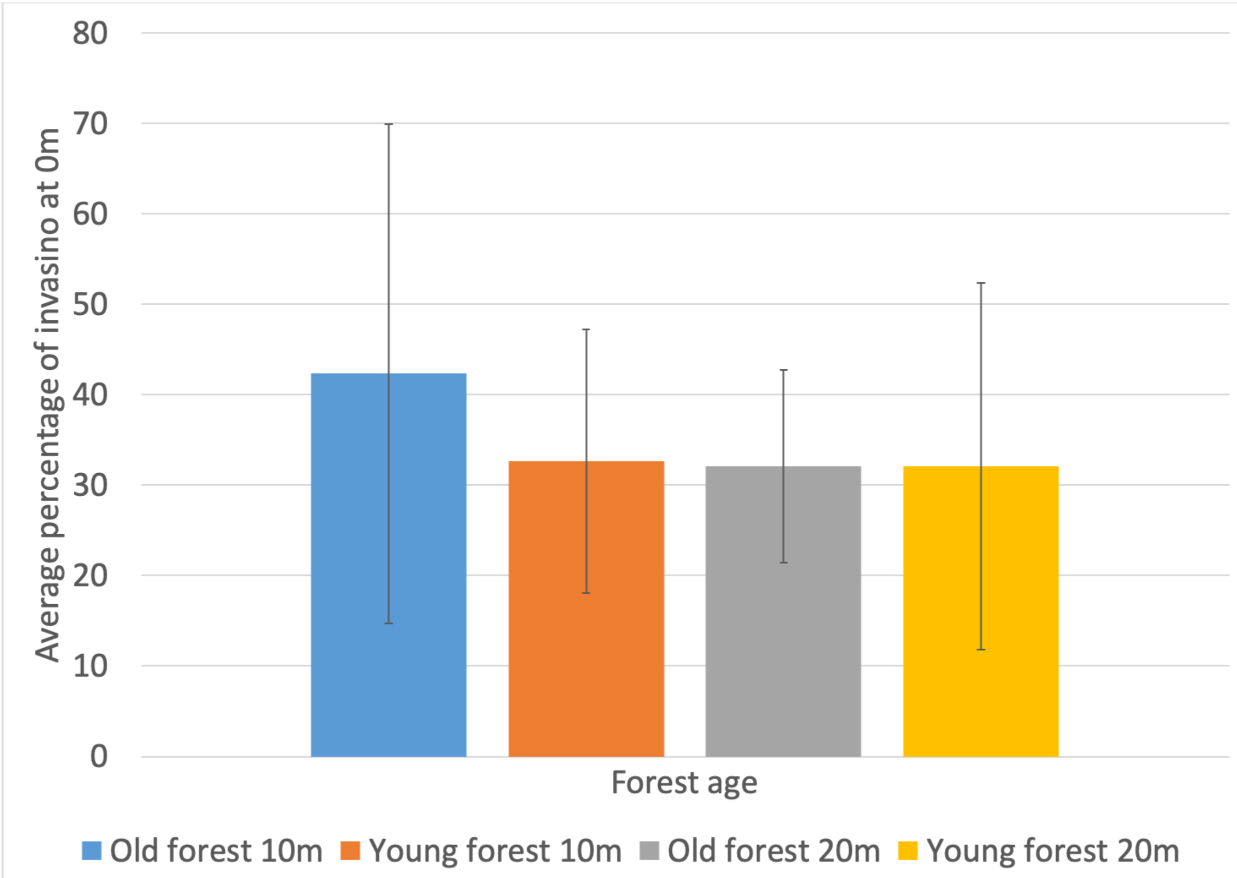

Fig. 5: Average percentage of invasion that plots 10m and 20m from trails contained in relation to the corresponding plots 0m from the trail. The error bars show ±1 SE .

Distance from forest edge:

The 2014 along-trail study found an insignificant relationship between invasion along trails and the distance of plots to the forest edge (P=0.29) (Fig. 6). The 2018 study found an insignificant tendency for plots 10m (P=0.213)(R^2=0.0531) and 20m (P=0.159) ($R^{2.}$ =0.0675) from the trail took up a higher percentage of the invasion in their corresponding plots 0m from the trail, meaning that close to forest edge, invasive plants were more abundant deeper into the forest than in plots farther from the forest edge (after controlling for the number of invasive plants right along the trail. This finding was not statistically significant however (Fig. 7).

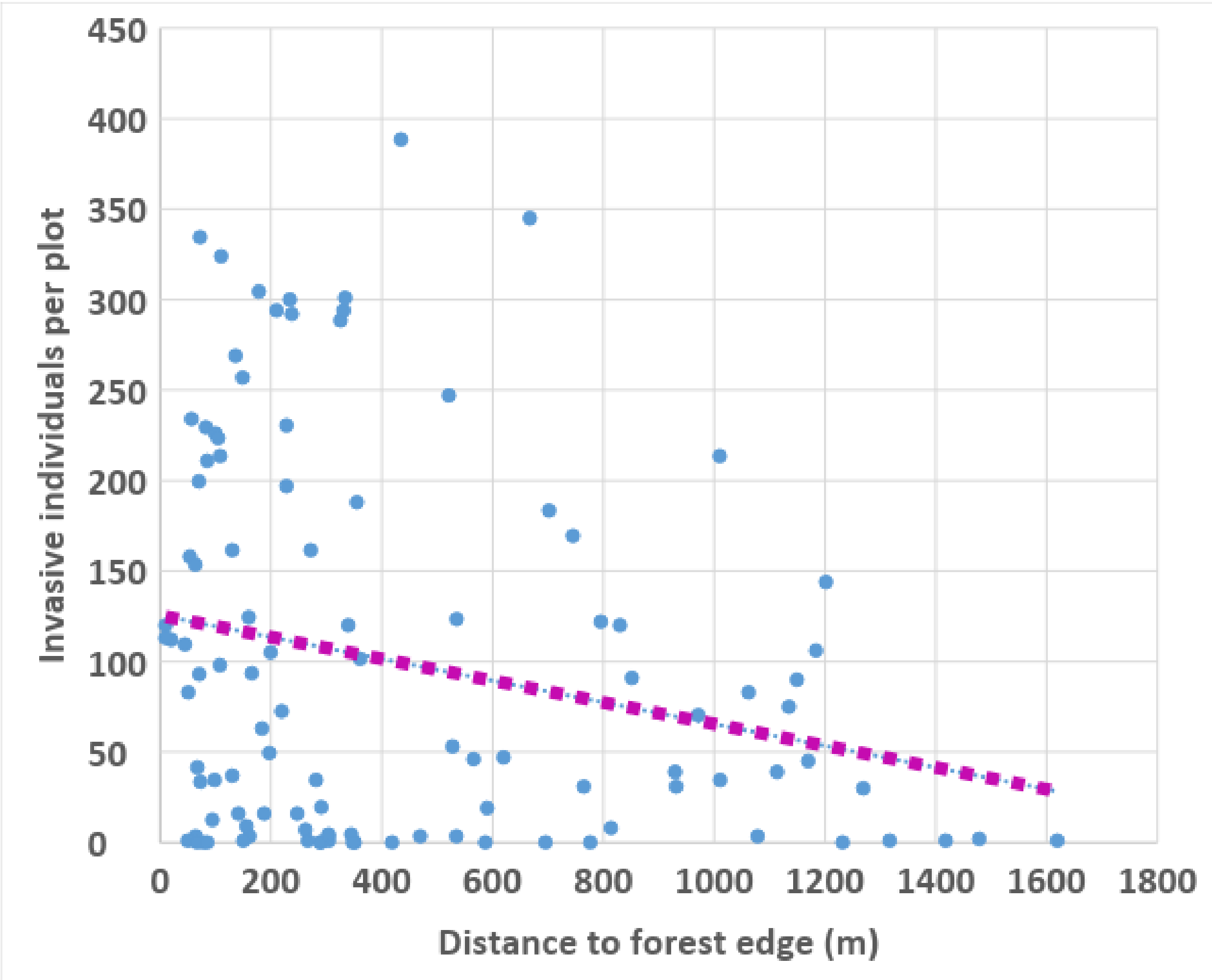

Fig. 6: 2014 data from along trails shows the relationship between the distance from the forest edge and the number of invasive individuals in 158 1x100m plots along trails of Barn Island Wildlife Management Area.

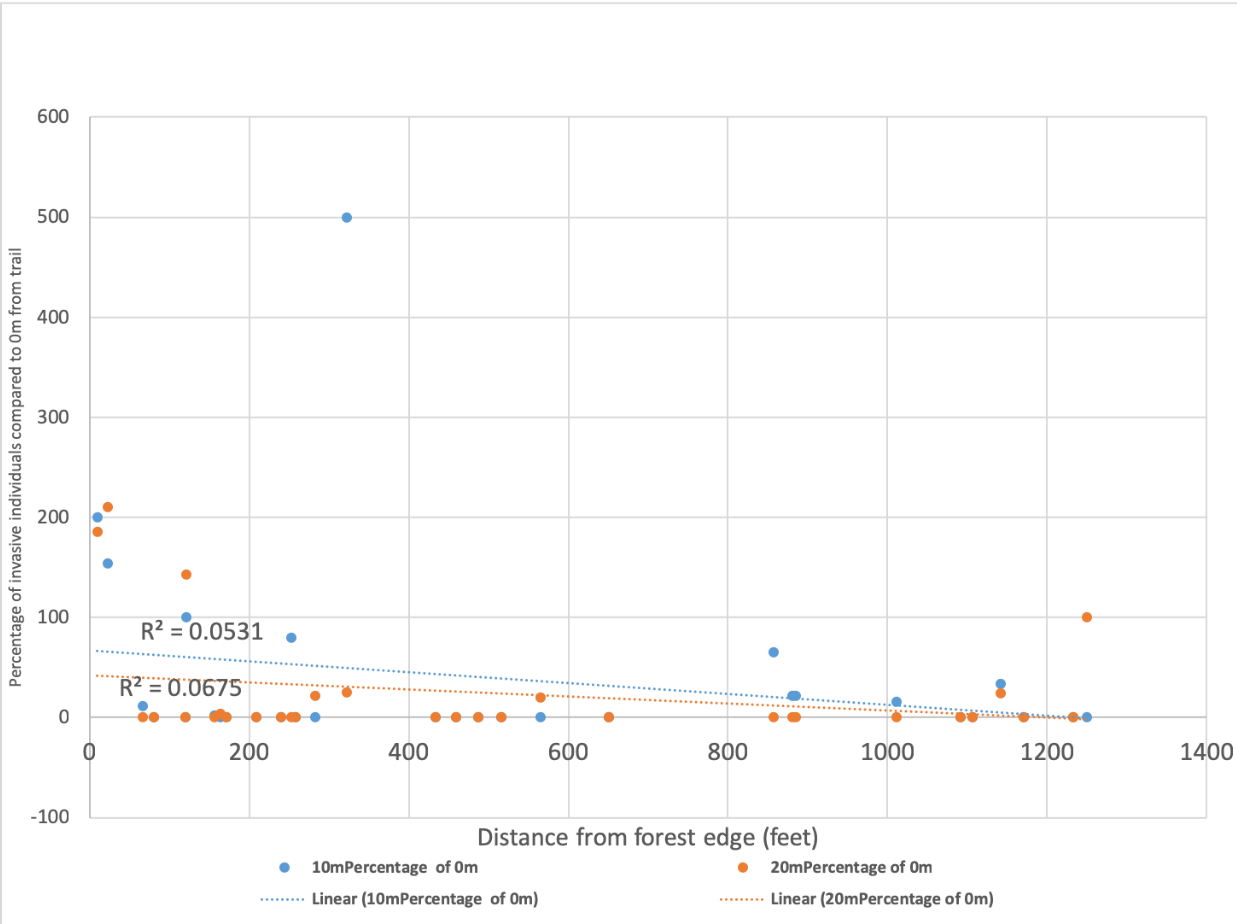

Fig 7: 2018 data shows the relationship between the percentage of invasion that plots 10m and 20m from the trail contain in relation to their corresponding plots 0m from the trail. For example, a value of 100% indicates that the plot contains the same number of invasive plants as its corresponding plot adjacent to the trail

Distance from trailhead:

There was no significant relationship between the distance of a plot from a major trailhead and amount of invasion (P=0.747) (Fig. 8).

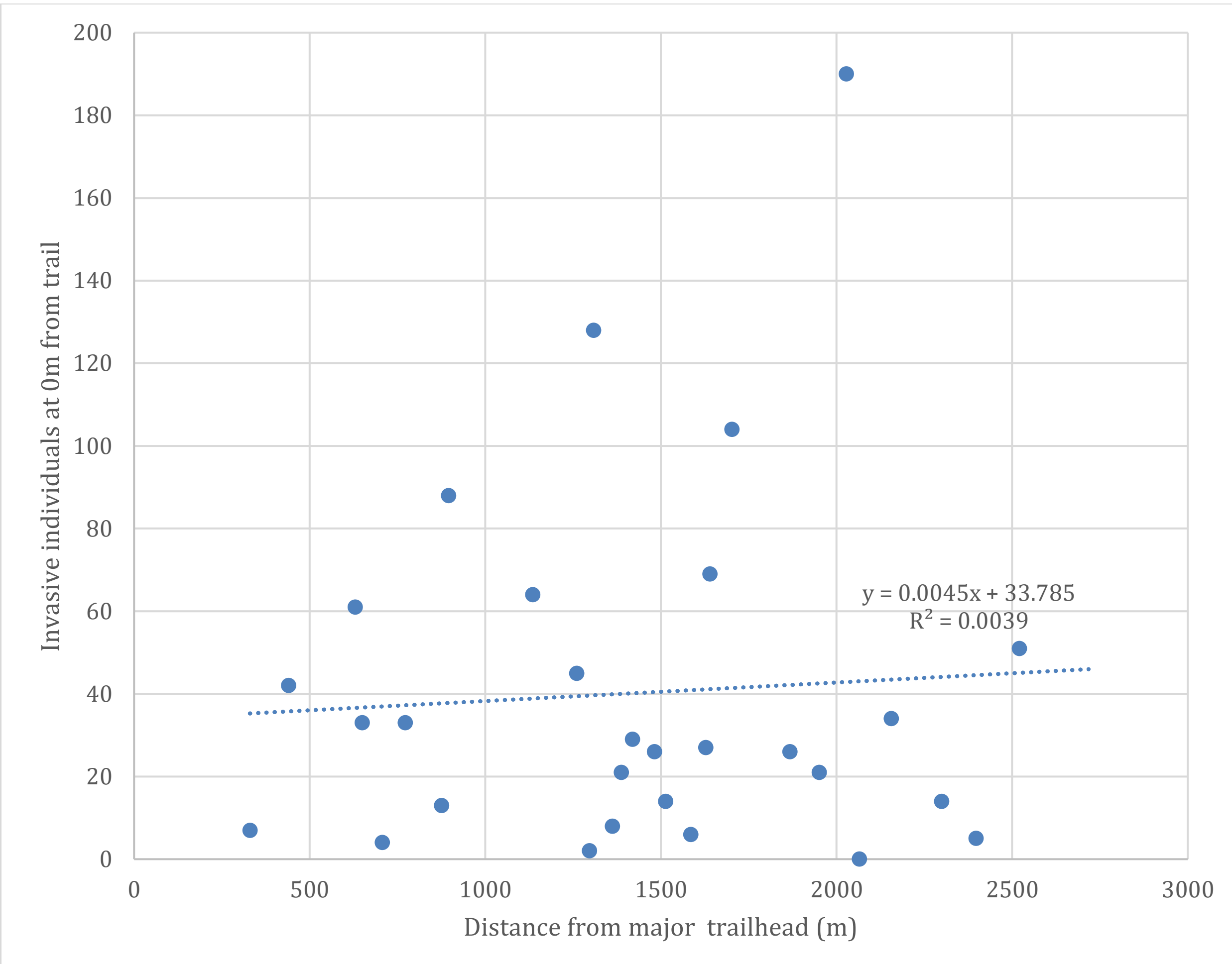

Fig. 8: Invasive individuals vs. distance from major trailheads (m).

Discussion

Invasive plants were found significantly more along trails than 10m or 20m away from trails. This finding suggests that some characteristics of recreational trails at Barn Island facilitates the spread of, or facilitates the creation of a suitable habitat for invasive plants, more so than other areas. If the presence of trails modifies habitats to a suitable place for plant invasion, it may be due to ground-level sources of disturbance (such as soil). My observation of canopy cover did not suggest any impact on invasion along trails, so other qualities that are distinctive of trails may play a role. Ansong and Pickering (2014) discuss the possibility of propagules' being carried by people, animals, and vehicles traveling along the trail. It is also possible that trails act as a pathway for dispersal of invasive plants at Barn Island. My findings do not clearly point towards whether invasive plants are taking advantage of the habitat modification of trails or using trails as pathways of invasion, but they do lead towards further questions to investigate.

I found no influence of invasion along trails based on their distance to trailheads, meaning that trailheads are not acting as importance starting points for invasion at Barn Island. There was however some potential influence of the proximity to the edge of the forest to the amount of invasive plants along trails. This could suggest that invasive plants use trails as a corridor for entering forests from whatever environments surround them. This pattern could also reflect that in general, invasive plants gradually spread deeper into forests from their surrounding environments.

My observation of canopy cover aimed to assess the role of canopy openness in why more invasive plants may grow adjacent to trails. However I did not find that canopy openness plays a role in invasion in my observations. Firstly, canopy openness did not vary based on an area's distance from the trail, while plant invasion did. Additionally, canopy openness had no influence on plant invasion at any distance from the trail. The lack of meaningful relationships related to canopy openness is consistent with a study at Allegheny National Forest of Pennsylvania, who also found significant impacts of trails, but no significant findings related to canopy openness (Huebner et al., 2009). While this is the case in forested areas, it is still quite possible that canopy openness would play a role in invasion in more open habitats.

My measurement of distance from the edge of the forest was compared to the distribution of plant invasion across plots 0m from the trail, 10m from the trail, and 20m from the trail. The 2014 study of plant invasion along trails at Barn Island Wildlife Management Area revealed an insignificant but higher abundance of invasive plants near the edge of the forest in comparison to deeper into the forest. I also analyzed the percentage of invasion that plots 10m and 20m away from the trail contain in relation to the total invasion of their corresponding plots at 0m from the trail. With this variable, I hoped to assess how invasive plants might penetrate forests from trails more or less easily based on if they are deep into the forest or close to its edge. I did not find a significant trend between the distance of a plot from the forest edge and the percentage of invasion that plots 10m or 20m from trails contained in comparison to their corresponding plots 0m from the trail. This sort of question looks into what the sources of invasion in an area may be. If there were more invasive plants in plots 10m and 20m from the trail as you approached the forest edge, that could suggest that invasion is notably more present coming from the edge of the forest.

I also investigated the distance plots are from trailheads, with a consideration of how the popular entry points for potential spreaders of propagules (recreational visitors, vehicles) may affect invasion. However, I did not find any significant trends between the distance of plots from trailheads and the invasion at 0m from the trail. Weiss et al.'s findings show a potential threat of recreational trailheads, so it is possible that other discoveries related to trailheads could be made by assessing their role in invasion by other means (Weiss et al., 2018). Birds can also play a role in invasive propagule dispersion, which given their behavior, would also not contribute to a trend related to trailheads and invasion.

Forest age was also taken into account. Generally, the amount of invasion at any distance from the trail was proportionally increased in young forest in comparison to old forest. Forest age however did not influence the extent to which invasion penetrating the forest from along the trails. While the average number of invasive individuals of plots in young forest at 0m, 10m, and 20m contained more invasive plants than their counterparts in old forest, the differences were not statistically significant. With that being said, the 2014 study of Barn Island invasion along trails showed significantly higher invasion in young forest than in old forest. Additionally, there were no significant differences between the percentage of invasion that plots 10m and 20m from trails contained of their corresponding 0m trails when comparing the percentages between plots in young and old forest. Flory and Kay (2009) found increased invasion in younger forests. While my findings insignificantly support an increase in invasion along trials in relation to forest age, it is more likely that forest age influences invasion in all areas, not just along trails. This means that forest age does not seem to influence the spread of invasion from the trail to 20m into the forest.

Based on the 2014 study of invasion along the trails of Barn Island Wildlife Management Area, more invasive plants grew along wide trails in comparison to narrow trails. Pickering and Norman's (2017) findings show more apparent impacts of wider trails in comparison to narrow and informal trails, consistent with the findings of the 2014 study. Pickering and Norman suggest that the impact of soil compaction and soil erosion due to trails may influence the plant composition. These potential factors would be consistent with the lack of influence of canopy cover on invasion, or the lack of influence of trail width on canopy cover.

While some of my findings are limited by their statistical insignificance, many of them are consistent with relevant literature on these topics. It is clear that the presence of trails influences the level of invasion at Barn Island Wildlife Management Area, but determining the driving factors to this tendency may call for a larger-scale study with more replications. The width of a trail was also found to influence levels of invasion, so further investigation into the ground-level differences between trail types could illuminate reasons for this. Qualities like these could suggest that trails contribute to modifying habitats in a way that welcomes plant invasion. Keeping in mind the work of Ballantyne and Pickering (2015), further investigation into the soil differences along trails and into the forest could provide more information.

Additionally, investigating the role of distance to the edge of the forest as it relates to invasion could also provide answers about how invasive plants in outer forests may grow along trails as pathways for invasion into the deeper forest. Young forests were shown to house more invasion at all distances from the trail in comparison to old forests, leaving questions about the qualities of young forest which might support this. Most pressingly, this study illustrates the importance of learning about the role of trails in invasion, with plant invasion being most heavy directly along trails in comparison to the invasion at deeper sections of forest.

Acknowledgement needed here!

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