Outdoor Recreation Activities as Vectors for Invasive Species in the Forest

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Abstract

Invasive species are generally regarded as a serious threat to forest ecosystems, however, the role that outdoor recreational activity plays in their spread remains understudied. This study examined whether the density of invasive plant species varied by distance from recreation trails categorized by high and low usage intensity. Strava global heat maps were used to determine high and low usage trails, and plotted perspective points on the Gaia GPS app. At each sampling location, I counted the number of invasive plants in two quadrats, one close and one far from the trail. The results showed no significant difference in invasive species density between high-use and low-use trails. Further, there was no significant difference in the density of invasive species close to and far from both types of trails. These findings suggest that humans may not have a significant role in the spread of invasive species along trails, and there may be other factors that affect the distribution in densities of invasive plants. Despite this, the findings support the need for more public awareness, and targeted management strategies in areas that are the most affected.

Key words: Invasive species, Outdoor Recreation, Distance from Trails, Usage Intensity, Density.

Introduction

Invasive plants outcompeting native flora is a well-studied phenomenon. In the past thirty years, research on the threats of invasive species to ecosystems, economies, and human health has been increasing (Zimmerman et al., 2014). Invasive plants have negative consequences for ecosystems because they decrease biodiversity, reduce trophic productivity, outcompete native vegetation, and alter ecosystem structure (Davies, 2011). Davies et al., (2011) found that native vegetation cover decreased with increasing density of an invasive grass, leading to decreased species richness, and diversity. In addition, invasive species may change nutrient pools, and alter natural fire regimes (Barney et al., 2013). Schmitz and Simberloff (1997) found that exotic (invasive) species have played a role in 42% of the declines of endangered and threatened species in the USA. Despite these well-studied impacts, non-native plants and seeds continue to be sold by garden centers or plant nurseries, therefore adding to a problem experienced around the world (Darcy & Burkart, 2002).

Recent studies have shown that the spread of invasive species is primarily caused by humans, through a variety of methods such as roads, and recreation trails (Christen & Matlack, 2009; Liedtke et al., 2020; Aziz et al., 2023). Once established, invasive species spread easily due to their dispersal ability (Coutts et al., 2010) Invasive plants often have higher population growth rates and greater reproductive capacities than native plants (Coutts et al., 2010). To accomplish rapid spread, invasive plants often have life cycle strategies that focus on rapid reproduction (Sakai et al., 2001). For example, some invasive plants can reproduce both asexually (cloning), and sexually (seeds, spores) to accomplish rapid spread (Sakai et al., 2001). Furthermore, the biggest environmental dispersers of invasive seeds are wind, water, and animals (mainly birds) (Sakai et al., 2001). Humans, however, have recently surpassed environmental dispersal, becoming the biggest spreader of invasive plants globally (Mack and Lonsdale, 2001). Humans disperse invasive species via roads, outdoor recreation, and their pets (Mack and Lonsdale, 2001). Roads act as both habitat, and conduits for the spread of invasive plants (Christen & Matlack, 2009). Human disruption of natural areas can cause negative impacts for ecosystems (Mack et al., 2000), and may increase the likelihood of plant invasions. A 2018 student research project at the University of British Columbia, found that habitats disturbed by humans were more likely to be dominated by invasive plants than intact forests (Bautista et al., 2018). In a recent study published in *Biological Invasions*, Liedtke et al., (2020) looked for invasive species by distance from trailheads in mountainous areas (Liedtke et al., 2020). They found that trails act as a conduit for the spread of invasive plants, though the prevalence of invasive plants decreased with distance from the trailhead (Liedtke et al., 2020). In a different article published in *Applied Vegetation Science*, Aziz et al., (2023) also sought to determine if trailheads acted as conduits for the spread of invasive plant species along the trail (Aziz et al., 2023). They found that invasive plant cover was highest near trailheads, but decreased with distance from the trailhead; however, contrary to their predictions, they found that in the forest interior, invasive plant cover increased with distance from the trailside (Aziz et al., 2023). Moreover, researchers at the University of British Columbia, in association with Metro Vancouver, studied the presence of invasive species in three types of greenspaces: parks and recreation areas, natural areas, and leisure facilities (Nguyen et al., 2021). They found that invasive plant species were associated with median household income, gardening expenditures, and greenspace type (Nguyen et al., 2021). They also found more invasive species in areas with higher levels of disturbance, and higher levels of human activity (Nguyen et al., 2021). These findings are relevant to my study hypothesis that outdoor recreation areas with higher levels of human activity, should have more invasive plants present.

North Vancouver has a large number of recreational areas, giving many opportunities for invasive plants to spread. Although inventories of invasive species in North Vancouver have been conducted (District of North Vancouver, 2024), no studies have examined the association between invasive species and use of and proximity to recreational trails. My study focused on six invasive species known to be present in North Vancouver: *Hedera helix* (English Ivy), *Ilex aquifolium* (English Holly), *Prunus laurocerasus* (English Laurel), *Rubus armeniacus*

(Himalayan Blackberry), *Daphne laureola* (Spurge Laurel), and *Vinca minor* (Periwinkle). In addition to these six invasive species, I counted any others observed in the study area, (as noted by the Invasive Species Council of British Columbia). Similar to the Aziz and colleagues (2023) study, I will measure 3 transects per trail at ~100m intervals with 100m transects perpendicular to the trailside. Using the methods described by Liedtke and colleagues (2020) to determine the percent cover of the forest, I estimated the relative amount of light in the study area as it may play a role in the density of invasive species at a given location. The data was not collected at the same time of day for all quadrats, thus the amount of light would vary at each location. Relevant to my study, are how invasive species reproduce, grow, and how they may be found in the study area. Table 1 provides important information about six of the most common invasive plants in North Vancouver.

Table 1: Invasive Species and growth information

Species	Scientific Name	Dispersal Method	Growth	Habitat	Fruits (Yes/No)	Soil Type
English Ivy	*Hedera helix*	Wind, Animals	Vegetative	Forest edge/ fragments	Yes (after maturity)	Well drained, loamy
English Holly	*Ilex aquifolium*	Wind, Birds, Mammals	Vegetative	Forest – edge and interior, garden	Yes	Well drained
Spurge Laurel	*Daphne laureola*	Wind, Birds, Mammals	Single stem, or multi branching	Garden, forest understories	Yes	Various
English Laurel	*Prunus laurocerasus*	Birds, small Mammals	Monopodial	Garden, forest, edge	Yes	Various
Himalayan Blackberry	*Rubus armeniacus*	Birds, Mammals	Vegetative	Forest edge, road side, anywhere with full sunlight	Yes	Well drained
Periwinkle	*Vinca minor*	Water, Wind, Ants	Vegetative	Forest edge/fragment	No (not frequently)	Well drained

See Figure 1 to see some common invasive species in North Vancouver.


Figure 1: Images of some common invasive plants. Left: Spurge Laurel, Middle: English Holly and Ivy, Right: Himalayan Blackberry and Periwinkle.

My study investigated whether the density of invasive species varied with distance from trails categorized by high-use and low-use intensity. I hypothesized that human activity on outdoor recreation trails are responsible for the introduction and dispersal of invasive plants into the forest. I predicted that: 1) high usage intensity trails will have more invasive species present off trail than low usage intensity trails, 2) deeper into the forest interior and further away from the trail, I expected to see fewer invasive species with greater distance, and 3) I anticipated that areas with higher forest cover would have fewer invasive species. Of the five invasive species I was looking for, I expected that English holly (*Ilex aquifolium*) would be the most represented out of all of the invasive species present in North Vancouver. The outcomes of my study may support the idea that trail use allows the spread of invasive plants and further may inform future management strategies of areas that are the most affected by invasive species.

Methods

Site Selection

Choosing locations for data collection started with identifying high-usage and low-usage intensity trails. To determine these trails, I used Strava, which is a social media fitness app where individuals can track their activities. On Strava, there is a global heat map which provides users options to show how much each route is used. I set my heat map to red for high-usage, and light blue for low-usage intensity. After identifying suitable high and low trails I marked their location on Gaia GPS. Using this program, I assessed trail choices using three criteria. First, if the trail was at least 500m long so that I could perform three transects on it. Second, I looked to see if there were any physical barriers such as slopes or riparian areas. Finally, I selected trails that were at least 500m away from other sampling locations to make sure that two trails were independent from each other. Of 20 potential sites, I ultimately included 12 sites based on these criteria. (See Figure 2 for Site Selection images)

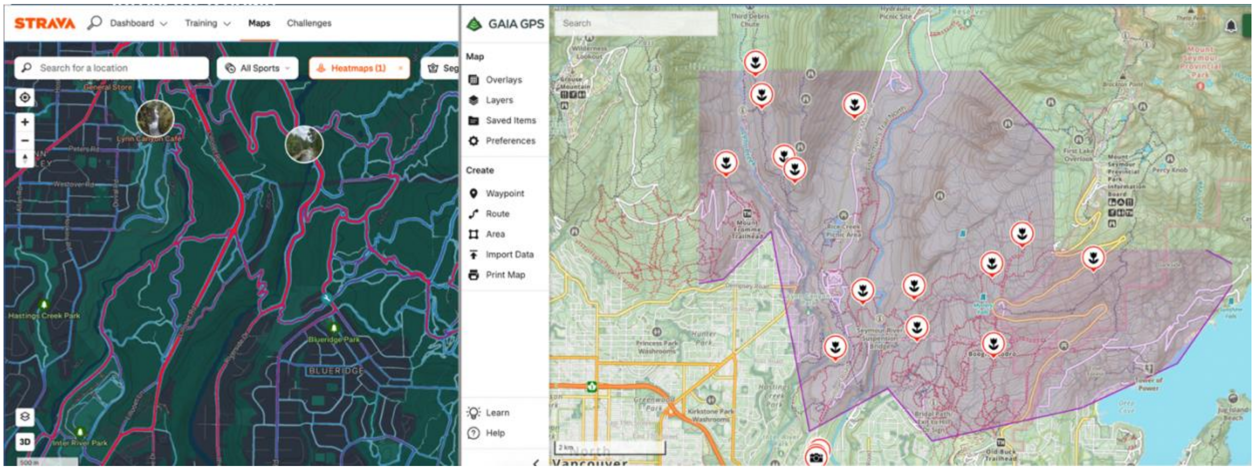

Figure 2: Site selection method. Left: Strava global heatmap where red is high usage and blue is low usage. Right: Gaia GPS showing sampling locations and study area.

Data Collection

After marking out prospective sampling locations based on the criteria listed above, data collection began. At each sampling location, I collected data along three transects spaced at least 100m apart. Each transect was 100m long, starting at the trail and heading perpendicularly into the forest, as estimated on the Gaia GPS app. On each transect, I collected data within two $20m^2$ quadrats, one close to the trail (10-30m from trail) and one far from the trail (70-90m from trail). In each quadrat I counted either the number of stems or estimated percent cover of invasive plants. The rationale for sometimes counting stems and estimating percent cover was to account for the differences in the structure of invasive plants found. See Table 2 for a breakdown of how I collected data for each species found. In each quadrat, I calculated the density value for each invasive plant found by dividing the number of stems (or percent cover) by the total area of 400m. In addition, in each quadrat I calculated the combined density as the sum of all species densities. By performing two quadrats, I aimed to capture whether there was variation in two areas at varying distances from the trail. In addition, at each quadrat I estimated the forest cover as a percentage out of 100%. In doing this, I would try and capture the relative level of light in the forest.

Table 2: Data collection method for individual species

Species	Type of Measurement	Structure of Plant
English Holly	Counting stems/# of plants	Shrub/tree
English Ivy	Percent cover estimate	Vine/shrub
English Laurel	Counting stems/# of plants	Shrub/small tree

Wall Lettuce	Percent cover estimate	Weed

Data Analysis

To test whether the density of invasive species differed significantly between high and low use trails, I conducted an ANOVA, with the response variable as density of invasive plants. In this analysis, I combined the density of the two quadrats for each transect, so each transect had a single density value. With the data, I conducted two different analyses, one with the combined density as the response variable, and a second with only the density of holly as the response variable. English holly was the most prevalent species found in my data collection. The independent variable for each analysis was trail usage (high or low). Analyses were performed using Excel, and visualized by box plots.

In the second part of the data analysis I performed two tests using two-way repeated measures ANOVA with combined density and density of holly set as the response variables, and intensity and distance as the independent variables (factors). Before conducting these analyses, I tested the assumptions of normality using the Shapiro Wilk test. The results from the Shapiro Wilk test showed that the data for both combined density and density of holly were not normally distributed. To account for this, I transformed both data sets by using a square root transformation. After the transformation, I performed two more Shapiro Wilk tests, and while the transformations did not make either data set normally distributed, they were more normally distributed than before. The data was then visualized using boxplots. All analyses were conducted using R v 4.4.3 (R Core Team, 2023). See Appendix 1 for full code.

In the final part of data analysis, I performed a correlation analysis with density of invasive plants as the response variable, and % forest cover as the independent variable. I did two correlation analyses, one with the combined density, and the other with density of holly. The two analyses used both high and low usage trails. This analysis took place on Excel, and yielded scatter plots. In addition to visualizing the data, I found the Pearson correlation coefficient (r) using the function '=CORREL'. On the correlation graphs, I included a trendline to show what kind of correlation might be present.

Results

Results from the ANOVA analysis indicated that there was no significant difference between high and low-usage trails. The results were not significant when using data combined across all species, nor was it significant for just the density of holly. With a level of significance (a) 0.05, the p-value for the combined density test was 0.527, which is much greater than 0.05. At the same level of significance, the p-value for the holly test was 0.623 which is also much greater than alpha. Figures 3 and 4 visualize the results from the two analyses.

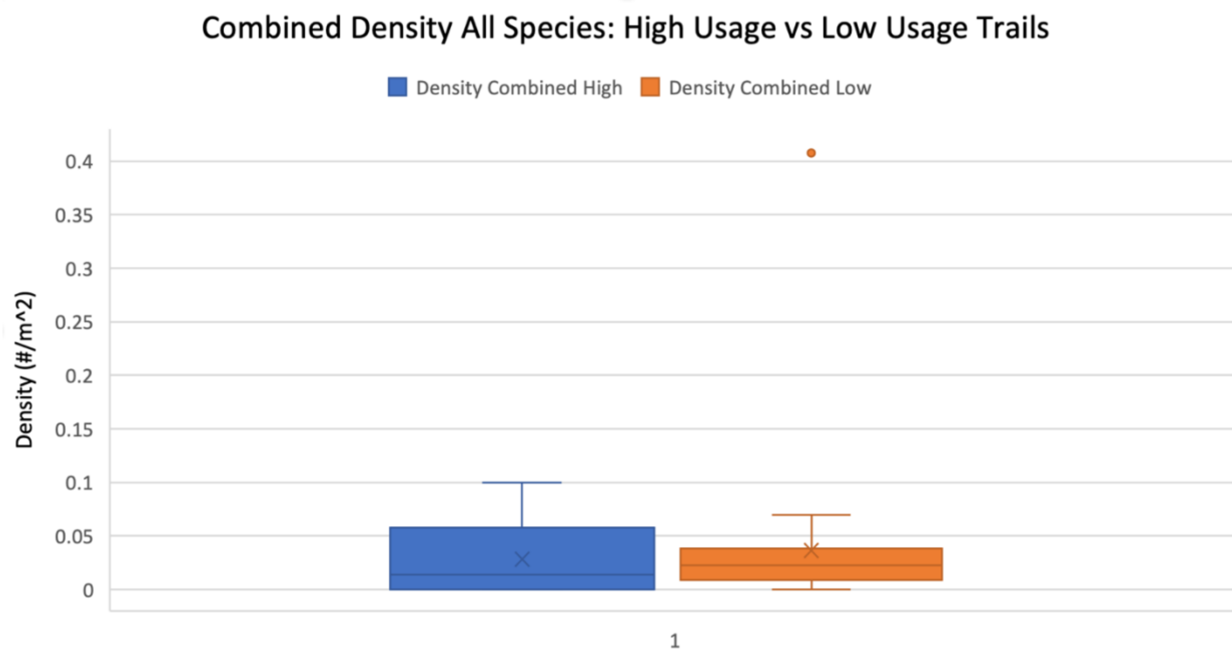

Figure 3: Boxplot showing no significant difference in densities of high and low usage trails.

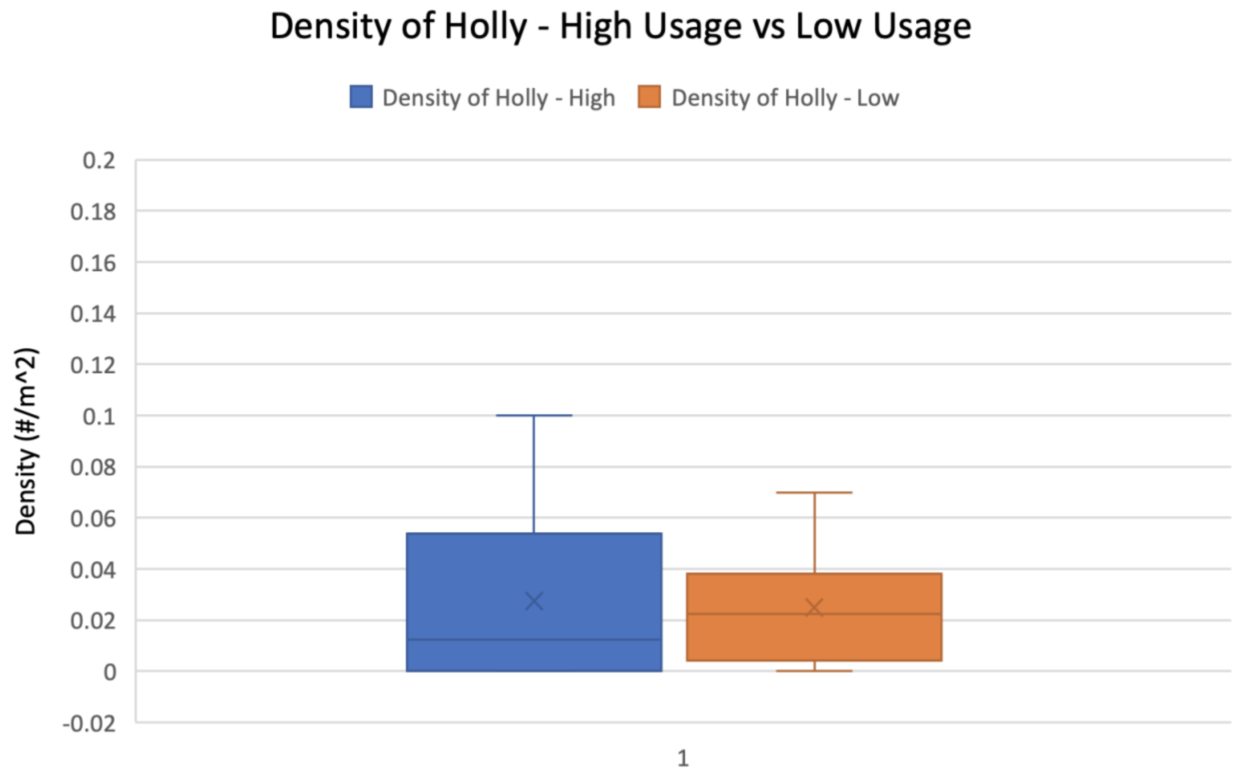

Figure 4: Boxplot showing no significant differences in density of Holly on high and low usage trails.

Results from the second analysis revealed that there was no significant difference between any of the factors when using combined density data. The two-way repeated measures ANOVA yielded results for the two independent variables intensity and distance, and the interaction between the two. At a level of significance of 0.05, the p-values were 0.962, 0.323, and 0.094 for intensity, distance, and their interaction, respectively. The results for this can be seen in Figure 5. For the same analysis with density of holly, there was also no significant difference between any of the factors. The p-values were 0.879, 0.521, and 0.073 for intensity, distance, and their interaction, respectively. The results for this part can be seen in Figure 6.

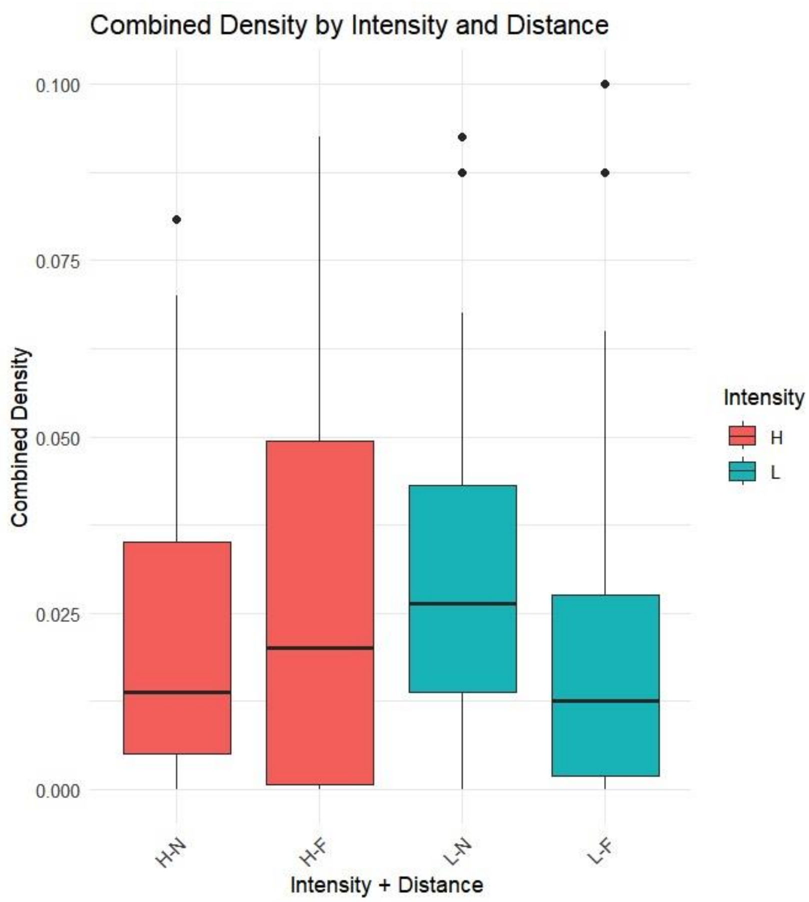

Figure 5: Boxplot looking at dependent variable combined density, and independent variables intensity and distance. H-N = high near, H-F = high far, L-N = low near, L-F = low far. The box plot shows no significant difference in any of the groups. I will note that there is an interesting interaction going on between L-N and L-F where the median combined density is larger for L-N than H-N. Further, the median density is larger in H-F compared to H-N.

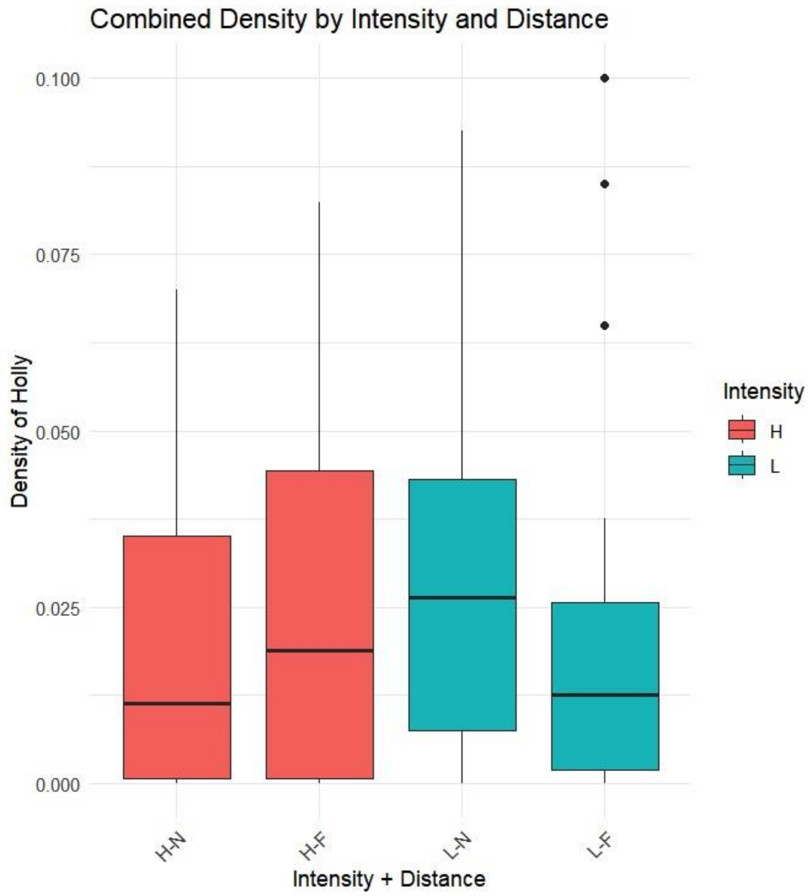

Figure 6: Boxplot looking at dependent variable density of holly, and independent variables intensity and distance. H-N = high near, H-F = high far, L-N = low near, L-F = low far. There is an interesting trend where L-N have a greater median density than H-N. Another interesting trend is that the median density is larger in H-F, compared to H-N.

The final part of the data analysis looked for correlation between percentage of forest cover and density of all species combined, and density of holly on both high and low usage trails. On high usage trails, for both categories, forest cover was negatively correlated with density (see Figure 7). For density of holly alone, r = -0.3248, and for combined density, r = -0.3259. On low usage trails, forest cover was also negatively correlated with combined density, and density of holly (see Figure 8). For density of holly, r = -0.1479, and for combined density, r = -0.1542. In both high and low usage trails, the r is close to 0, indicating weak correlation. By only a slight margin, trails that are highly used have a stronger negative correlation with density of invasive species.

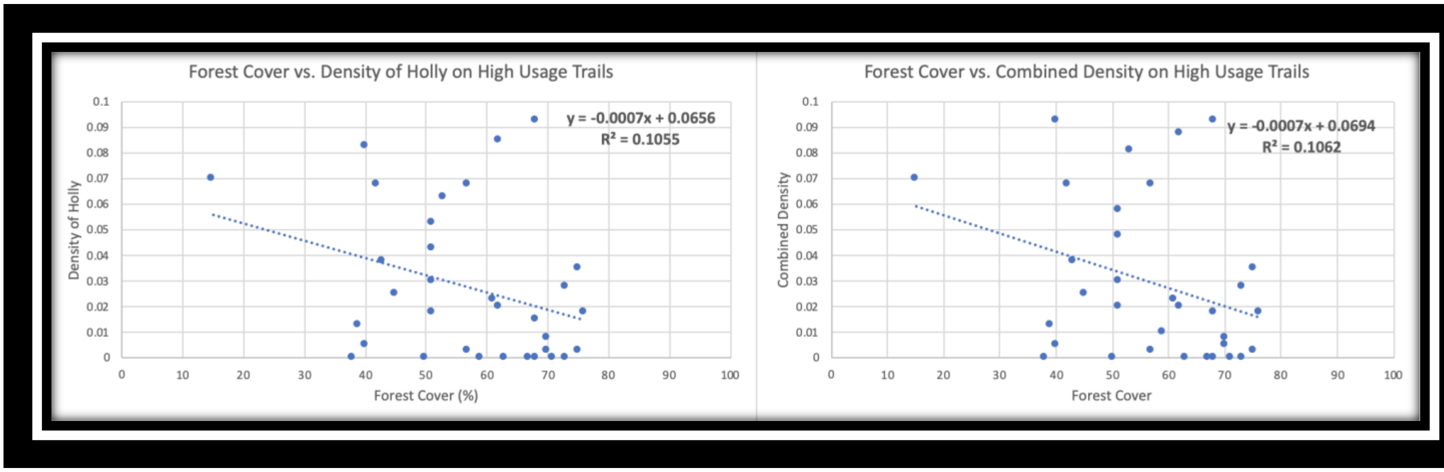

Figure 7: Scatter plot showing the negative correlation for a) Density of Holly and b) Density of all species combined on High Usage Trails

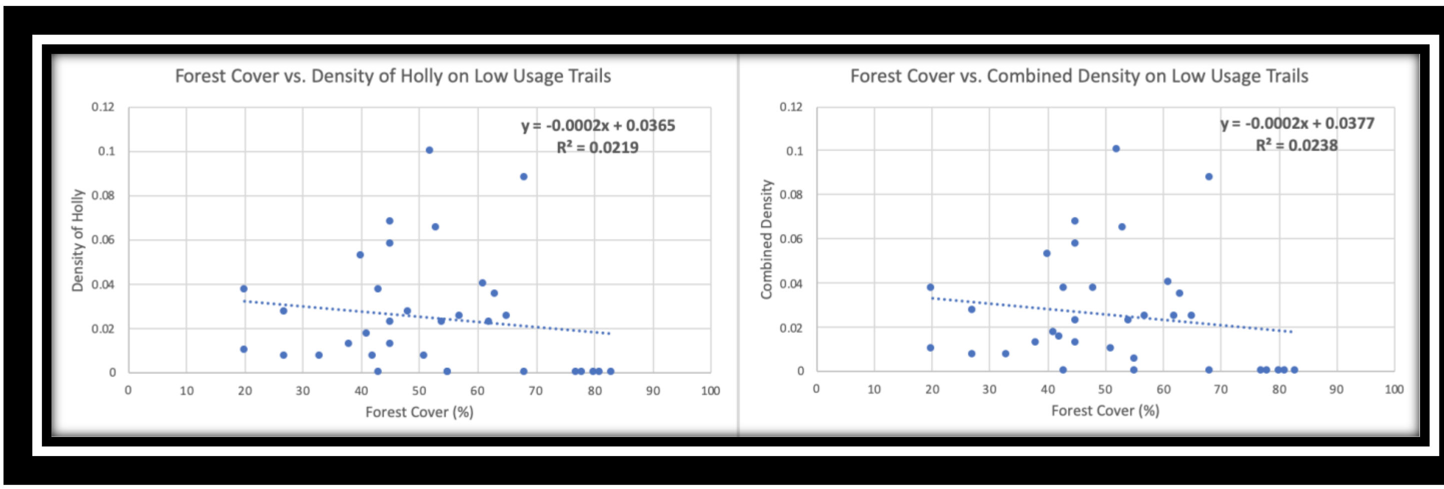

Figure 8: Scatter plot showing the negative correlation between % Forest Cover and a) density of Holly and b) density combined across all species on Low Usage Trails

Discussion

Results from the first data analysis found no significant difference in density of invasive plants between trails categorized by high-usage and low-usage. This was consistent for combined density of all species identified, and density of holly alone. The two non-significant results indicate that the hypothesized interaction is not supported, however, there may be reasoning to explain this. I predicted that trails highly used by outdoor recreation activities would have more invasive species present, and in general, I noticed more invasive plants. However, not all were located within the quadrat I used for observation. On low-use trails, I observed invasive plants present on the trail, but often they did not proliferate into the forest. Another observation while doing the transects was that if there was a slope, either up or downhill, there were fewer invasive species present on the slope. Often, I would find a patch of plants at the either the top or bottom of the slope but none as I went along. This trend was consistent during the data collection. In addition, I observed that where there was a stream or small flowing water body, invasive plants typically were growing there. My observation is consistent with research by Aronson et al., (2017) who found in their study that 55% of riverbank vegetation in the study areas were made up of non-native (invasive) plants.

The results from the second data analysis reveal that there is not a significant statistical difference between any of the four groups: high-far, high-near, low-far, and low-near. Aside from this, there are still important trends to consider. In Figures 5 and 6, the median for both combined and holly densities are higher in quadrats on low vs high usage trails. This shows that there is not a consistent trend delineating high and low usage trails with respect to density of invasive plants. Contradictory to my prediction that there would be more invasive species closer to, rather than farther from the trail, far quadrats on high usage trails had a higher median density than near quadrats. This may indicate that the invasive plants I observed can establish better in forest areas with mild disturbance. Human activity may still play a role in the dispersal of invasive plants off trail, however, in future research I would consider other variables such as dispersal mechanisms that may play a greater role. Other studies have found that trails may act as a conduit for the spread of non-native plants (Liedtke et al., 2020; Aziz et al., 2023), and in my study, I observed this at varying levels. Visually, there were greater densities of invasive plants close to the trail, but I did not observe a consistent pattern. For example, at some sites, there were none at first, but more at second quadrat. At other sites, there was an infestation of invasive plants at the first, and significantly fewer at the second. When looking at the data before analyzing it, I saw that in most cases the densities were slightly larger in near quadrats compared to far, but the difference was not statistically significant. To account for this variation, and small differences between near and far, the sample size would have to be increased and more trails be sampled.

In the study, and consistent with my expectations, the data showed that English holly (*Ilex aquifolium*) was the most represented invasive species in the forest. Throughout the data collection process, I noticed that there was plenty of holly scattered along the sides of the trails. This finding was consistent with Church (2016), that holly is capable of invading forests and becoming widespread in managed forests. Holly is a shade tolerant evergreen species, but can also thrive as light becomes available (Church, 2016). Along the trails, I estimated varied levels of forest cover (level of light), yet I did not find a significant correlation between forest cover and density of holly. In fact, there was a weak negative correlation between percentage of forest cover and density of holly. This result is consistent with my prediction that higher levels of forest cover would see fewer invasive species present. The weak negative correlation suggests that the level of light is not an important variable in determining density of holly. However, a more accurate forest cover estimation could be used, which may alter this result. In addition, I looked at percentage forest cover and combined densities across all species, and there was an even weaker negative correlation. In association with my predictions, these results make sense because all of the species that I found during data collection are shade tolerant, and can thrive in the understory. Another important factor to note is the dispersal mechanism of English holly is primarily by birds, with up to 96% of seeds being dispersed by American Robins (*Turdus migratorius*) (Zika, 2010). With this factored in, there should be no pattern in the distribution of holly in the forest. My results support this, as there is not a significant difference between high and low usage trails, meaning humans are not likely taking part in the spread of holly throughout the forest. Moreover, during the data collection process I noted that there was lots of holly present outside of the quadrats where data was collected. To more accurately determine how much holly is present in the forest, I could perform a continuous transect that continues further into the forest and count the number of hollies on both sides. Further, the method of counting hollies could be refined, as it was difficult to fully capture all of them when some are big trees, and others are small shrubs.

Throughout my data collection, I only found four invasive species: English holly (*Ilex aquifolium*), English ivy (*Hedera helix*), English laurel (*Prunus laurocerasus*), and wall lettuce (*Lactuca muralis*) at one site. In Table 1, I note several invasive species that have naturalized in North Vancouver. Two species that I thought would be present, Himalayan blackberry (*Rubus armeniacus*) and periwinkle (*Vinca minor*), were not present in any of the transects sampled. Himalayan blackberry prefers habitats with well-drained moist soils, often in disturbed sites, and areas with full sunlight (Gaire et al., 2015). Within the trails sampled, these conditions were not met, which provided some reasoning to why they were not present. Periwinkle is a forest edge species, that also prefers moist conditions (Panasenko et al., 2018). The forest that was sampled was not forest edge, thus why periwinkle was not found in my surveys. As mentioned previously, percentage forest cover negatively correlated with density combined, and of holly. The measures of forest cover were estimates, and their accuracy should be considered. However, the negative correlation indicates that as forest cover increases, the density of invasive species decreases slightly. This could show that decreasing the light availability makes it harder for some invasive species to establish (i.e. Himalayan blackberry). However, researchers have found that some invasive plants can colonize closed-canopy forests at the same level as native species (Yamamoto & Jones, 2024). This indicates that the presence of invasive species depends on the site conditions, and if a species can tolerate shady conditions, it will be able to thrive in the forest.

My initial hypothesis was that human activity and outdoor recreation are responsible for the accidental introduction and dispersal of invasive plants into the forest. It has been found that areas with high levels of outdoor recreation and tourism have higher abundance and richness of invasive species (Anderson et al., 2015). In addition, it has been found that introduced plants can escape from cultivation and horticulture, and become invasive in the new environment (Reichard and White, 2001). Thus, these two factors provide reasoning for how invasive plants may have come to be present in the forest. An outcome of this research is that the relationship between invasive plant species and proximity to recreational trails were not statistically significant. However, humans have played a role in introducing invasive species and there is evidence of this along most of the sampled trails. This study is important because it demonstrates that there are many invasive plants present in the forest which are taking over space and resources from native plants. Invasive plants are a threat to North Vancouver's forests; thus, my study provides data that could inform forest management strategies and public awareness. The outcome of this research provokes me to think further about why the density of invasive species is higher in certain areas. Future research could look at how the density of invasive species changes based on varied site conditions. This could be accomplished by manipulating site conditions over a set time span. The sites could be disturbed to various levels; no disturbance (control), minor disturbance (some trampling, small removal of vegetation), intermediate disturbance (trampling, removal of vegetation), and high disturbance (clear cut, or full removal of vegetation and terraforming). This could be repeated across several areas, taking into consideration site history, and other landscape features such as proximity to a riparian area. In addition, it would be interesting to do an enclosure experiment along trails of varying usage intensities. This experiment could help determine if trampling from humans, dogs, and other mammals has an impact on vegetation, and further, if it provides good habitat for invasive species colonization.

Conclusion

Human use of outdoor recreation trails appear not to be responsible for the spread of invasive species into the forests of North Vancouver. Humans alter the natural landscape, and have a substantial role in creating conditions for invasive species to thrive. In the case of outdoor recreation, trails are created by removing vegetation, and transforming the landscape to make it accessible for hikers and cyclists. This transformation creates optimal habitat, as can be seen in North Vancouver, where there are many invasive species found along the sides of trails. Further, this establishment of invasive plants on trails allows them to disperse naturally, and take over more areas in the forest. Despite finding no distinct pattern in this study, there is something going on in the forest. Thus, more research must be done to get to the bottom of this issue that continues to affect native biodiversity in North Vancouver's forests.

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References

Abrahamczyk, S., Otto, J., & Maximilian Weigend. (2024). The reproductive biology of the neophyte *Prunus laurocerasus* in Central Europe. *Plant Species Biology*. https://doi.org/10.1111/1442-1984.12500

Anderson, L. G., Rocliffe, S., Haddaway, N. R., & Dunn, A. M. (2015). The Role of Tourism and Recreation in the Spread of Non-Native Species: A Systematic Review and Meta-Analysis. *PLOS ONE*, *10*(10), e0140833. https://doi.org/10.1371/journal.pone.0140833

Aronson, M. F. J., Patel, M. V., O'Neill, K. M., & Ehrenfeld, J. G. (2017). Urban riparian systems function as corridors for both native and invasive plant species. *Biological Invasions*, *19*(12), 3645–3657. https://doi.org/10.1007/s10530-017-1583-1

Aziz, N., Holmes, M. A., Bennion, L. D., Reeb, R. A., & Kuebbing, S. E. (2023). Hiking trailheads, but not trailsides, associated with higher cover of non-native plants' trail impact on non-native plant cover. *Applied Vegetation Science*, *26*(1), e12716. https://doi.org/10.1111/avsc.12716

Barney, J. N., Tekiela, D. R., Dollete, E. S., & Tomasek, B. J. (2013). What is the "real" impact of invasive plant species? *Frontiers in Ecology and the Environment*, *11*(6), 322–329. https://doi.org/10.1890/120120

Bautista, B., Hu, H., Kaye, M., & Lu, Z. (2018). Comparing Percent Cover of Select Invasive Plant Species (Rubus armeniacus, Ilex aquifolum, and Hedera helix) at Salish Creek and Canyon Creek in Pacific Spirit Park. *The Expedition*, *8*. https://ojs.library.ubc.ca/index.php/expedition/article/view/191467

Herbert, J. (2021). *Comparison of English holly (Ilex aquifolium) management methods in Redwood Park, Surrey, British Columbia Prepared For Rob Landucci NRP Urban Forestry Manager City* *of Surrey Prepared By*. https://iscmv.ca/docs/Comparison_of_English_holly_management_methods_in_Redwood_Park_-_FINAL_REPORT.pdf

Christen, D. C., & Matlack, G. R. (2009). The habitat and conduit functions of roads in the spread of three invasive plant species. *Biological Invasions*, *11*(2), 453–465. https://doi.org/10.1007/s10530-008-9262-x

Church, E. (2016, April 6). *Invasive English holly (Ilex aquifolium L.) in Clear-Cut and Forest Units in a Western Washington Managed Forest*. Washington.edu. https://digital.lib.washington.edu/researchworks/items/95db109c-afc3-4e1f-a44b-1b5f56791bd1

Coutts, S. R., Van Klinken, R. D., Yokomizo, H., & Buckley, Y. M. (2011). What are the key drivers of spread in invasive plants: Dispersal, demography or landscape: and how can we use this knowledge to aid management? *Biological Invasions*, *13*(7), 1649–1661. https://doi.org/10.1007/s10530-010-9922-5

Davies, K. W. (2011). Plant community diversity and native plant abundance decline with increasing abundance of an exotic annual grass. *Oecologia*, *167*(2), 481–491. https://doi.org/10.1007/s00442-011-1992-2

Davies, K. W., & Sheley, R. L. (2007). A conceptual framework for preventing the spatial dispersal of invasive plants. *Weed Science*, *55*(2), 178–184. https://doi.org/10.1614/WS-06-161

Dennehy, C., Alverson, E. R., Anderson, H. E., Clements, D. R., Gilbert, R., & Kaye, T. N. (2011). Management strategies for invasive plants in pacific northwest prairies, savannas, and oak woodlands. *Northwest Science*, *85*(2), 329–351. https://doi.org/10.3955/046.085.0219

District of North Vancouver. (2024). *District of North Vancouver 2023 Invasive Plant Inventory* (pp. 1–38) [Draft #1].

Gaire, R., Astley, C., Upadhyaya, M. K., Clements, D. R., & Bargen, M. (2015). The biology of canadian weeds. 154. Himalayan blackberry. *Canadian Journal of Plant Science*, *95*(3), 557–570. https://doi.org/10.4141/cjps-2014-402

Invasive species council of british columbia. (2025, January 23). Invasive Species Council of British Columbia. https://bcinvasives.ca/

Jiménez-Hernández, H. A., Bonilla-Valencia, L., Martínez-Orea, Y., Zamora-Almazan, M. J., Espinosa-García, F. J., & Castillo-Argüero, S. (2023). Effects of Hedera helix L. removal on the understory early regeneration in an oak temperate forest in Mexico City. *Ecological Processes*, *12*(1), 31. https://doi.org/10.1186/s13717-023-00443-y

Lei, T. (2014). Environmental preferences and constraints of *Daphne laureola* , an invasive shrub in western Canada. *Canadian Journal of Forest Research*, *44*(11), 1462–1467. https://doi.org/10.1139/cjfr-2014-0261

Liedtke, R., Barros, A., Essl, F., Lembrechts, J. J., Wedegärtner, R. E. M., Pauchard, A., & Dullinger, S. (2020). Hiking trails as conduits for the spread of non-native species in mountain areas. *Biological Invasions*, *22*(3), 1121–1134. https://doi.org/10.1007/s10530-019-02165-9

MACK, R. N., & LONSDALE, W. M. (2001). Humans as Global Plant Dispersers: Getting More Than We Bargained For. *BioScience*, *51*(2), 95. https://doi.org/10.1641/0006-3568(2001)051[0095:hagpdg]2.0.co;2

Mack, R. N., Simberloff, D., Mark Lonsdale, W., Evans, H., Clout, M., & Bazzaz, F. A. (2000). Biotic invasions: Causes, epidemiology, global consequences, and control. *Ecological Applications*, *10*(3), 689–710. https://doi.org/10.1890/1051-0761(2000)010[0689:BICEGC]2.0.CO;2

Panasenko, N. N., & Anishchenko, L. N. (2018). Influence of invasive plants parthenocissus vitacea and vinca minor on biodiversity indices of forest communities. *Contemporary Problems of Ecology*, *11*(6), 614–623. https://doi.org/10.1134/S1995425518060070

R Core Team. (2023). *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing. https://www.r-project.org/

Reichard, S. H., & White, P. (2001). Horticulture as a Pathway of Invasive Plant Introductions in the United States. *BioScience*, *51*(2), 103. https://doi.org/10.1641/0006-3568(2001)051[0103:haapoi]2.0.co;2

Sakai, A. K., Allendorf, F. W., Holt, J. S., Lodge, D. M., Molofsky, J., With, K. A., Baughman, S., Cabin, R. J., Cohen, J. E., Ellstrand, N. C., McCauley, D. E., O'Neil, P., Parker, I. M., Thompson, J. N., & Weller, S. G. (2001). The population biology of invasive species. *Annual Review of Ecology and Systematics*, *32*, 305–332. https://www.jstor.org/stable/2678643

Schmitz, D. C., & Simberloff, D. (1997). Biological invasions: A growing threat. *Issues in Science & Technology*, *13*(4), 33.

Wells, F. H., Lauenroth, W. K., & Bradford, J. B. (2012). Recreational trails as corridors for alien plants in the rocky mountains, usa. *Western North American Naturalist*, *72*(4), 507–533. https://www.jstor.org/stable/42003924

Yamamoto, M. H., & Jones, C. C. (2024). Comparing long-term patterns of spread of native and invasive plants in a successional forest. *Oecologia*, *205*(1), 13–25. https://doi.org/10.1007/s00442-024-05554-7

Zika, P. F. (2010). Invasive hollies (Ilex, aquifoliaceae) and their dispersers in the pacific northwest. *Madroño*, *57*(1), 1–10. https://doi.org/10.3120/0024-9637-57.1.1

Zimmermann, H., Brandt, P., Fischer, J., Welk, E., & Von Wehrden, H. (2014). The Human Release Hypothesis for biological invasions: Human activity as a determinant of the abundance of invasive plant species. *F1000Research*, *3*, 109. https://doi.org/10.12688/f1000research.3740.1

Appendix 1

Full R code for second data analysis:

```
#First set the working directory, there are better ways of importing the data, but this way I can
modify the csv file and then reload to get it into R
#changed back slash to forward slash to fix error
setwd("C:/Users/davidlisle/Documents")

#tell R which is the CSV file to use

DLdata<-read.csv("Betweensubjectsdesign.csv")

library(rstatix)
library(tidyverse)

#briefly look at the data

head(DLdata)

hist(DLdata$Combined.Density)


#transforming the data to seek normality?

DLdata$sqrtCden<-sqrt(DLdata$Combined.Density)

hist(DLdata$sqrtCden)

hist(DLdata$Holly.Density) #visualizing holly density in a histogram

DLdata$sqrtHden<-sqrt(DLdata$Holly.Density) #transforming holly density by using sqrt
function to seek normality

hist(DLdata$sqrtHden) #visualizing transformed data
```

```
#normality tests - Shapiro wilk

shapiro.test(DLdata$Combined.Density)

shapiro.test(DLdata$sqrtCden)

shapiro.test(DLdata$sqrtHden) #shapiro wilk test for normality for transformed holly density

shapiro.test(DLdata$Holly.Density) #shapiro wilk test for normality for holly density

#code for two-way repeated measures Anova

library(tidyverse)
library(rstatix)

# 1. Convert to factors
DLdata <- DLdata %>%
  mutate(
    Trail = as.factor(Trail),
    Distance = as.factor(Distance),
    Intensity = as.factor(Intensity)
  )

# 2. Aggregate repeated measures per condition
DL_avg <- DLdata %>%
  group_by(Trail, Intensity, Distance) %>%
  summarise(
    sqrtCden = mean(sqrtCden),
    .groups = "drop"
  )

# 3. Run the mixed (repeated measures) ANOVA
res.aov <- anova_test(
  data = DL_avg,
  dv = sqrtCden,
  wid = Trail,
  within = Distance,
  between = Intensity
)

# 4. Show results
get_anova_table(res.aov)

#***Same code for Holly density instead of combined density***

 library(tidyverse)
```

```
library(rstatix)

# 1. Convert to factors
DLdata <- DLdata %>%
  mutate(
    Trail = as.factor(Trail),
    Distance = as.factor(Distance),
    Intensity = as.factor(Intensity)
  )

# 2. Aggregate repeated measures per condition
DL_avg <- DLdata %>%
  group_by(Trail, Intensity, Distance) %>%
  summarise(
    sqrtHden = mean(sqrtHden),
    .groups = "drop"
  )

# 3. Run the mixed (repeated measures) ANOVA
res.aov <- anova_test(
  data = DL_avg,
  dv = sqrtHden,
  wid = Trail,
  within = Distance,
  between = Intensity
)
# 4. Show results
get_anova_table(res.aov)

#Visualizing the two-way repeated measures Anova for Combined.Density and Holly.Density

#setting factors

DLdata$Intensity <- as.factor(DLdata$Intensity)
DLdata$Distance <- as.factor(DLdata$Distance)
DLdata$Trail <- as.factor(DLdata$Trail)

#Compute summary statistics by groups:

#First summary statistics for Combined.Density

DLdata %>% group_by(Distance) %>% get_summary_stats(Combined.Density, type =
"common")
DLdata %>% group_by(Intensity) %>% get_summary_stats(Combined.Density, type =
"common")
```

#Second summary statistics for Holly.Density

```
DLdata %>% group_by(Distance) %>% get_summary_stats(Holly.Density, type = "common")
DLdata %>% group_by(Intensity) %>% get_summary_stats(Holly.Density, type = "common")
```

#Visualizing the two-way repeated measure ANOVA for Combined.Density first, then Holly.Density second. Same code for both

```
# Create a combined group from Intensity and Distance
DLdata <- DLdata %>%
  mutate(Group = interaction(Intensity, Distance, sep = "-"),
         Group = factor(Group, levels = c("H-N", "H-F", "L-N", "L-F")))

# Boxplot using Combined.Density, grouped by Intensity-Distance combo
ggplot(DLdata, aes(x = Group, y = Combined.Density, fill = Intensity)) +
  geom_boxplot() +
  labs(title = "Combined Density by Intensity and Distance",
     x = "Intensity + Distance ",
     y = "Combined Density") +
  theme_minimal() +
  theme(axis.text.x = element_text(angle = 45, hjust = 1))

# Create a combined group from Intensity and Distance
DLdata <- DLdata %>%
  mutate(Group = interaction(Intensity, Distance, sep = "-"),
         Group = factor(Group, levels = c("H-N", "H-F", "L-N", "L-F")))

# Boxplot using Holly.Density, grouped by Intensity-Distance combo
ggplot(DLdata, aes(x = Group, y = Holly.Density, fill = Intensity)) +
  geom_boxplot() +
  labs(title = "Combined Density by Intensity and Distance",
     x = "Intensity + Distance",
     y = " Density of Holly ") +
  theme_minimal() +
  theme(axis.text.x = element_text(angle = 45, hjust = 1))
```