FUNCTIONAL DIFFERENCE IN PLANT COMMUNITIES AS A DRIVER OF GREEN ROOF ECOSYSTEM SERVICES

by

Catlin Bradbury

A Thesis Submitted to
Saint Mary's University, Halifax, Nova Scotia
In Partial Fulfillment of the Requirements for
the Degree of Bachelor of Science with Honours

April 2021, Halifax, Nova Scotia

Approved: ______________________________
Dr. Jeremy Lundholm
Supervisor

Approved: ______________________________
Dr. Tony Charles
Examiner

Date Submitted: April 27, 2021

Abstract

Green roofs provide ecosystem services that help humans in urban environments. Ecosystem services provided by green roofs include reducing storm water run-off, better regulation of building temperatures, reduced heat flux and urban heat island effect and providing a place for wildlife to inhabit. This study aims to expand the knowledge of how plant species functional traits and the plant community's functional diversity determine the ecosystem services green roofs provide. The experimental design compared seven species mixture treatments that differed in functional diversity, comprised of 11 plant species, with monoculture treatments. Nine replicates of each treatment were planted in trays and established on a roof in Halifax, NS, in a block design accounting for shading from an adjacent building. This study examined 10 response variables that indicate ecosystem services and used regression to assess the ability of functional diversity in the mixtures to predict ecosystem services. There was a very weak negative relationship between functional diversity and two response variables: canopy density and floral abundance. Position on the roof relative to shade showed that areas more sheltered by an adjacent building had greater stability in summer soil temperature regardless of functional diversity. While functional diversity was not positively related to any of the ecosystem services, several of the species mixture treatments outperformed the best monoculture treatments. Additional research on functional divergence as a predictor for green roof ecosystem services needs to be conducted.

Acknowledgement

I would like to give thanks to the following individuals for their support and help during my honours experience. My supervisor Dr. Jeremy Lundholm for guiding me through this process and helping me with statistical analysis, writing my thesis and providing positive feedback. Dr. Tony Charles for taking the time to review and give feedback on my thesis. Amy Heim for helping with set up of experimental design, plant identification, collecting data and for being a supportive individual. Kayla Williams, Taylor Hicks and Terrell Roulston for helping with the collection of data and being encouraging peers. DesignLIFES Research for helping to fund my research. Saint Mary's University for their hospitality and ability to provide excellent assistance during a global pandemic. Finally, I would like to give a special thanks to my partner and family for their continued support and for providing me the opportunity to peruse my passion in biology.

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1.0 Introduction

1.1 Urbanization and Loss of Green Space

The human population continues to grow at an alarming rate with an estimated population of more than 11 billion predicted for the year 2100 (Murdoch et al. 2018). This increased human population world-wide will create an increased the need for housing or space for these individuals. Urbanization of areas that were once filled with green space are now covered by roads and buildings. Building roads and infrastructure can cause loss in natural systems with the increase of storm water runoff, increase in erosion, urban heat island effect, loss of habitats and increased pollution (Harris 2008). Most architecture negatively affects the environment but around 32% of the horizontal surfaces on the building's roof can be perfect to implement green roofs (Oberndorfer et al. 2007). These roofs can be utilized by installing sustainable architecture, which has been used in urban settings as far back as 2100 B.C. (Velazquez 2005). They provide ecosystem services to help offset human disturbance (Velazquez 2005).

1.2 Green Roofs

Green roofs are built on rooftops of buildings and are usually partially or completely covered by vegetation (Clarke 2018). A green roof is made up of a waterproof membrane, substrate and vegetation (Licht and Lundholm.2006). Choosing plant species for a green roof is determined by what soil depth is used. Green roof specialists tend to use a shallower substrate on green roof to reduce weight loading (Berardi et al., 2014). Shallow substrate green roofs (<20 cm deep) use plant species that don't have large or long root structures because of the low soil depth, but usually require little to no maintenance

(Weddle 2012). Shallow substrate green roofs have a small weight load, which allows for less reinforcement of the rooftop to handle increased weight (Weddle 2012).

Many species of plants can be used on a green roof but for shallow substrate roofs, species that are generalist and can survive harsh conditions are most successful (Oberndorfer et al. 2007). Plant species on shallow substrate green roofs share similar characteristics, including low, mat-forming or compact growth; evergreen or tough foliage, twiggy growth; and other drought-tolerance or avoidance strategies (Oberndorfer et al. 2007). In Nova Scotia, plant species that are found on the coastal barrens are used because their natural habitat has similarities to rooftop environments. Coastal barren ecosystems endure harsh winds, low soil depth and salt spray (Licht and Lundholm 2006). Native plant species are better than non-native species because they may have equal or better survival rate and they help with local biodiversity (Weddle 2012). On shallow substrate roofs *Sedum* species do the best because of shallow soil depth, drought tolerance, high light intensities and ability to handle harsh weather conditions (Oberndorfer et al. 2007). Other plant species used on shallow substrate green roofs are grasses and herbaceous perennials (Oberndorfer et al. 2007). These plant species all work together to help provide benefits to these constructed ecosystems.

1.3 Environmental Benefits of Green Roofs

Ecosystem services are benefits to humans provided through the functioning of natural or artificial ecosystems. Ecosystem services provided by green roofs include reducing storm water run-off (Oberndorfer et al. 2007), better regulation of building temperatures (Weddle 2012), reduced heat flux and urban heat island effect (Bass and Baskaran 2003) and provision of habitat for wildlife (Coffman and Davis 2005). Green roofs also increase roof membrane longevity by reducing UV light exposure and are more visually appealing than conventional roofs (Oberndorfer et al. 2007).

1.3.1 Water Retention

Urban areas are subject to large quantities of storm water runoff because they are comprised of nonporous surfaces such as buildings and roads (Oberndorfer et al. 2007). The amount of storm water runoff produced by urban areas is roughly five times more than forested areas similar in size (Carter and Butler 2008). This increase of storm water runoff can become a problem for urbanized areas because of increased quantity of water input into sewage treatment plants, increased chances of flooding, increased erosion, spreading of harmful pollutants and harming of nearby habitats (Moran et al. 2005). Water retention on green roofs is very important with the increasing amount of urbanization that is happening with our growing populations.

Green roofs are manufactured to provide a variety of ecosystem services but one of the most important is the reduction of storm water runoff (Heim 2013). Conventional roofs that are flat will help retain some water, but green roofs are shown to retain a larger percentage of rainfall (Burszta-Adamiak et al. 2019). On green roofs, rainwater can be used by the plants or stored in the substrate for delayed runoff or evapotranspiration (Oberndorfer et al. 2007). A study by Burszta-Adamiak et al. (2019) compared two green roofs to a conventional roof and the results showed that the average percentage of retained water for green roofs was between 81.2-81.5% whereas the conventional roof only retained 33.6% of the water (Burszta-Adamiak et al. 2019).

1.3.2 Urban Heat Island Effect, Heat Flux and Energy Conservation

The urban heat island effect happens when urban areas have warmer air temperatures than other areas that are nearby (Bass and Baskaran 2001). The buildings and roads increase air temperature because they provide less shade and moisture compared to natural landscapes and they absorb more sun rays and produce additional heat (Bass and Baskaran 2001). The heat island effect can cause increased energy consumption, increased pollution and heat-related illness or death (Marafa and Alibaba 2019). Reducing the urban heat island effect by installing green roofs would help mitigate these increases in temperatures. A study by Marafa and Alibaba (2019) reported green roofs resulted in building energy savings between 86.2-86.5% because of decreased heat flux across the roof membrane. The amount of plant coverage on a green roof affects indoor environments and building energy demand (Yaghoobian and Srebric 2015). A study by Yaghoobian and Srebric (2015) concluded that green roofs are effective for urban heat island mitigation and affect the outdoor air temperature through convective heat transfer. Another study by Bass et al. (2002) showed a temperature decrease of 2 degrees Celsius in some areas by using a regional simulation model using 50% green roof evenly spaced out in Toronto. Energy conservation is determined by weather conditions, size of the roof, plant species, growth phase of plants, soil composition and building type (Zhou et al. 2018). A green roof will decrease the daytime temperature of the roof surface in summer by intercepting solar radiation, and thus decreasing the energy consumption of the building by limiting air conditioning costs required as a response to the excess solar heat absorbed by the impervious surfaces of a rooftop (Simmons et al. 2008).

1.3.3 Wildlife Habitats

Wildlife habitat and ecosystems have been destroyed and replaced by buildings and roads. This loss in natural ecosystems has been negatively impacting native plant and animal communities. Avian species have been negatively affected by urbanization of natural areas because of increased predation by domesticated animals and collision with human structures (Partridge and Clark 2018). Green roofs can reconcile some of these problems by providing shelter and food resources for invertebrates and avian species that once depended on the ecosystem that was lost (Coffman and Davis 2005). Green roofs can be used as a rest station for migrating avian species, which will increase the survival and reproductive success of these species (Partridge and Clark 2018). A green roof can be used to help with declining bee populations by limiting the distances between fragmentations of their habitat and resources (Colla et al. 2009). A study by Colla et al. (2009) showed that green roofs have high bee diversity and can help offset the decreasing habitat loss, increased pesticide use, and pathogen spillover from managed bees and invasive species. Helping the bee populations increase to ensure that they can continue to pollinate many agricultural crops, which will help with our growing population (Colla et al. 2009). Humans need to think about aiding bee population by considering the plant species flowering time, size and quantity of flowers, colour of the flower and how tall the stock grows (Colla et al. 2009). These are all functional traits that can determine if the plants are suitable to be used by bees (Colla et al. 2009).

1.4 Functional Traits and Functional Diversity

Plant communities vary in their species diversity, and green roofs range from monocultures of a single species or genus or can be highly diverse (Lundholm 2015). Ecosystems with diverse plant communities can outperform monocultures or low diversity plant communities when looking at multiple ecosystem services they provide (Lundholm 2015). A study by Butler and Orians (2011) study found during a drought, herbaceous species on a green roof would have higher survival rate when planted with *Sedum* species. This shows not all mixture treatments can perform at same rate because how the functional traits differ within plant communities can affect their performance.

Functional traits are measurable features of a plant species that affect their fitness in an ecosystem (Bello et al. 2013). Some examples of functional traits are seed mass, leaf thickness, wood density and many more. Functional traits are used to help predict how a plant species fitness will be affected by environmental changes because functional traits show what resource and habitat requirements the species needs to survive (Bello et al. 2013). Plant species that have a trait that is more valuable in a certain ecosystem usually will have a higher abundance of individuals in that community (Bello et al. 2013). Plant functional traits also affect the functioning and provision of services from ecosystems. A study by Cook-Patton and Bauerle (2012) shows that plant species should be chosen based on their functional traits that provide ecosystem services we need, such as helping reduce storm water runoff, roof cooling, habitat gain and other factors. To obtain the highest overall yield of ecosystem services, the plant community must be functionally diverse (Cook-Patton and Bauerle 2012).

Functional diversity is the driving force behind understanding how ecosystems operate (Villéger et al. 2008). Functional diversity is calculated by three functional diversity indices which are: functional richness, functional evenness and functional divergence (Villéger et al. 2008, Bello et al. 2013). However, this study only focussed on functional divergence because it quantifies the degree to which the species within a community are more similar or more different in terms of their trait values. (Villéger et al. 2008, Bello et al. 2013). Functional divergence indicates the degree of niche differentiation and ideally you want high functional divergence because it lowers resource competition (Mason et al. 2005), and can result in overall higher resource uptake. Functional divergence is expected to increase ecosystem service provisioning in two ways. First, greater functional divergence in a plant community may lead to greater resource use and productivity, and the rate of resource use is important in determining green roof ecosystem services. The effect of plants on stormwater retention depends on their ability to use soil water; more functionally diverse communities are expected to use more water in total, leading to greater overall stormwater retention (Lundholm et al., 2015). Likewise, for cooling the roof surface, greater amounts of aboveground biomass are associated with lower soil temperatures, so a functionally diverse community that can more efficiently use local resources should be able to produce more biomass and a stronger cooling effect. Second, when considering a suite of ecosystem services, species that are functionally different are likely to optimize different services, so having a mix of species with high functional divergence is likely to lead to greater ecosystem multifunctionality (Manning 2019). In other words, we expect higher performance across a range of different services if we have plants in the community with divergent functional traits.

1.5 Research Objectives

This study aims to expand the knowledge of how plant species functional traits and plant community's functional diversity determine the ecosystem services they provide. The research objectives of this project include:

1) This study aims to determine if functionally different plant communities provide higher levels of ecosystem services than functionally similar plant communities. This study used functional divergence to create plant communities that range from functionally similar to functionally different. The treatments that have higher functional diversity could improve a single function or service by having multiple plant species working together to achieve the highest yield for a single ecosystem service or function. Higher functional diversity could also improve several functions or services at the same time by having multiple plant species working together in a treatment but optimizing different ecosystem services or functions while coexisting.

2) This study aims to determine whether species-diverse communities provide higher levels of ecosystem services than monoculture communities. This study compared monoculture and diverse community treatments to help determine which provided more ecosystem services.

2.0 Methods

2.1.1 Experimental Design

The experimental design and installation were completed by Amy Heim (PhD Student) in 2018. This experiment utilized eleven plant species (Table 1) which were divided into four groups based on functional trait characteristics. The functional traits of 146 vascular species of plants that occur naturally within one hour's drive from Saint Mary's University (44°37"N 63°34"W) were measured between 2016 and 2019. The traits analyzed were height, leaf thickness, specific leaf area, leaf dry matter content, specific root length, and root radius. All these traits were collected from the Chebucto Head coastal barren site (44°30"N 63°31"W) or from the Saint Mary's University green roof. For each aboveground trait, 10 healthy adult plants of each species were randomly selected and was measured. The belowground traits were collected from their natural environment for all species but three species from five healthy adult plants of each species at the end of August 2019. Roots were stored in a solution containing 70% ethanol-30% water solution at 4ºC until November 2019, at which time traits were calculated. The three species that weren't collected from natural environment were collected from the SMU green roof or grown from seeds. *Sedum spurium* and *Festuca rubra* roots were collected from five healthy adult plants growing on a green roof adjacent to the green roof experiment. *Deschamsia flexuosa* roots were collected from five healthy plants grown in greenhouse located at Saint Mary's University from seeds collected from Chebucto head.

Seven species mixture treatments (Table 2) were used based on functional similarities and functional differences. Each of the seven treatments (Table 2) was selected by analyzing community traits through an R package created by Laliberté and Legendre (2010) to calculate average functional dispersion (Fdis).

Table 1. The eleven plant species scientific names, codes given for statistical analysis and different functional groups used in this experiment.

Species	Code	Functional Group
Sedum album	SAL	Succulent
Sedum sexangular	SS	Succulent
Sedum acre	SA	Succulent
Solidago bicolor	SB	Forb
Solidago puberula	AM	Forb
Symphyotrichum novi-belgii	SN	Forb
Festuca rubra	FR	Grass
Danthonia spicata	DS	Grass
Deschampsia flexuosa	DF	Grass
Sedum spurium	PUR	In Between
Sibbaldiopsis tridentata	ST	In Between

Table 2. The seven treatments showing the different plant communities used in this experiment and if they are functionally similar or different.

Treatment	Community	Community Codes	Similar or Different
1	*Sedum acre, Sedum album, Sedum sexangular*	SA.SAL.SS	Similar
2	*Solidago puberula, Solidago bicolor, Symphyotrichum novi-belgii*	AM.SB.SN	Similar
3	*Festuca rubra, Danthonia spicata, Deschampsia flexuosa*	FR.DS.DF	Similar
4	*Danthonia spicata, Sibbaldiopsis tridentata, Sedum spurium*	DS.ST.PUR	Similar
5	*Sedum acre, Solidago bicolor, Danthonia spicata*	SA.SB.DS	Different
6	*Sedum acre, Solidago bicolor, Sibbaldiopsis tridentata*	SA.SB.ST	Different
7	*Sedum acre, Sibbaldiopsis tridentata, Danthonia spicata*	SA.ST.DS	Different

2.1.2 Experimental Procedure

The plants were grown in the greenhouse from seed in growing trays between January 2018 to May 2018 or harvested from a green roof on the Saint Mary's University campus, except for *Solidago puberula* and *Deschampsia flexuosa* which were harvested from abandoned lots in the HRM area. The treatments were applied to planter trays ("modules") such that each module received a single treatment. Each module (1ft by 1ft) had a drainage mat and 10 cm of SOPRAFLOR X soil (SOPREMA, Strasbourg, France) (Figure 2). The treatments comprised monocultures of each species, the seven mixture treatments and controls that had only the drainage mat and soil. The plants were transplanted from growing trays into modules in May 2018. The mixture treatments (Table 2) had nine equally spaced individuals per module and monocultures had nine equally spaced individuals per module of the same species. Nine replicates of each treatment were placed on Saint Mary's University's Atrium roof. One replicate was placed randomly in each of nine blocks to account for spatial variation in shading from the adjacent Science building (block 9 was closest to the adjacent building and most shaded; block 1 was least shaded).

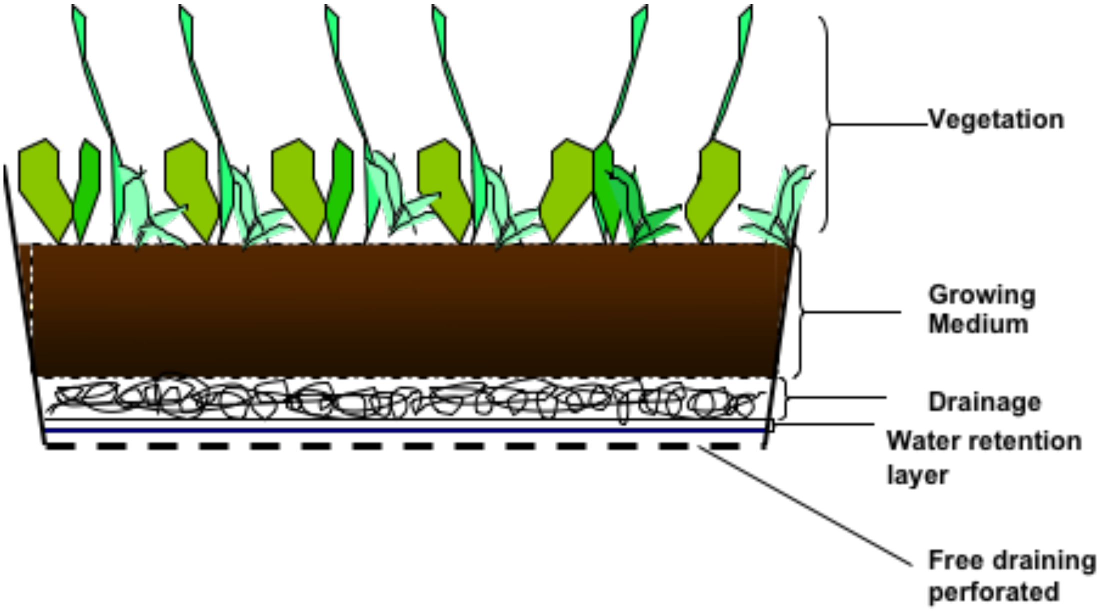

Figure 2. A diagram showing the different layers involved in a green roof module. Module layer is broken down into plant vegetation, growth medium (soil), the drainage mat, water retention layer and perforated bottom to allow water to drain freely. https://sites.google.com/site/lundholmlab/research/green-roof

2.2 Data Collection

2.2.1 Temperature

The soil temperatures (in °C) were recorded using a Taylor 9878 Slim-Line Pocket Thermometer Probe (Commercial Solutions Inc., Edmonton, Alberta, Canada) once a month from July 2019 to June 2019 and June 2020 to September 2020. Data collected in July 2019 was done by Amy Heim. These readings were all taken within 2 hours from solar noon on the day of measurement, only on sunny days in order to record the maximum soil temperatures; lower maximum temperatures under hot conditions are associated with greater provisioning of the roof cooling service (Lundholm et al., 2010). If sky was cloudy then no measurements were taken because this would provide soil with less intense sun rays, in return giving lower soil temperatures. The temperatures were taken at approximately 2cm below the soil substrate in the center of each module. The temperature reading was recorded once it was stable.

2.2.2 Heights

The plant heights (in cm) were recorded using a standard meter stick once a month from June 2020 to September 2020. The height of the tallest of each species in an individual module was recorded. The heights were taken from the base of the above ground living biomass to the top of plant including flowers. Heights were measured as they are associated with higher performance of several ecosystem services (Lundholm et al., 2015).

2.2.3 Water Retention

The volumetric water content percentage (VWC%) was recorded one day before a rain event and again the day after the rain event ended. The difference in VWC between these days was calculated to determine water retention. Measurements were taken once a month between July 2020 to September 2020. The VWC was measured by using a ProCheck handheld machine and a GS3 soil moisture sensor (Decagon Devices Inc., Pullman, Washington, United States). Sensor was inserted approximately 5cm below the soil substrate in the center of each module. VWC reading was recorded once it was stable.

2.2.4 Floral Resources

The floral coverage was recorded once every two weeks from June 2020 to September 2020. The floral coverage was recorded using a 1ft by 1ft (55 squares by 55 squares) sheet of grid paper. Each square represents 0.033% of the modules surface area and was calculated by 1/(55x55) x 100 = 0.033%. The flower of each species was then placed on the grid paper to get the approximate floral coverage percentage. This was done for several flowers to get an average floral coverage percentage. Using the average floral coverage percentage, flowers were counted by species in each module. Only flowers that were completely open and weren't dead were recorded because they could be accessed by pollinators. Grass species flower coverage was not used in this study because their flowers are wind pollinated; they usually have no pollinators visit them.

2.2.5 Canopy density

Canopy density data was collected by using a metal 3D square (Figure 3) and was recorded once every two weeks from June 2019 to September 2020. The pin frame square was placed over each module and how many times each species' live aboveground biomass touched one of the rods it was recorded. If a species was in the module but failed to come in contact with a rod, it was recorded as 1. If all individuals of a species had died off, it was recorded as 0. Canopy density provides a general measure of plant size and aboveground biomass and is positively correlated with several ecosystem services (Lundholm et al., 2015).

Figure 3. Metal 3D pin frame square that is 1ft cubed with 16 points of intersection.

2.3 Data Analysis

The temporal mean and standard deviation across all sampling dates was derived in excel for temperature, water retention, canopy density and height. Temporal means were used to estimate the overall performance of a given service. Generally, higher values are equated with greater provisioning of ecosystem services, except summer soil temperatures, for which lower temperature indicates greater provisioning of the roof cooling service. Standard deviations were used as an index of temporal stability, with lower standard deviations considered to indicate greater stability. Floral resources were given sampling intervals between 0-7 that represented how many times out of the 7 collection dates that flowers were present in an individual module (e.g. If a module had flowers blooming 3 out of 7 collection dates, then it would receive a 3) for an estimate of flowering duration (an estimate of temporal stability of floral resource provisioning). Total abundance of floral coverage was calculated by the sum of all floral coverage across all sampling times for each module. The ten response variables were then used for statistical analysis.

A linear regression was applied to all ten response variables (only including mixture treatments) against Fdis value for each replicate. A one-way mixed model ANOVA, with "block" as a random effect was used to compare planting treatments (including monocultures and controls) for each of the ten response variables.

3.0 Results

3.1 Linear Regression

An analysis was done on the ten response variables using a linear regression and the results in table 3 showed that height mean and height standard deviation had a strong negative relationship with functional divergence (Fdis), indicating that the most functionally diverse treatments tended to be consistently short throughout the growing season. There were two other significantly negative relationships between response variables and Fdis (floral abundance and canopy density) (Table 3). Other variables had no significant relationships with functional divergence.

Table 3. Linear regressions for response variables vs functional diversity (Fdis).

Response Variable	Regression Coefficient	P Value	T Value	Degree of Freedom	R Squared
Temperature Mean	0.14790	0.451	0.755	243.0058	0.00159492
Temperature Standard Deviation	0.10869	0.159	1.412	243.0017	0.00309909
Flower Abundance	-0.34580	0.040	-2.063	250.0000	0.01280000
Flowering Duration	-0.22250	0.150	-1.446	250.0000	0.00432500
Height Mean	-3.90000	4.17E-05	-4.174	243.0142	0.05686632
Height Standard Deviation	-3.72980	7.33E-06	-4.583	243.0346	0.07441932
Water Retention Mean	0.04732	0.908	0.115	243.0280	5.02E-05
Water Retention Standard Deviation	0.50150	0.214	1.246	243.0370	0.00593618
Canopy Density Mean	-0.11315	0.041	-2.056	243.0306	0.01578776
Canopy Density Standard Deviation	-0.08265	0.148	-1.450	243.0322	0.00795492

3.2 ANOVA

The results of the ANOVA test on all ten response variables showed that nine out of the ten had significant differences attributable to planted treatment. For soil temperature mean, ANOVA test results showed that mixture treatment DS.ST.PUR (24.2±0.7) is significantly cooler than all other groups except for SA.SAL.SS (25.3±0.6) and FR.DS.DF(25.4±0.7) (Figure 4). This result also showed that monoculture treatments DS (26.4±0.7), ST (27.5±0.7) and PUR (27.1±0.9) were much warmer than DS.ST.PUR (Figure 4). For temporal stability of soil temperature, most monoculture treatments significantly had more temperature temporal stability than mixture treatments (Figure 5).

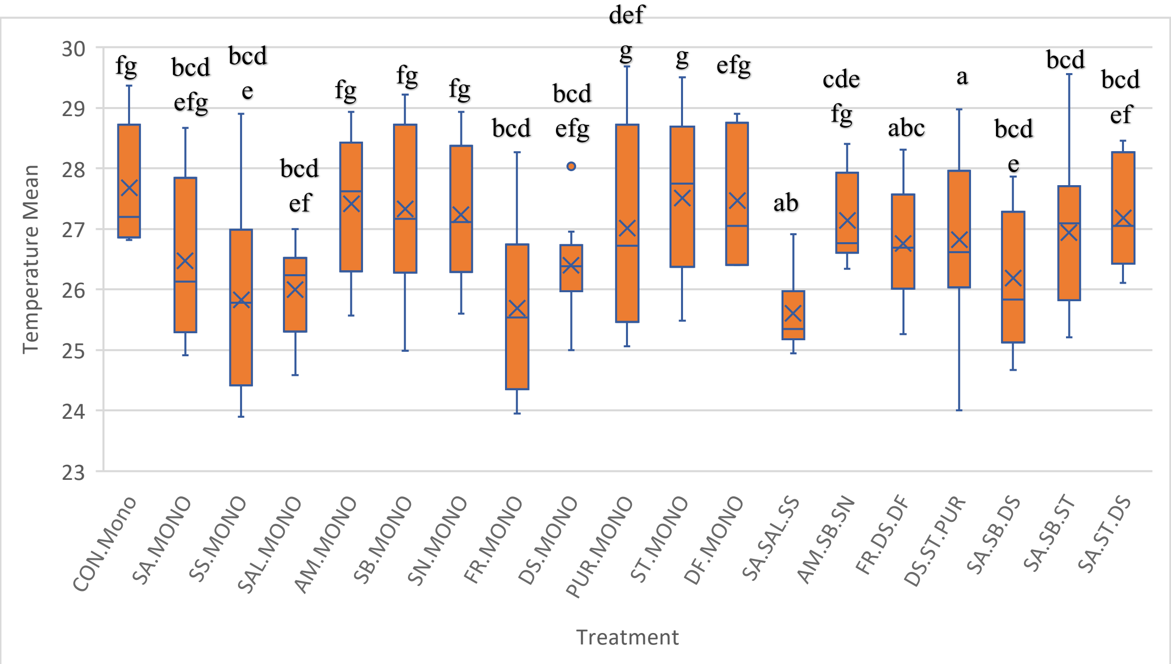

Figure 4. A one-way mixed model ANOVA, with "block" as a random effect was used to compare planting treatments for the average temporal temperature mean ± standard error. The result of the ANOVA test was significant with p-value<0.05. This bar graph shows the overall ecosystem service performance for the average temporal mean for temperature for all treatments (n=152) and y-axis begins at 23 because there was no value lower. Bars that share a letter are not significantly different.

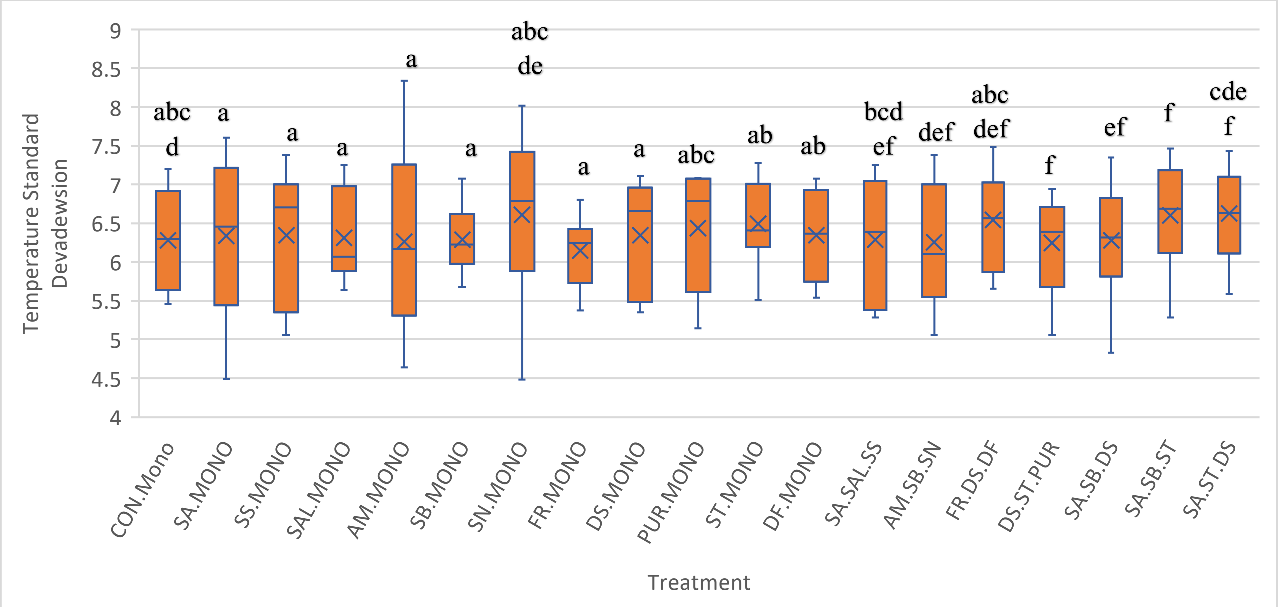

Figure 5. A one-way mixed model ANOVA, with "block" as a random effect was used to compare planting treatments for the average temporal standard deviation for temperature mean ± standard error. The result of the ANOVA test was significant with p-value<0.05. The graph shows the temporal stability of ecosystem services for the average temporal

standard deviation for temperature for all treatments(n=152) and y-axis begins at 4 because there was no value lower. Bars that share a letter are not significantly different.

For total floral abundance, the monoculture treatment SA (47.212±4.708) had roughly twice as much floral abundance than all other treatments (Figure 6). Any treatment that had SA had more floral abundance than those that didn't (Figure 6). All mixture treatments had more floral abundance, even if not significantly different monoculture treatments excluding SA monoculture (Figure 6). The flowering duration was calculated and averaged to figure out which treatment had the longest flowering time, this ranged from 0 to 7. Mixture treatments tended to have the longest flowering durations, even if not significantly different from monocultures (Figure 7).

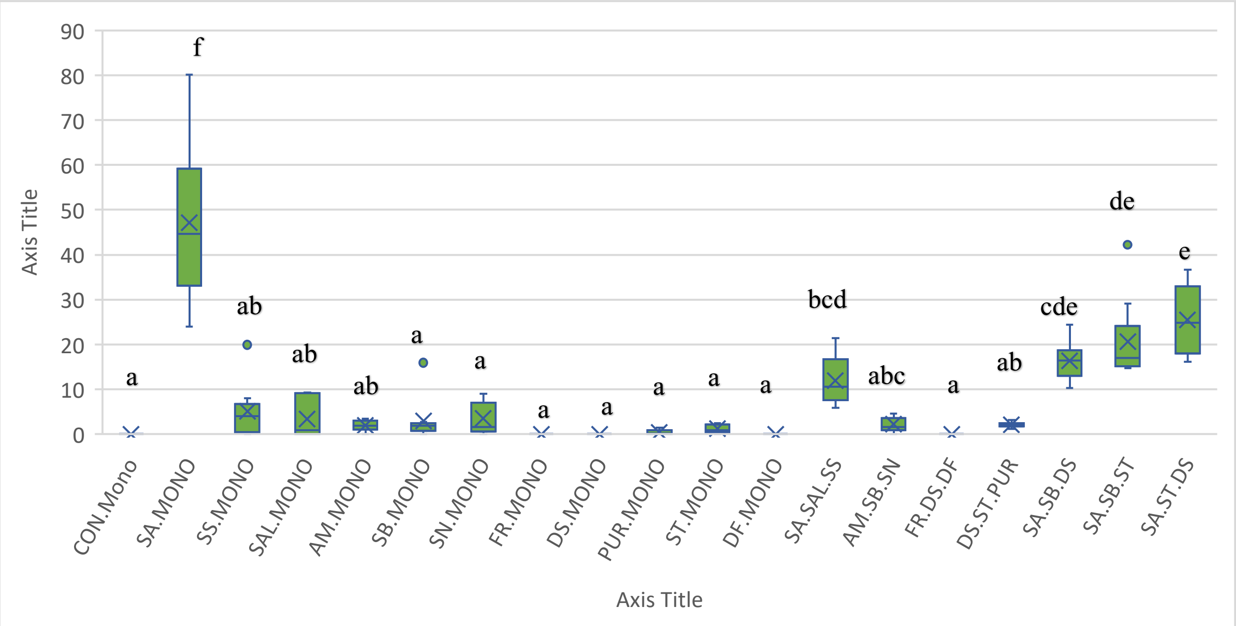

Figure 6. A one-way mixed model ANOVA, with "block" as a random effect was used to compare planting treatments for the average floral abundance mean ± standard error. The result of the ANOVA test was significant with p-value<0.05. This bar graph shows the overall ecosystem service performance for the average temporal floral abundance for all treatments (n=152). Bars that share a letter are not significantly different.

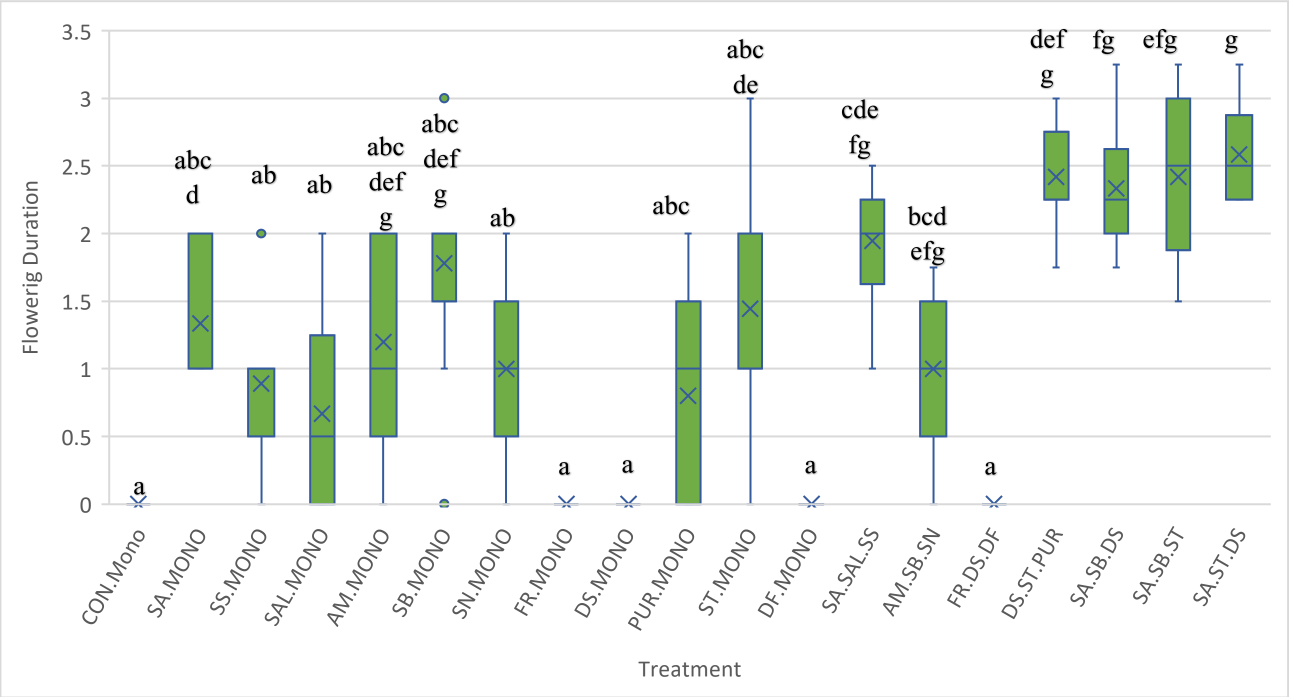

Figure 7. A one-way mixed model ANOVA, with "block" as a random effect was used to compare planting treatments for the average temporal flowering duration mean ± standard error. The result of the ANOVA test was significant with p-value<0.05. The graph shows the temporal stability of ecosystem services for the average temporal flowering duration for all treatments(n=152). Bars that share a letter are not significantly different.

The height was measured for all plant species and the data showed that the monoculture treatments FR (46.99±3.81), DF (34.88±4.58) and DS (25.59±3.77) were significantly the tallest plant species (Figure 8). The mixture treatment FR.DS.DF (23.74±3.77) outperformed all other mixture treatments and was significantly different from all other mixture treatments other than SA.SB.DS (17.34±3.76) treatment (Figure 8). Several of the mixture treatments were significantly less consistent in height temporal stability than some of the monocultures (Figure 9).

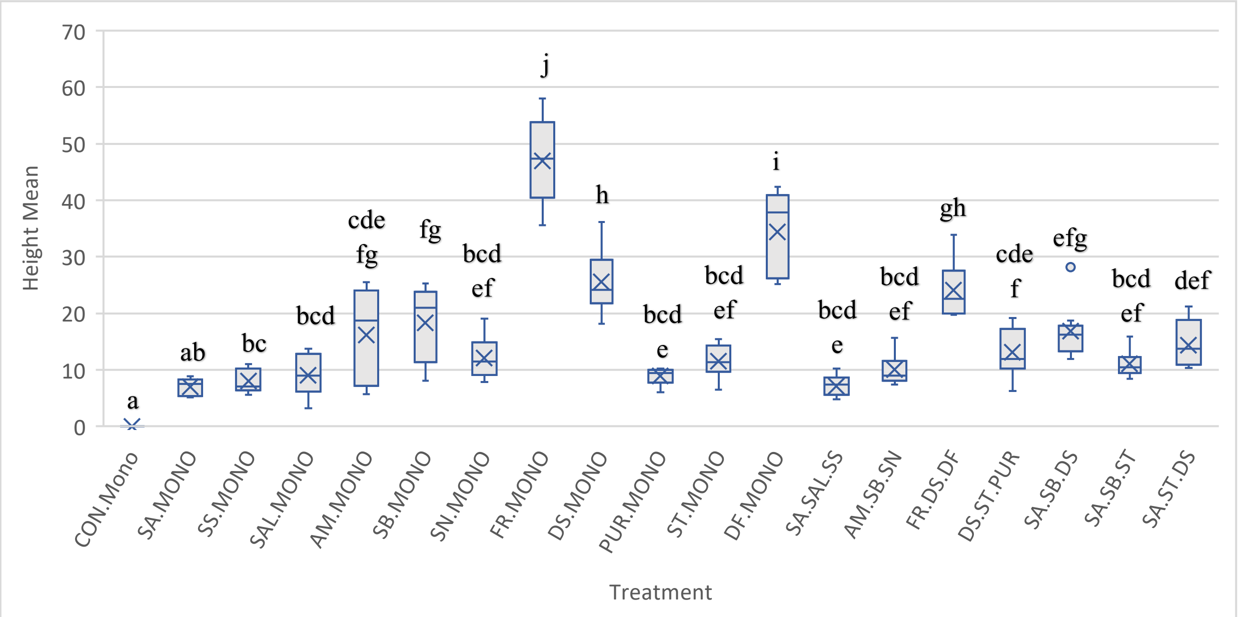

Figure 8. A one-way mixed model ANOVA, with "block" as a random effect was used to compare planting treatments for the average temporal height mean ± standard error. The result of the ANOVA test was significant with p-value<0.05. This bar graph shows the overall ecosystem service performance for the average temporal mean for height for all treatments (n=152). Bars that share a letter are not significantly different.

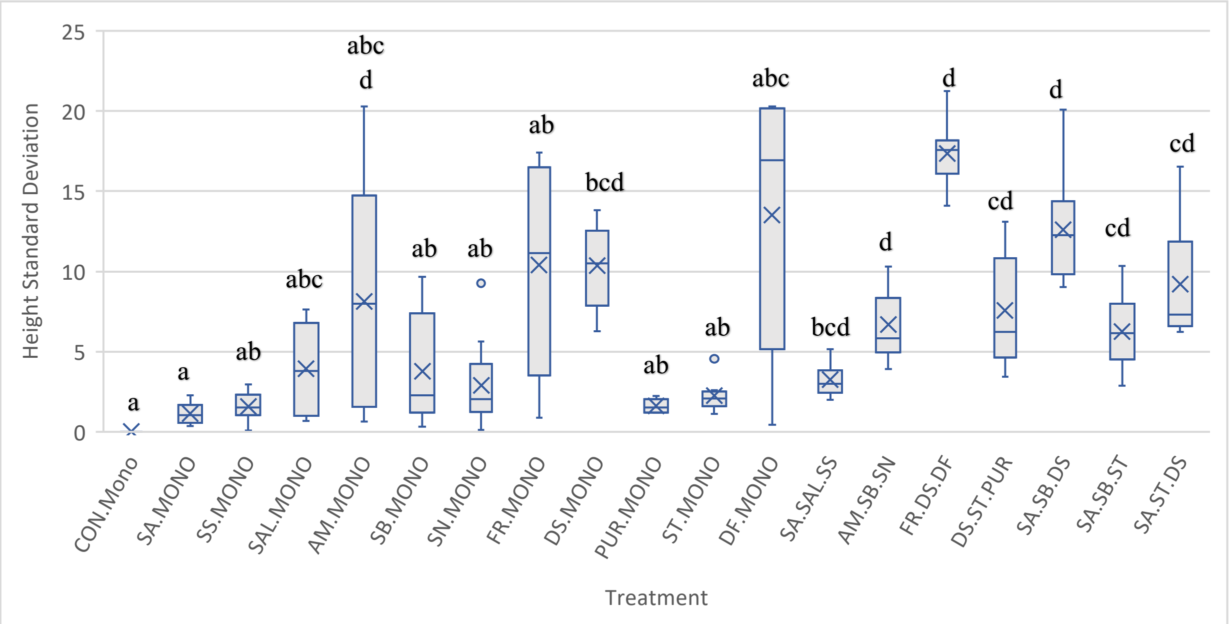

Figure 9. A one-way mixed model ANOVA, with "block" as a random effect was used to compare planting treatments for the average temporal standard deviation for height mean ± standard error. A coefficient of variation as an index of temporal variability was used to erase the effect of the mean. The result of the ANOVA test was significant with p-value<0.05. The graph shows the temporal stability of ecosystem services for the average temporal standard deviation for height for all treatments(n=152). Bars that share a letter are not significantly different.

For mean stormwater retention, the mixture treatment AM.SB.SN (15.53±2.99) was statistically better at water retention than monoculture treatment SS (9.57±2.99) (Figure 10). There was no significant difference in water retention standard deviation among treatments (Figure 11).

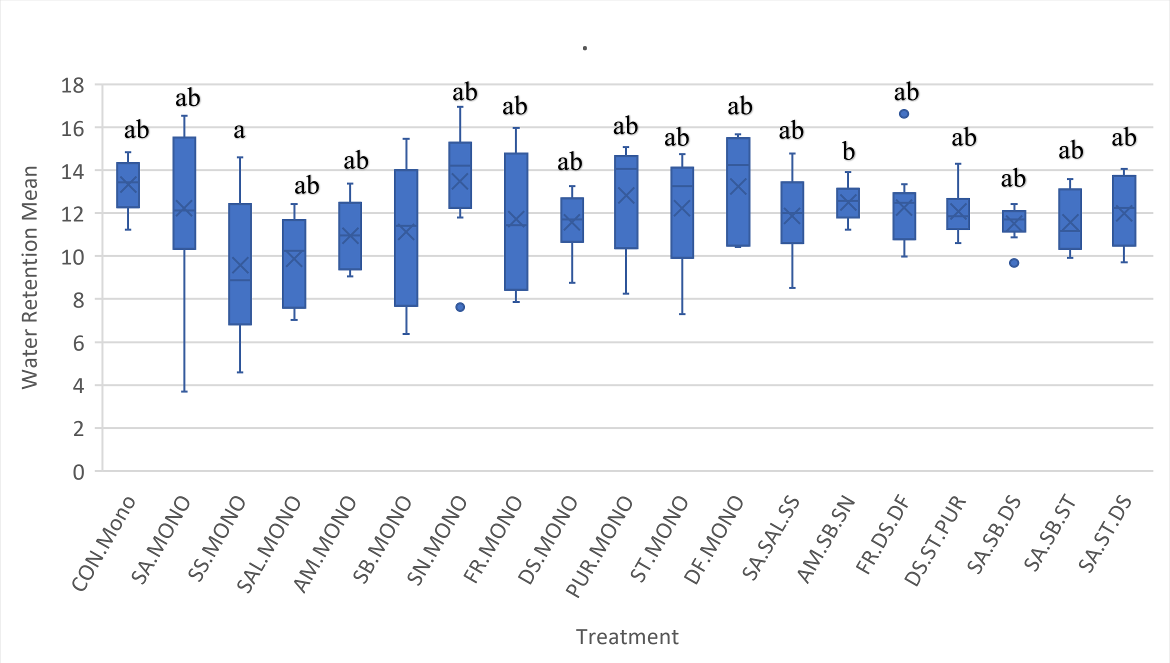

Figure 10. A one-way mixed model ANOVA, with "block" as a random effect was used to compare planting treatments for the average temporal water retention mean ± standard error. The result of the ANOVA test was significant with p-value<0.05. This bar graph shows the overall ecosystem service performance for the average temporal mean for water retention for all treatments (n=152). Bars that share a letter are not significantly different.

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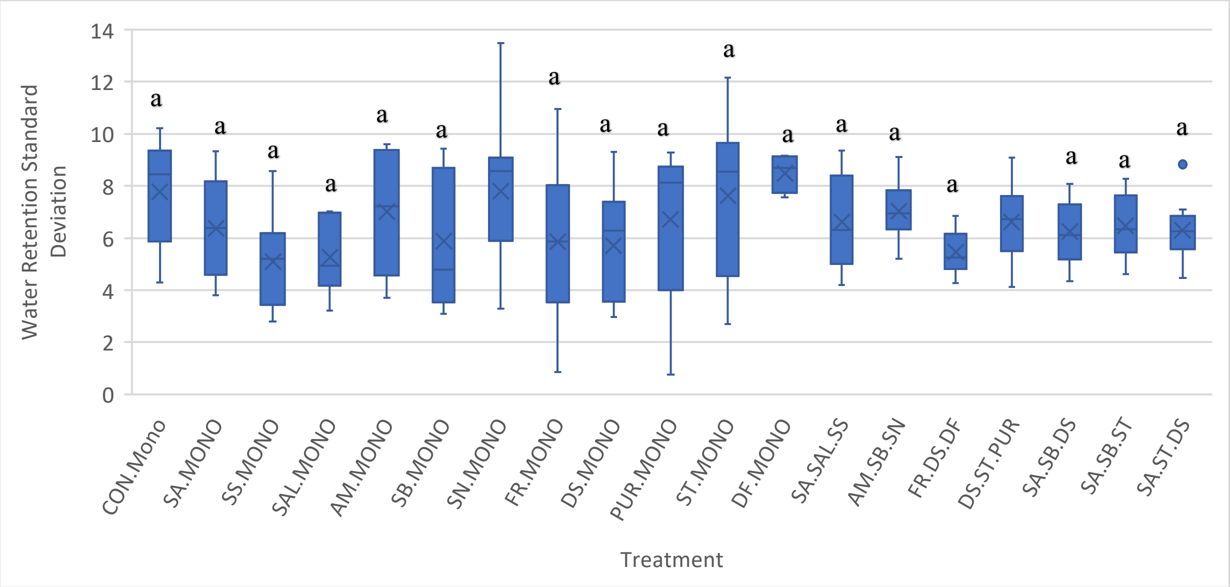

Figure 11. A one-way mixed model ANOVA, with "block" as a random effect was used to compare planting treatments for the average temporal standard deviation for water retention mean ± standard error. A coefficient of variation as an index of temporal variability was used to erase the effect of the mean. The result of the ANOVA test was not significant with p-value>0.05. The graph shows the temporal stability of ecosystem services for the average temporal standard deviation for water retention for all treatments(n=152). Bars that share a letter are not significantly different.

For canopy density, monoculture treatment SS (42.10±4.53) had a significantly higher mean canopy density than all treatments except for monoculture treatment FR (38.25±4.53) (Figure 12). Monocultures have the greatest temporal stability for canopy density (Figure13). The mixture treatments AM.SB.SN (0.834±0.132) and FR.DS.DF (0.808±0.132) were significantly less consistent in canopy density temporal stability than monocultures excluding AM (0.640±0.164) treatment (Figure 13).

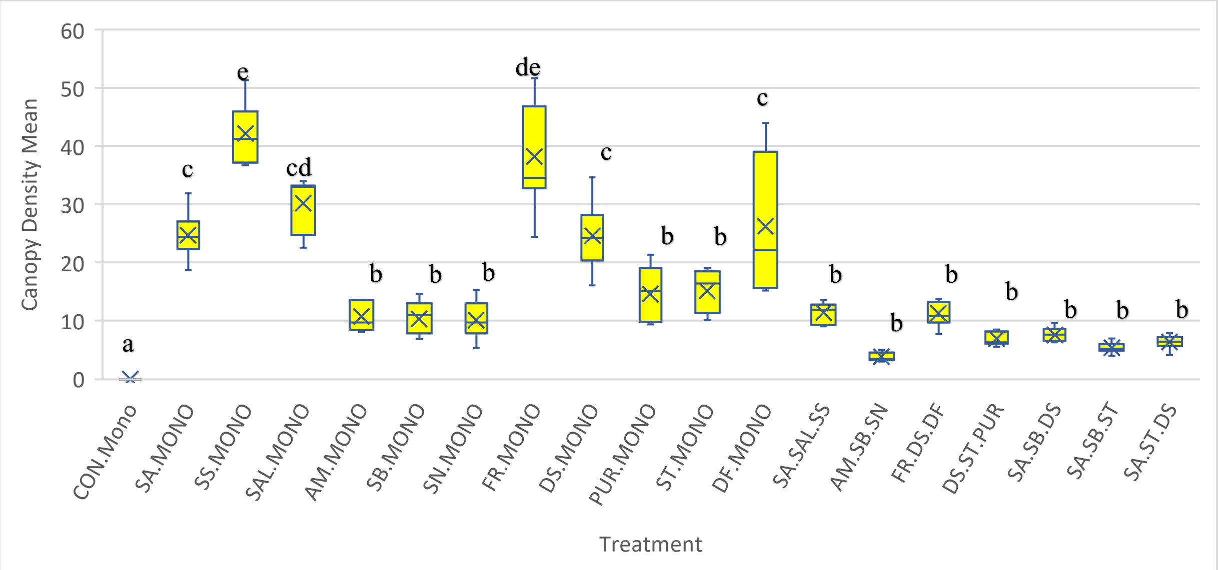

Figure 12. A one-way mixed model ANOVA, with "block" as a random effect was used to compare planting treatments for the average temporal canopy density mean ± standard error. The result of the ANOVA test was significant with p-value<0.05. This bar graph shows the overall ecosystem service performance for the average temporal mean for water retention for all treatments (n=152). Bars that share a letter are not significantly different.

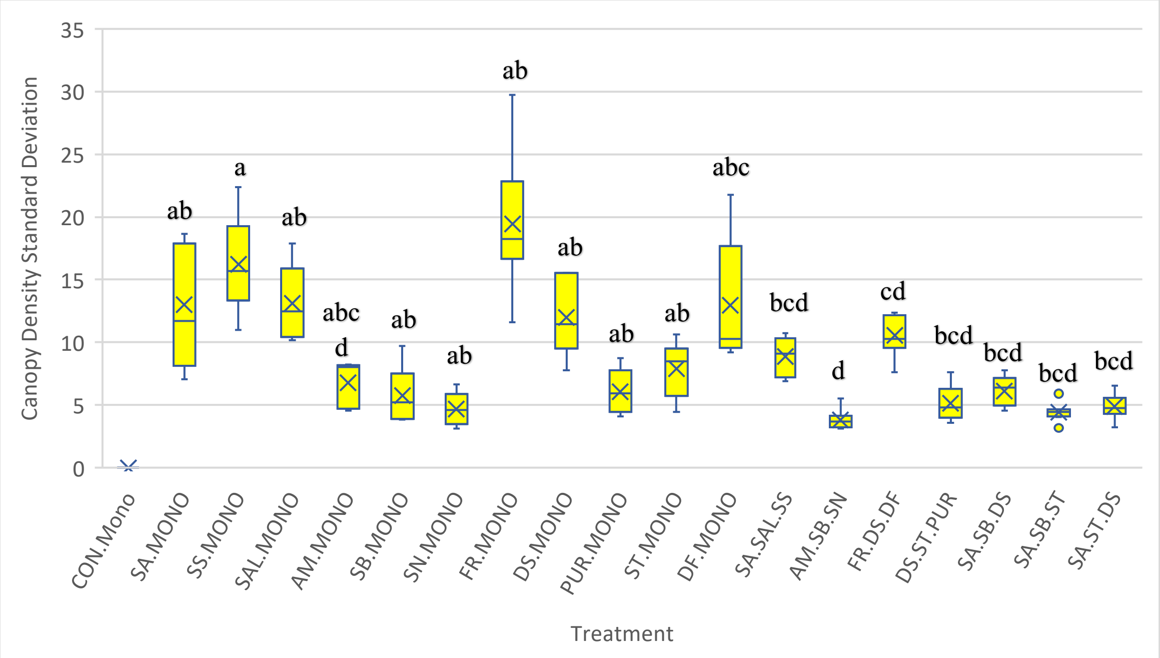

Figure 13. A one-way mixed model ANOVA, with "block" as a random effect was used to compare planting treatments for the average temporal standard deviation for canopy density mean ± standard error. A coefficient of variation as an index of temporal variability was used to erase the effect of the mean. The result of the ANOVA test was significant with p-value<0.05. The graph shows the temporal stability of ecosystem services for the average temporal standard deviation for canopy density for all treatments(n=152). Bars that share a letter are not significantly different.

4.0 Discussion

4.1 Linear Regression

Two response variables, height mean and standard deviation, had negative relationships with functional divergence (Fdis) within the plant community (Table 3). The results also showed that canopy density mean and floral abundance had weak negative relationships with Fdis (Table 3). These results contrast with the prediction that Fdis should be positively correlated to ecosystem service provisioning and I found that none of the ecosystem service indicators was positively correlated with Fdis. Potential reasons for these negative correlations could be combining the five functional traits into one measurement (Fdis), using functional traits that aren't good ecosystem service predictors, only looking at functional divergence index, and functional traits may be poor predictors of ecosystem services.

Combining all five traits together to generate the index of functional dispersion (Fdis), may include traits that do not affect ecosystem services or affect them in opposite ways. Using the combined index could obscure any positive correlation between a dispersion in a single trait and the response variable. Additional analysis should be done for each trait to compare single functional divergence values to each ecosystem service. Those functional divergence variables could be predictors of any of the ecosystem services. A study by Mason et al. (2005) stated that when measuring functional diversity using multiple characters, you must ensure that the functional characters used are not directly correlated because this may result in high or low values of functional diversity. To ensure that this wasn't a factor the data could be reanalyzed to compare each individual trait to each response variable. This could result in a positive correlation between functional dispersion in certain traits and certain response variables and show that some traits can be used as predictors for ecosystem service provisioning.

Several of the functional traits chosen for this study have been shown to be good predictors of ecosystem services (Reich 2012; Bardgett et al. 2014). Determining which of the traits analyzed were positively correlated with functional diversity, if any could result in finding a good predictor of ecosystem services. Comparing the data collected to other functional traits that weren't used in this study could also show that one of them would be a good predictor for ecosystem service provisioning. This would be helpful in future green roof research and help with choosing the plant species that work best together, while providing the most ecosystem services.

This study looked at the functional groups and how different or similar their functional traits were. Functional diversity has been generally accepted to consist of three independent components- functional divergence, functional richness and functional evenness (Mason et al. 2005). Only looking at the functional divergence index could have affected the results. Functional richness has been defined as the amount of functional trait space filled and functional evenness is defined as the evenness of abundance distributed in filled trait space (Mason and Mouillot 2013). When looking at divergence we assumed all three indices are independent from one another. A study by Villéger et al. (2008) showed that none the three indices were able to meet all the criteria for functional diversity and you need the combination of all three to being able to predict ecosystem functioning. The results could be reanalyzed using all three indices and that may lead to a positive correlation.

Using functional traits to predict ecosystem services might be hard because they aren't consistent or there might be other factors to be aware of. A study by von der Plas et al. (2020) results suggest that there is a limit to what functional traits can predict for long-term biodiversity. Analyzing the abiotic factors might improve the prediction of ecosystem services that the community can provide (von der Plas et al. 2020).

4.2 ANOVA

The results of the ANOVA test on all ten response variables showed that nine out of the ten had significant differences in the performance of ecosystem services among planted treatments. There was no significant difference in water retention standard deviation. When looking at the temperatures average temporal means it showed that the mixture treatment DS.ST.PUR (24.2±0.7) is significantly cooler than all other groups except for SA.SAL.SS (25.3±0.6) and FR.DS.DF(25.4±0.7) (Figure 4). This was interesting because the DS (26.4±0.7), ST (27.5±0.7) and PUR (27.1±0.9) monoculture treatments all had higher temperatures than DS.ST.PUR (Figure 4). This shows that when these three species are planted in the same community, they lower soil temperature between 0.8 to 3.3 degrees Celsius. A study by Lundholm et al. (2010) showed that combining three different plant species containing *Danthonia spicata, Sedum spurium* and a forb decreased the temperature of the soil more than any of the monocultures. This compliments the findings of this study by showing mixture treatments containing different groups of plants will usually outperform monocultures. For temporal stability of soil temperature, most monoculture treatments significantly had more temperature temporal stability than mixture treatments (Figure 5). Most monoculture treatments had more temporal stability than the control but monocultures ST (6.49±0.41) and SN (6.61±0.4) (Figure 5). This shows that more diverse communities usually can lower soil temperature and be more consistent in lowering soil temperature than monocultures.

The ANOVA test showed that the monoculture treatment SA (47.212±4.708) had roughly twice as much floral abundance than all other treatments (Figure 6). All treatments that contained SA had a higher floral abundance compared to those without SA (figure 6). To ensure that floral abundance is high in a plant community for pollinators and other species that use flowers for shelter or nutrients; the species *Sedium acre* should be included. All mixture treatments tended to have a longer flowering duration then monocultures, even though they weren't significantly different (Figure 7). This shows that having different species that flower at different times will allow for pollinators to have longer access to this food source.

Height is an important trait that is correlated with many ecosystem services such as stormwater retention, substrate cooling, substrate winter temperature increase and reducing UV light (Lundholm et al. 2015). The monoculture treatments FR (46.99±3.81), DF (34.88±4.58) and DS (25.59±3.77) were significantly the tallest (Figure 8). The mixture treatment containing all three grass species FR.DS.DF (23.74±3.77) outperformed all other mixture treatments and monocultures except the three monocultures FR, DF and DS (Figure 8). Several of the mixture treatments were significantly more consistent in height temporal stability than some of the monocultures (Figure 9). This data shows that plant communities that are more diverse have a steadier growth in height than monocultures.

Storm water runoff is a problem in urban areas and green roof help with this problem by retaining and using some of the water (Burszta-Adamiak et al. 2019). The results for mean stormwater retention showed that mixture treatment AM.SB.SN (15.53±2.99) was statistically better at water retention than monoculture treatment SS (9.57±2.99) (Figure 10). The data also showed that all mixture treatments had higher water retention than monocultures and control treatments (Figure 10). All monocultures had less water retention than control treatment. This shows that not only do mixture treatments increase water retention, but having only one species can decrease water retention. There was no significant difference in water retention standard deviation among treatments (Figure 11). There was significant difference but several of the monoculture treatments were less consistent at retaining water than the control treatment (Figure 11).

The ANOVA test showed that canopy density for monoculture treatment SS (42.10±4.53) had a significantly higher mean canopy density than all treatments except for monoculture treatment FR (38.25±4.53) (Figure 12). A study by Lundholm et al. (2015) results showed that grass species tend to have higher canopy density and *Festuca rubra* had the highest canopy density. Several of the monoculture treatments had more canopy density than mixture treatments (Figure 12). Monoculture treatments have the greatest temporal stability for canopy density (Figure13). The mixture treatments AM.SB.SN (0.834±0.132) and FR.DS.DF (0.808±0.132) were significantly less consistent in canopy density temporal stability than monocultures excluding AM (0.640±0.164) treatment (Figure 13).

The results have several mixture treatments that outperform most of the monoculture treatments. To determination of the best mixture treatment from this data, we looked at the four means for height, water retention, canopy density and soil temperature because grass data was not collected for floral abundance and flowering duration. There were two mixture treatments that seemed to overall outperform all other mixture treatments. The first mixture treatment FR.DS.DF was the tallest mixture treatment (23.74±3.77), the third lowest soil temperatures (25.4±0.7), the fourth for water retention (14.99±2.98) and best mixture treatment for canopy density (14.2±4.53). The other mixture treatment SA.SAL.SS was one of the shortest treatments (10.79±3.77), second for soil temperature (25.3±0.7), the second for water retention (15.19±2.98) and second-best mixture treatment for canopy density (14.15±0.4.54). These would be considered the best two mixture treatments and depending on which ecosystem services you believe are more valuable, that would determine which treatment you would choose. Mixture treatment FR.DS.DF would provide better canopy density and taller plants. Mixture treatment SA.SAL.SS would provide lower soil temperatures and more water retention. Other factors to determine which treatment is better could be that succulents are drought resistant (Li and Yeung 2014) and they produce flowers that are not wind pollinated, which allows for pollinators to visit them for nutrients and shelter (Colla et al. 2009).

A study by Li and Yeung (2014) stated *Sedum spp.* have been able to survive around 113 days without watering depending on soil types. This would make Sedum spp. an ideal choice on green roofs, especially in dryer areas. Grass species need more water to be able to survive than *Sedum spp.* All of the Sedum spp. used in this study have flowers that pollinators can use for nutrients and shelter, while the grass species are typically wind pollinated (Colla et al. 2009). Mixture treatment SA.SAL.SS was fifth highest in floral abundance (47.212±4.708) and flowering duration (3.244±1.097). Even though other mixture treatments outperformed mixture treatment SA.SAL.SS in floral abundance and flowering duration, none of those treatments outperformed in the other response variables.

5.0 Conclusion

This study aimed to look at functional traits as a predictor of ecosystem services by using a functional divergence index. Another objective of this study was to compare mixture treatments and monoculture treatments to see which provided better quality and more ecosystem services. Functional diversity was not positively related to any of the ecosystem services. The results did show that several of the species mixture treatments outperformed the best monoculture treatments. Several studies concluded similar results that more diverse plant communities provide more and better-quality ecosystem services than monoculture communities (Lundholm et al. 2010, Bello et al. 2013, Marafa et al. 2019). The two best mixture treatments in this study were SA.SAL.SS and FR.DS.DF. I do believe mixture treatment SA.SAL.SS would perform more ecosystem services than FR.DS.DF because the treatment also has the ability to produce flowers that can aid in nutrients and shelter for avian and invertebrate species (Coffman and Davis 2005; Colla et al. 2009). Additional research on functional divergence as a predictor for green roof ecosystem services needs to be conducted.

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