Evaluation of Survivability of Different Landscape Plants in Various Wet Feet Conditions

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Abstract

Extreme flooding and soil saturation testing of various plant types at Ozbreed were conducted over a decade, with the last few years witnessing six flood events. Rapid urbanisation has severely impacted the environment, particularly in urban areas, where it has resulted in erosion, nutrient loss, biodiversity loss, and other problems. To address these problems, careful landscape planning is necessary, including selecting suitable plants that can endure extreme conditions and help to restore biodiversity. Recent heavy rain and flooding has highlighted plant loss due to extended wet conditions. Finding plants that survive in both excessively wet and dry is highly topical. This study provides research results that can help Landscape professionals choose the right plant for wet and dry conditions. Three testing areas were considered, heavy clay-type soil, a bio-retention swale, and a floodplain. Results showed that Evergreen baby and Shara *Lomandra* varieties thrived in heavy clay-type soil, and using Phyto guard and Rhizovital treatment methods can increase the survival rate of Tanika *Lomandra* in wet feet conditions with root rot diseases. Results revealed the best plants in bio-retention swales, such as *Callistemon* and *Westringia* varieties. Results also showed what plants to avoid planting in floodplains such as some *Acacia* and *Lomandra* varieties.

In conclusion, this study provides key recommendations for landscape planners to successfully plant in wet feet conditions, floodplains, and bio-retention swales. The recommended plants include *Callistemon*, *Lomandra*, *Westringia*, *Nandina*, and *Raphiolepis*, among others.

Keywords: *Landscape plants, flood plains, bio-retention swale, wet feet*

Chapter I

Introduction

A. Background of the Study

Ecosystems have been negatively impacted by rapid urbanisation. And with humans having evolved into an urban species, more and more areas are unfortunately being developed into urban cities (Rastandeh and Jarchow, 2020). Urbanisation, in turn, has hugely altered land use, disrupted hydrological networks and significantly reduced biodiversity (Kazemi et al., 2010). This inevitable and exponential loss of biodiversity in urbanised natural landscapes is evident in one study (Morash, 2016). Moreover, urbanisation has also proven to dramatically affect a species' natural habitat in a certain area (Elmqvist et al., 2013) – it can have a colossal impact on watersheds, giving them increased nutrient and contaminant concentrations, heavily altered hydrology, and diminished groundwater supplies (Morash, 2016). With the threat of irreversible environmental damage coming from urbanisation, there arises a need to offset these impactful effects.

One way to effectively address the myriad negative impacts of rapid urbanisation is to tackle biodiversity loss, and this can be done through urban landscaping. Biodiversity enhancements have proven to be a great solution to minimise the effects of urbanisation (Kazemi et al., 2010). Through urban landscaping, biodiversity can be preserved in highly urbanised areas, or at least significantly reduce biodiversity loss. Urban landscapes can also provide aesthetic and economic benefits to those living in urban areas. Therefore, planning how to build urban landscapes to enhance biodiversity is important.

The first thing to know is what species can survive in urban landscapes. Landscape plants are usually low-maintenance plants used to provide aesthetics to a certain landscape, as well as to provide functionality, including erosion protection, nutrient absorption, and other engineering solutions. Landscape plants also add to the biodiversity in an urban setting. Landscape artists use both exotic and native plants in landscaping, typically making of use of trees, shrubs, annuals, perennials, and other ground covers.

Trees are the tallest landscape plants used (Damask, 2020). They provide shade and aesthetics for a landscape. They may also be used as support structures for other plants. Typical trees used are evergreen and deciduous trees. Evergreens have all-year-round foliage, while deciduous trees shed their leaves during the cold season.

There are also shrubs, which are often called small trees (Smith, 2021). They have compact and dense foliage used for foundation and mass planting (Smith, 2021, Damask, 2020). Landscape shrubs that are often used commercially can either be *Callistemon* or the bottle brush, *Westringia*, or *Grevillea*.

Another kind of plant used in landscaping are annuals, which, like the aforementioned, provide aesthetic ornamentals when in season (Damask, 2020). However, these plants have only one season in their life cycle. Therefore, annuals would need to be replanted yearly (Smith, 2021). Common annuals include cosmos, sunflower, nasturtium, and morning glory.

Meanwhile, perennials are considered the backbone of a landscape (Smith, 2021). These are plants that can live for more than two years. Some perennial plants are hibiscus, lavender, roses, and periwinkle. Meanwhile, Biennial plants usually grow foliage in the first year and then flower in the second year. Some biennial plants are foxglove and dianthus. However, deciduous shrubs, as well as annuals, are not popular and not often used commercially in Australia, given that many perennials live and thrive in the said area.

Lastly, there are grasses used for landscaping, which are called ornamental grasses. They are different from the types of grass used in lawns and backyards. Ornamental grasses are primarily used to add texture and height to a landscape mixed with annual flowers when used in mass plantings (Damask, 2020). One example of ornamental grasses is the coast-tussock grass.

Meanwhile, strappy leaf plants are grass-like plants that have a thicker, more ridged leaf, and generally do not seasonally die back like grasses, often staying evergreen in winter in Australia. Some examples are Lomandra and Dianella. Ground covers can also provide good landscape coverage, as they add a different texture to the aesthetics of a landscape. Some ground covers include plumbago and English ivy.

Landscape designs should be well thought of before implementation. In doing so, the possible implications of using certain varieties of landscape plants must first be known to ensure the synergy of the environment and the landscape being developed. Akron Beacon Journal (2013) outlined the functions of plants when used in landscaping, which include architectural, climate control, and aesthetic functions.

The architectural functions of plants such as trees and shrubs include their usage as covers and shade providers in a certain landscape. Trees can also be used for the privacy of private establishments. Some plants can also diffuse sounds due to their foliage adaptation to the environment. Others are used for their psychological effect, which helps maintain order in a certain area.

Plants can also have climate control functions – the foliage of trees can diffuse solar radiation, providing a cooler temperature on the ground. Meanwhile, shrubs can also function as windbreakers. The more diverse the plants in a certain landscape are, the better the air quality and temperature are in that area.

However, many people believe that landscape plants' primary function is to improve the aesthetics of the landscape. This is why designing a landscape is not only affected by which plants need to be used but also how these plants will look together. Aesthetic cohesion in colour, form, and texture is considered when choosing landscape plants (Brown, 2015).

B. Significance of the Study

In recent years, there has been a significant increase in flooding events worldwide. Severe flooding events result in heightened environmental alteration of different landscapes, especially those in urban areas. These floods can provide a competition-free space for vegetation to occur

(Uchida et al., 2022). However, a way to prevent this competition-free scenario is to find a variety of plant species that can not only survive in these heavy wet feet conditions but thrive in them. Determining which plants can thrive in these conditions is crucial for developing a resilient landscape in severe weather conditions.

This is because in Australia, many landscapes that become inundated regularly when rains are frequent, also become ravaged by severe drought in dry times. Some example situations like this include bio-retention swales and rain gardens, adjacent areas that get runoff from hard surfaces such as roadsides, or below paths, flood plains or towns that can flood, green walls and green roofs, or general landscapes that get too wet when heavy rainfall patterns occur, or excess irrigation is provided, then get too dry when drought occurs, or the irrigation is changed.

In general landscapes across Australia, the landscape trade is currently facing large-scale deaths of plants. Some plants that have been alive for 20 years or more are dying due to excess rainfall in parts of Australia. Conifers for example are suffering in these wet parts, so finding plants that survive in both excessively wet and dry conditions is highly topical, and this study provides research results that can help landscape professionals choose the right plant for wet and dry conditions.

C. Objectives of the Study

The main objective of this study is to identify which plants can survive in plots in extreme wet conditions. The specific objectives are:

- To determine which type of *Lomandra* species are suitable for heavy wet soils;

- To identify the plants suitable for plots such as bio-retention swales; and
- To assess which plants can thrive in extreme flooding conditions.

D. Scope and Limitations of the Study

This study is limited to landscape plants that can be grown in Australia. These plants include common varieties, comparator plants, and varieties developed by Ozbreed. Table 1 lists the genus of the plants considered in this study. The study focuses on the survivability of the plant varieties grown in each testing area. Though all the testing areas are observed to be heavy wet soils, the amount of moisture in each soil plot was not recorded.

Table 1. Landscape plants used in this study.

Acacia	*Dietes*	*Melaleuca*
Agapanthus	*Eremophila*	*Murraya*
Aloe	*Eucalyptus*	*Myoporum*
Alopecurus	*Fraxinus*	*Nandina*
Baeckea	*Gardenia*	*Orange*
Buffalo	*Gazania*	*Ozothamnus*
Callistemon	*Grevillea*	*Pennisetum*
Callistris	*Hibbertia*	*Phormium*
Camelia	*Imperata*	*Pimelea*
Casuarina	*Kunzea*	*Plectranthus*
Cordyline	*Liriope*	*Raphiolepis*
Cupaniopsis	*Lomandra*	*Westringia*
Dianella	*Magnolia*	*Zoysia*

Chapter II

Review of Related Literature

Floods are one of the major natural threats to plants (Pucciariello et al., 2014). These occurrences have been found to decrease the accumulation of biomass and increase plant deaths (Pires et al., 2018). Dixon (2003) has found that extreme floods significantly impact all vegetation in flooded areas. Numerous studies have explored the different factors affecting the impact of floods on plants.

A. Flood impact on the regional and total flooded areas

Zhang et al. (2021) categorised these factors into six: temperature, plant age, flood velocity, geomorphic change, plant height to flood depth ratio, and waterlogging tolerance time to flood duration ratio. They studied extreme flood impacts by proposing two risk indices: unit risk biomass (URB), which represents the flood impact regionally, and total risk biomass (TRB), which represents the flood impact over the entire flooded area. They found out that URB varied with space in the flooded area. This means that flood impacts in some areas differ from other areas. They also found that both URB and TRB varied with time as different crop species and parameters were present because of the changing seasons.

B. Effect of flooding water temperature on plant growth

Setter and Waters (2003) studied the possible germplasm improvement for waterlogging tolerance in wheat, barley, and oats. In this study, they found that soil, air, and water temperatures affect plant growth. The general trend they observed was at higher temperatures, the oxygen depletion in plants increases. This oxygen depletion affects the growth of wheat, barley, and oats adversely.

Auchincloss et al. (2012) studied the effects of inundated temperatures on the growth of Fremont cottonwood. They found that at higher water temperatures during complete waterlogged conditions, the mortality rate of Fremont cottonwood seedlings increased to 64% as compared to the 39% mortality rate at lower water temperatures.

Another study by Wang et al. (2017) examined the effects of waterlogging on the growth, yield, and quality of cotton in China. During their experiment, the highest temperature recorded was 36℃. They inferred that high temperatures after waterlogging can cause a significant decrease in cotton yield. They based their inference on a paper by Najeeb (2015) which links higher temperatures with oxygen depletion. In the paper, he explained that at high temperatures, there will be significant oxygen depletion which in turn accelerates the respiratory activity of cotton root. This result agrees with the results observed by Setter and Waters (2003).

Meanwhile, Gattringer et al. (2017) explored the influence of flooding water temperature on the growth of floodplain meadow species. They found out that summer floods may have more significant detrimental effects on floodplain meadow seedlings. This led to the conclusion that temperature is directly proportional to the damage of flood to floodplain meadow species growth.

Based on the studies described above, plants tend to have higher mortality rates when they are submerged in water at higher temperatures. The primary reason for this is that higher temperatures accelerate oxygen depletion in plants.

C. Effect of erosion on plant loss risk

Dixon (2003) studied the effects of the flow pattern of the river on riparian seedlings. One of the key findings was that at summer peak flows, there is a decrease in the survival rate of newly germinated and older seedlings. He discussed that the decrease in survival rate can be attributed to high shear stress caused by soil erosion during the peak flow as well as anoxic conditions brought about by prolonged submergence in water.

Meanwhile, Kui et al. (2018) studied the effects of erosion on the risk of plant loss during floods. They observed live cottonwood and tamarisk seedlings in a simulated flume setup. They found out that floods that occur in sediment deficit conditions increase the risk of plant loss by 35% due to bed degradation. Typical sediment deficit conditions can occur downstream of dams which greatly erodes the soil when flooding occurs. Therefore, based on their result, erosion due to flood has an inverse proportionality with the survival rate of plants.

From these two studies, it can be generalised that erosion increases the mortality rate of plants during extreme waterlogged conditions. The shear stress and bed degradation due to erosion adversely affect the mortality of plants.

D. Relationship between plant age and survivability of plants

Zaidi et al. (2004) studied the tolerance of *Zea mays L.* to excess moisture. Their experiments showed that maize is highly susceptible to excess moisture, especially before the tasseling stage. However, at the latter stages of the plant, this susceptibility decreases. This can be attributed to the poorly developed brace roots at the early stages and enhanced anoxic conditions caused by waterlogging.

Meanwhile, Stokes (2008) observed the population dynamics of invasive black willow in Australia in different hydrological regimes. One of the key findings observed was the relationship between plant age and the survival rate of plants when exposed to extreme wet conditions. She found out that more mature plants can survive floods. Gattringer et al. (2017) also verified this when the relationship between seedling deaths and seedling age when submerged in floods was studied. They concluded that the risk of seedling death decreases as the seedling age increases.

E. Effect of flood velocity on plant survivability

Miyamoto and Kimura (2016) observed the tree population dynamics on a floodplain near the Kako River in Japan. They found that flood velocity changes depending on the peak discharges of the river that floods the floodplain. The data also showed that flood velocity decreases in areas with a large number of trees. Zhang et al. (2021) inferred that a high flood velocity can cause a high risk of soil erosion since higher velocities are observed with lower tree populations. From these observations, they concluded that flood velocity directly affects the mortality rate of plants.

F. Relationship between flood depth and plant mortality

Higgisson et al. (2008) studied the responses of nitre goosefoot to the depth of experimental flooding. The plants in the experiment were subjected to three depths of experimental flooding (10cm, 50cm, and 75cm). They found that nitre goosefoot plants can survive flooding as long as the plants are not submerged completely. The leaf production of nitre goosefoot plants increased as well when submerged in shallow flooding.

Auchincloss et al. (2012) also studied the effects of inundated depth on the growth of Fremont cottonwood. Their results showed that completely submerged plants have a higher mortality rate than the control plants with no inundation and plants inundated to the soil surface.

Their results also showed no significant difference in mortality rates of the control plants and the plants inundated to the soil surface.

Both the studies above showed that plants can survive inundated conditions as long as the plants are not fully submerged. Meanwhile, low flood depth has no significant effect on the survivability of plants.

G. Effect of flood duration on the survivability of plants

Kramer et al. (2008) studied the effect of flooding in terms of damage and mortality of adult trees found in floodplains. Their study revealed that several riparian tree species have increased mortality rates with the increasing flood duration while some species such as Salix spp. and Populus spp. have no mortality in both the flooded and unflooded areas. The results also showed that flooding duration has the most effect on the damage and mortality of trees.

In another study, Vreugdenhil et al. (2006) observed six different wood species found in nature reserves along the Lower Rhine in the Netherlands. They found that with increasing flooding duration, there is also a decreasing presence of hardwood species. Their study also revealed the increased presence of softwoods with increased flooding, more when it happened during March-October, which is considered the growing season. For most species, it is observed that the duration of inundation was the best explanatory variable.

Meanwhile, McDaniel et al. (2016) studied the response of corn roots to flooding and their recovery after the said situation. Results showed that the observed plants showed a cease in growth within 24 hours, and recovered after three (for corn root) to five days (for root mass). Their study also showed that there is a significant decrease in root mass only after reaching more than 35 days of inundation.

These studies mentioned above showed that flood duration can greatly affect plant growth and recovery. It was also found out that certain plant species can survive long durations of inundation, while some can survive depending only on the season and other variables.

Chapter III

Methodology

Three testing areas were considered in the study. The survival of the plant species grown in each testing area was observed. Results were then discussed based on the survival rate of the landscape plants in each testing area.

A. Plant species considered and used in the experiment.

Different field experiments were conducted to find the survival responses of various landscape plants in heavy to extreme wet conditions. The plants planted in testing area 1 are 16 *Lomandra* varieties, three *Liriope* varieties, and one *Eremophila* variety. Meanwhile, there are 30 varieties of different plants that were planted in testing area 2. Table 2 lists the plants that were planted in testing area 2. A total of 84 varieties of different plants were planted in testing area 3. The following table lists the plant varieties observed in testing area 3.

Table 2. List of Plants Observed in Testing Area 2

Plant type	Variety
Callistemon	Better John™ *Callistemon viminalis* 'LJ1'
Callistemon	Green John™ *Callistemon viminalis* 'LJ23'
Callistemon	Macarthur™ *Callistemon viminalis* 'LC01'
Callistemon	Slim™ *Callistemon viminalis* 'CV01'
Dianella	Little Jess™ *Dianella caerulea* 'DCMP01'
Dianella	Lucia™ *Dianella caerulea* 'DC101'
Elymus	Couch
Liriope	Amethyst™ *Liriope muscari* 'LIRTP'
Liriope	Just Right® *Liriope muscari* 'LIRJ'
Lomandra	Shara™ *Lomandra fluviatilis* 'ABU7'
Lomandra	Lucky Stripe™ T *Lomandra hystrix* 'LMV200'
Lomandra	Evergreen Baby™ *Lomandra labill.* 'LM600'
Lomandra	Tanika® *Lomandra longifolia* 'LM300'

Lomandra	Trophic Cascade™ *Lomandra hystrix* 'LHWP'
Lomandra	Katie Belles™ *Lomandra hystrix* 'LHBYF'
Lomandra	VitraTech *Lomandra*
Nandina	Obsession™ *Nandina Domestica* 'SEIKA'
Nandina	Blush™ *Nandina domestica* 'AKA'
Pennisetum	Kikuyu
Pennisetum	Nafray® *Pennisetum alopecuroides* 'PA300'
Rhaphiolepis	Cosmic Pink™ *Rhaphiolepis indica* 'RAPH02'
Rhaphiolepis	Cosmic White™ *Rhaphiolepis indica* 'RAPH01'
Tristaniopsis	Luscious® *Tristaniopsis laurina* 'DOW10'
Westringia	Ozbreed Aussie Box® *Westringia* 'WES08'
Westringia	Grey Box™ *Westringia fruticosa* 'WES04'
Westringia	Low Horizon™ *Westringia fruticosa* 'WES06'
Westringia	Mundi™ *Westringia fruticosa* 'WES05'
Westringia	Naringa™ *Westringia* 'WES01'
Zoysia	Nara Native Turf
Zoysia	Empire

Table 3. List of Plants Observed in Testing Area 3

Acacia binervia	*Hibbertia scandens*
Acacia cognata dwarf type	*Yalba*
Acacia implexa	*Kunzea baxteri*
Acacia melanoxylon	Isabella® *Liriope*
Acacia redolens	*Liriope* Just Right®
Acacia spectabilis	Katie Belles™ *Lomandra*
Acacia fimbriata	Katrinus deluxe™ *Lomandra*
Agapanthus	Lom 3pp.03 *Lomandra*
Agapanthus breeding trial	Lom 5.12 *Lomandra*
Aloe	Lom SS.03 *Lomandara*
Nafray® pennisetum alopecuroides	Lom3pp.07
Pennisetum alopecuroides	*Lomandra* 3RR.04 Shara™ Blue
Purple lea *Pennisetum alopecuroides*	*Lomandra* breed for wet feet in general breeding trial
Baeckea virgata breeding	Lucky Stripe™ *Lomandra*
Buffalo Grass breeding	Nyalla® *Lomandra*
Callistemon ground cover selection	*Shara*
Callistemon Slim	Tanika® *Lomandra*
Common *Callistemon spp*	Trophic Cascade

Green John™ *Callistemon*	*Magnolia*
Macarthur™ *Callistemon*	*Melaleuca linariifolia*
Red Alert™ *Callistemon*	*Melaleuca* Narrow form
Callitris Spp	*Melaleuca nesophila* Breeding selections
Camelia	*Murraya*
Casuarina cunninghamiana	*Myoporum insulare*
Casuarina glauca	Yareena™ *Myoporum*
Cordyline	Blush™ *Nandina*
Cupianopsis anacoides	Flirt™ *Nandina*
Breeze® *Dianella*	Obsession™ *Nandina*
Dianella breeding. Mainly *Dianella caerulea*, or cross breeds	Orange tree
Dianella Little Jess™	*Ozothamnus* Rice flower
Lucia Dianella	*Pennisetum alopecuroides* (Planted from 90mm pots 6 weeks prior to last biggest flood
Mixed *Dianella* breeding	Green Mist *Phormium*
Bannanna Split™ *Dietes*	Sweet Mist® *Phormium*
Dietes Fine Devine	*Pimelea*
Dietes Grand Star	*Plectranthus cillatis*
Blue Horizon™ *Eremophila*	Cosmic Pink™ *Rhaphiolepis*
Eucalyptus spp	Cosmic White™ *Rhaphiolepis*
Fraxinus Griffithii New breed	Grey Box™ *Westringia*
Gardenia	Mundi™ *Westringia*
Gazania	Zen grass *Zoysia spp*
Crimson Villea™ *Grevillea*	*Zoysia Spp* Turf breeding.
Grevillea	*Zoysia tenuifolia*

B. Testing Area 1: Flat land with heavy clay-type soil

To find out the variety of plant species that can survive in heavy clay-type soil, an area that receives ample water to have heavy clay-type soil was chosen. The area was relatively flat land below a production area of *Liriope*, grass-like flowering perennials. Since the soil is near the nursery, the area was always watered by water runoff from the nursery. However, the soil was irrigated when needed. Because of this, the soil remained saturated with water, and the chosen area is a known area where plants placed in the past had root rot diseases.

A preliminary trial was conducted in this testing area. Along with three varieties of *Liriope* planted in the area, four varieties of *Lomandra* and a variety of *Eremophila* were planted in the testing area to find whether *Lomandra*s can survive in wet feet conditions.

After the preliminary trial, there are four trials conducted in this testing area. A trial was conducted to determine which *Lomandra* type can survive wet feet. A second trial was conducted in lower elevations to test the survivability rate of *Lomandra* types in wet feet conditions and the presence of root rot diseases. Another trial was done using the best-performing *Lomandra* types, where plants of each type were planted on wet feet at a higher elevation. Lastly, a trial was conducted to determine which root rot treatment was the most effective.

C. Testing Area 2: Bioretention swale

Area 2 was aimed to mimic a bio-retention swale, with the goal of cleaning the water of nutrients and other contaminants. The chosen area was a drainage channel, where nursery water flowed from runoff into a dam for recycling. This area was always wet since it received runoff daily. After irrigation, the swale also had water with a depth of approximately 3 to 5 cm. Although area 2 had one designated area, another area was used as a test for planning purposes. The health of the landscape plants in this testing area was observed and was rated three times to assess which plants can thrive under these conditions.

D. Testing Area 3: Floodplain trial grounds

Unlike the first two setups, area 3 was a floodplain area originally used as grounds for new breeding trials since Ozbreed needed more space for testing. It was decided to risk using the area since it had not flooded for almost 30 years. The testing area included the floodplain area and also the slope above the floodplain. When the continuous rains and floods frequently came, the soil was often wet since this area had around 10 metres of water settled on it for approximately 2 weeks or more on multiple occasions. 6 flooding events occurred within 2 years, with most being major flood events. Since it was accidental, area 3 only had one evaluation. The survivability of each plant type was observed and recorded to see which plants can adapt in landscapes that can potentially have frequent floodings.

E. Statistical Analysis

To determine if the factors considered in this study are significant or not for the survival of the plants in wet feet, statistical analysis was done. Two-way ANOVA and Pearson correlation coefficients were used to analyze the data gathered in testing area 2 to determine if the variety used and the plant age have an effect on the survival rate of the plants on soils mimicking a bioretention swale. The correlation coefficient was also calculated for the data gathered from testing area 3 to determine if the number of floods has an effect on the survivability of the landscape plants on floodplains.

Chapter IV

Results and Discussion

A. Survivability of Selected wet feet tolerant *Lomandra* types in heavy clay-type soil in Testing Area 1

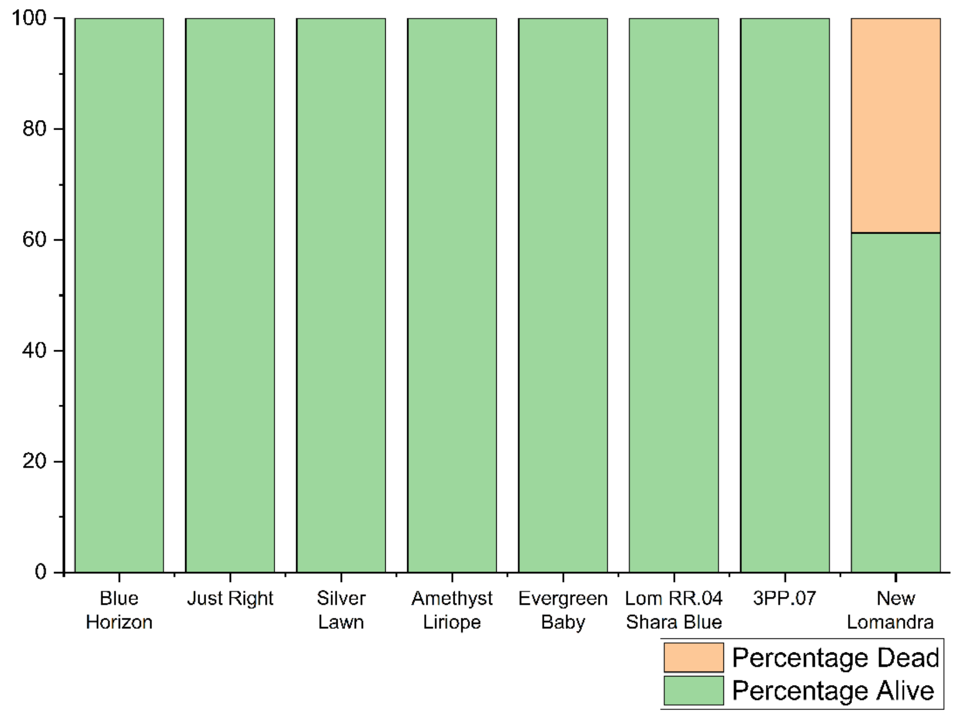

Figure 1. The survival rate of *Liriope*, *Eremophila*, and *Lomandra* varieties in testing area 1.

Figure 1 shows the survival of *Liriope*, *Eremophila*, and *Lomandra* varieties in testing area 1. The lone *Eremophila* planted in this testing area was Blue Horizon™ *Eremophila glabra* prostrate 'EREM1' PBR. This *Eremophila glabra* was specifically bred for wet tolerance. Only two mature plants were planted. The results show that this variety can withstand wet feet conditions with a 100% survival rate. Four *Lomandra* types were also planted in this testing area. 500 Evergreen baby plants, 12 Shara blue plants, 5 3PP.07 plants, and 12 male new *Lomandra* breeding plants were planted in this testing area. The results show that Evergreen baby, Shara blue, and 3PP.07 varieties all have a 100% survival rate. Meanwhile, the new previously untested *Lomandra* breeding plants had a 61.29% survival rate.

Three *Liriope* varieties were also planted in this testing area. 2000 Just right plants, 1000 Silver lawn plants, and 500 Amethyst plants were planted. The results show that *Liriope* varieties can thrive under bioretention swale-like conditions.

From these trials, all the landscape plants planted in this area were found to thrive under wet feet conditions except for the new *Lomandra* breeding plants. *Lomandra*s, *Liriope*s, and the Blue Horizon *Eremophila* can be used to provide biodiversity in these conditions.

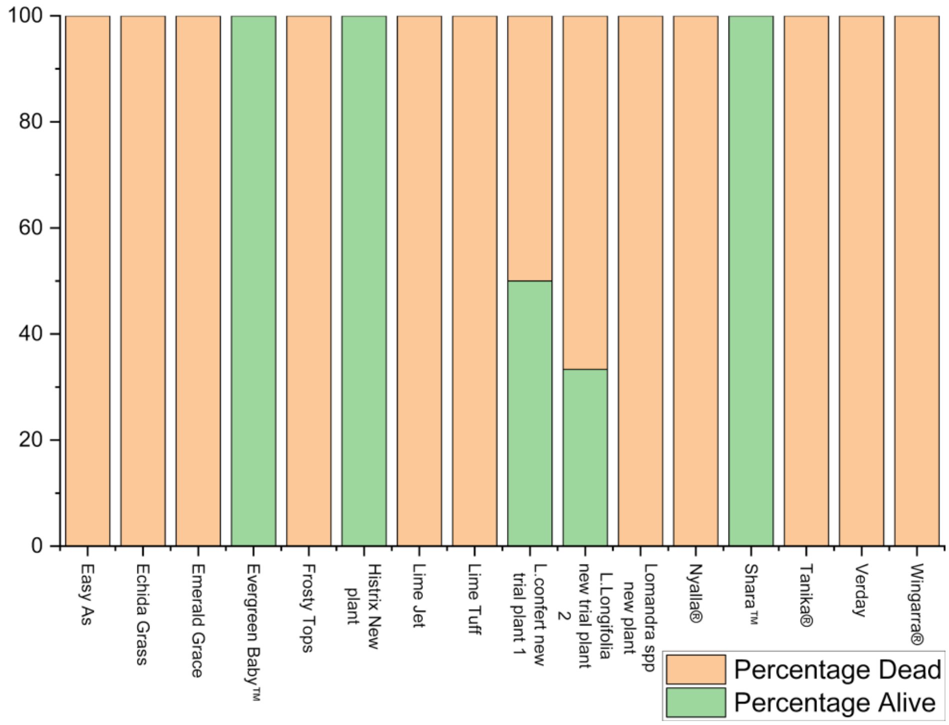

Figure 2. Trial 1 for heavy clay-type soil.

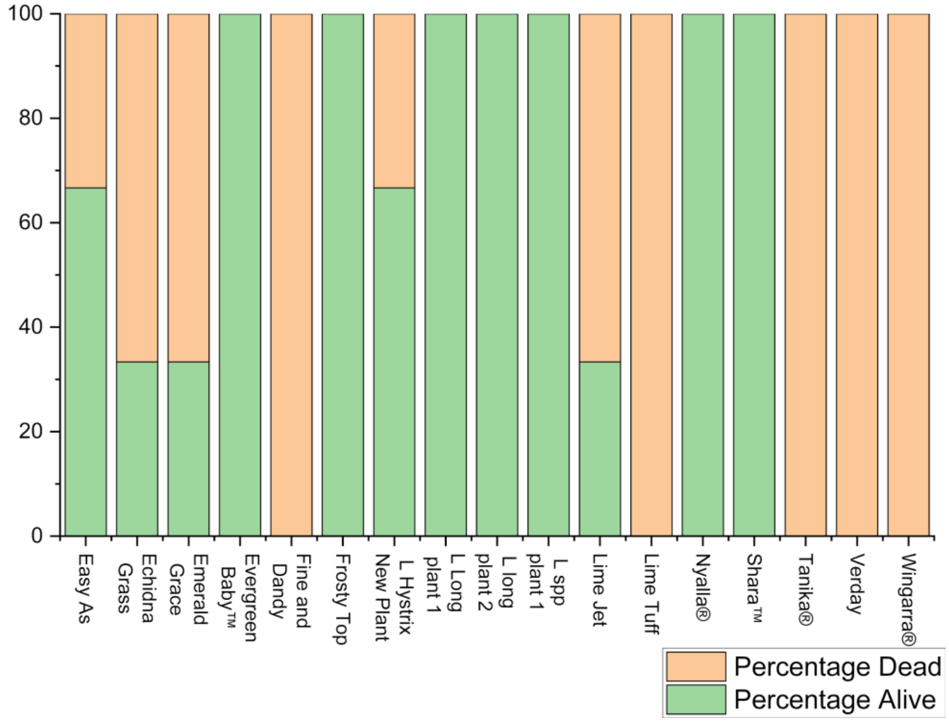

Figure 3. Trial 2 for heavy clay-type soil (lower elevation, presence of root crop diseases).

The goal of planting *Lomandra* types in this testing area is to find which varieties can survive in heavy wet soils. Commonly used *Lomandra* varieties were considered for this experiment. Figures 2 and 3 show the two trials done to assess which *Lomandra* varieties can handle periodic wet feet. From trial 1, Evergreen baby, Shara, and Selected Dwarf Hystrix plants showed a 100% survival rate. However, other *Lomandra* types exhibited a poor ability to survive in wet feet conditions. *Lomandra confertifolia* showed a 50% survival rate and *Lomandra* longifolia had a 33% survival rate. Meanwhile, other *Lomandra* types had a 0% survival rate.

In the second trial, the different *Lomandra* types were planted in lower elevations where the soil is known to have root rot diseases. The second trial showed better performance of other *Lomandra* types and a good performance against root rot diseases. Frosty Top, Nyalla, *Lomandra* long new trial plant 1 (which is a selection of swamp Lomandra longifolia types), *Lomandra* long new trial plant 2 (which is a selection of swamp Lomandra longifolia types), and *Lomandra* spp new trial plant 1 all showed a 100% survival rate. Evergreen Baby and Shara *Lomandra* varieties also showed a 100% survival rate. This result means that these two varieties can adapt well to wet feet conditions.

Meanwhile, the compact Hystrix variety showed a decrease in survival rate with a 67% survival rate compared to 100% in trial 1. Hystrix types are known for wet feet tolerance, yet this compact form is less tolerant, as such this plant has been discontinued. Easy As performed better in trial 2 with a 67% survival rate as compared to 0% in trial 1. Also, Echidna Grasses, Emerald Grace, and Lime Jet had a 33% survival rate in trial 2. This trial showed that both Evergreen baby and Shara exhibited strong resistance against root rot diseases as well as a high survival rate in wet feet conditions.

The two best performing *Lomandra* types, which are Evergreen baby and Shara, were planted in wet feet soil and higher elevation. The two types also showed a 100% survival rate. A total of 30 Evergreen baby plants and 1000 Shara plants survived the said condition.

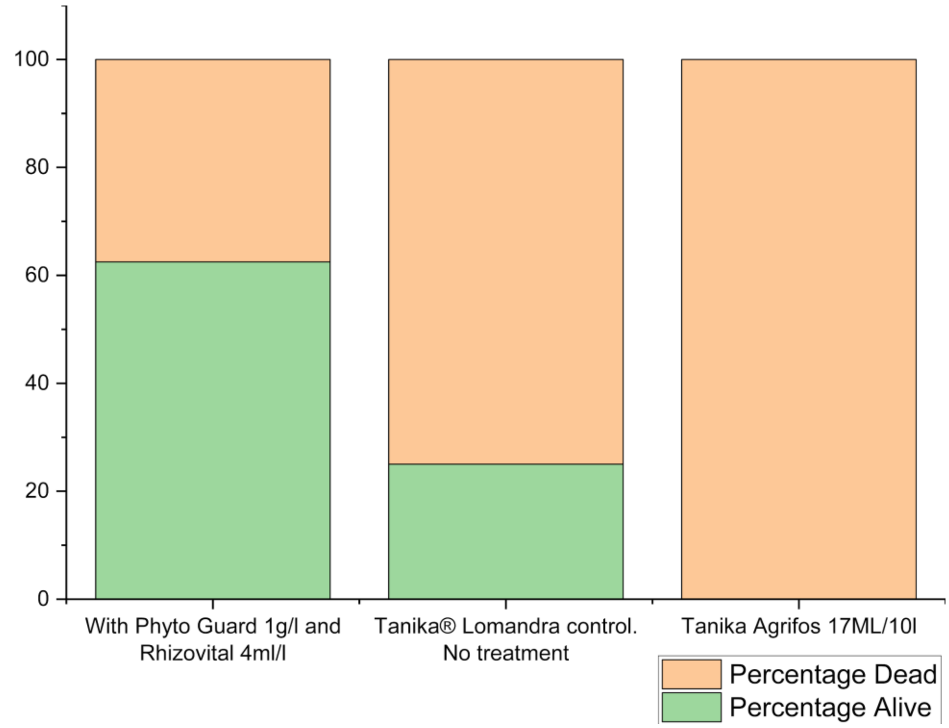

Figure 4. Root Rot Treatment Trial for Tanika *Lomandra* longifolia in wet feet conditions.

Another trial was done to test the root rot treatments. Tanika *Lomandra* longifolia plants were used in this trial, which is well known to do well on dry slopes, flat areas and non-wet feet conditions, and poorly in Sydney in humid wet conditions. Eight plants received no treatment, which served as the control for this trial. Another eight plants received 1 g/L of Phyto guard and 4 mL/L of Rhizovital for root rot treatment. Then, another eight plants received 1.7 mL/L of Agri-Fos as root rot treatment. Figure 4 shows the survival rate of the three conditions tested for root rot treatments. The plants with Agri-Fos did not survive. This means that Agri-Fos did not effectively prevent Tanika from having root rot diseases. Meanwhile, the control performed better, with a 25% survival rate. The plants with Phyto guard and Rhizovital performed the best, with a 62.5% survival rate.

The trials showed that *Lomandra* could be used by landscape designers in conditions that are periodically heavily saturated. The best *Lomandra* for this condition are Evergreen baby and Shara. Also, for heavily wet soils with root rot diseases present, using 1 g/L of Phyto guard and 4 mL/L of Rhizovital for Tanika *Lomandra* longifolia increases the survival rate of the plant in such conditions.

B. Survivability of different Landscape plants on soils mimicking a bioretention swale

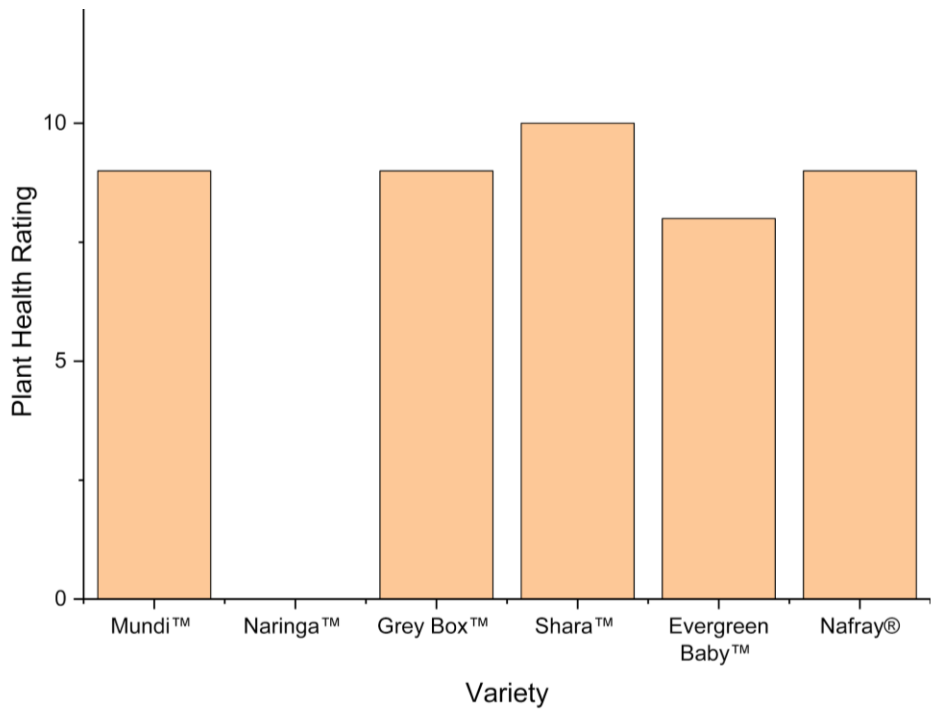

Figure 5. Plant health rating of different native varieties in the bio-retention swale.

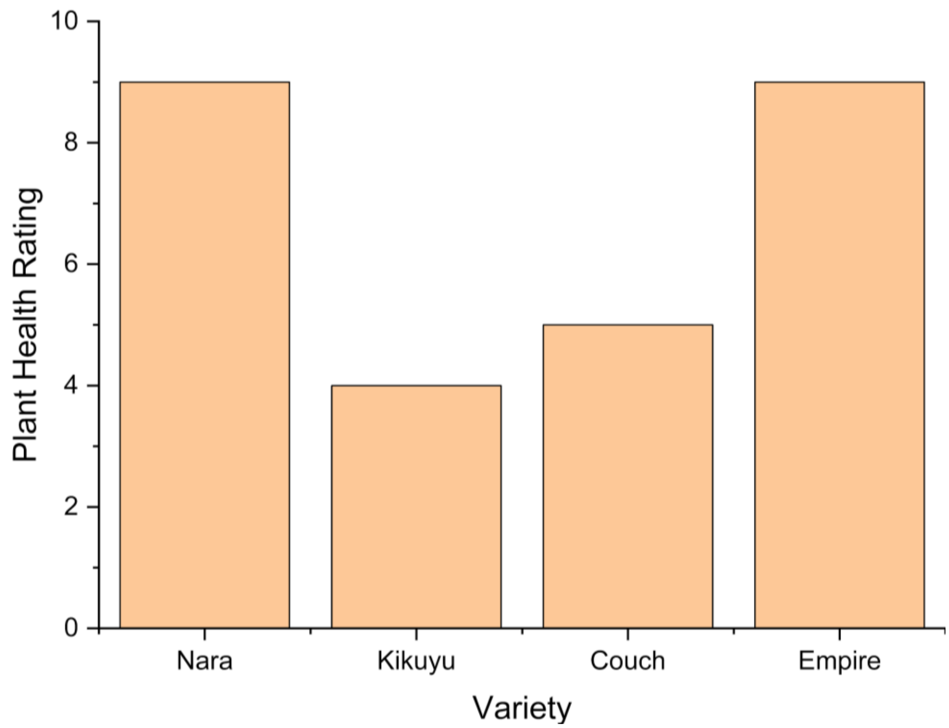

Figure 6. Plant health rating of different turf varieties in the bio-retention swale.

Figures 5 and 6 show the plant health rating of native plants and turf varieties in the bio-retention swale. The age of these plants is 9 years. These varieties served as the baseline of what plants to test on bio-retention swale conditions. Among the native varieties, only the Naringa™ *Westringia* 'WES01' did not survive under this condition. All the other native varieties had a good plant health rating ranging from 8 to 10. Meanwhile, Nara and Empire thrived better than Kikuyu and Couch as seen in Figure 6.

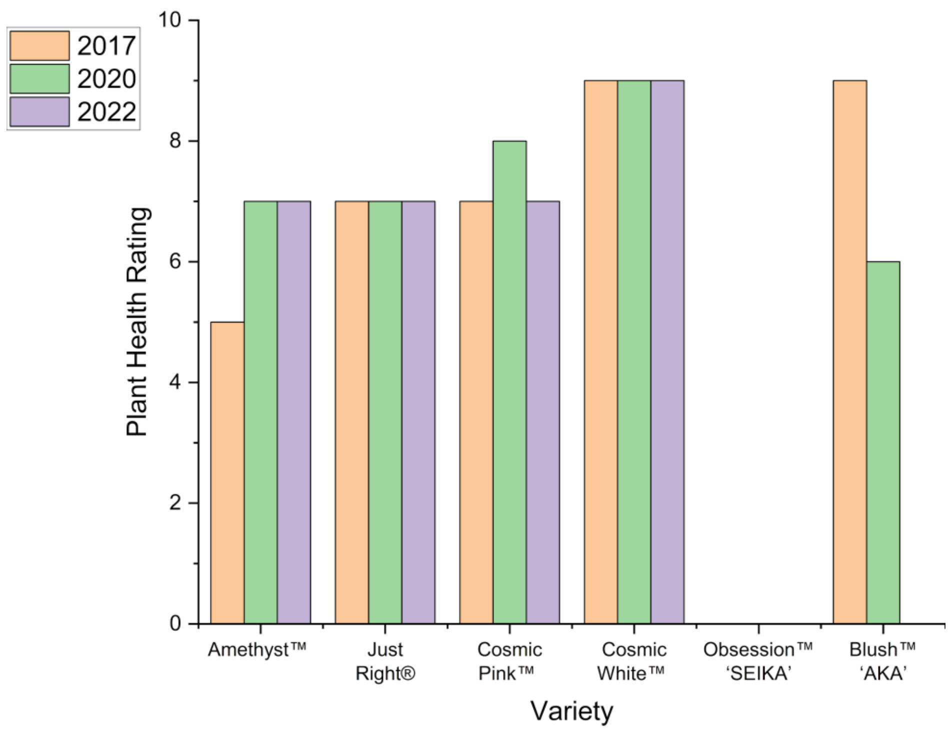

Figure 7. Plant health rating of different exotic varieties in the bio-retention swale.

After the preliminary experiment, three exotic plants with two varieties each were planted in soils mimicking bio-retention swale conditions and their plant health was evaluated when the plants reached 2, 5, and 7 years old. The two *Liriope* varieties and the two *Rhaphiolepis* varieties showed good plant health ratings all throughout the experiment. Meanwhile, the two *Nandina* didn’t thrive under these conditions. The Blush™ *Nandina domestica* ‘AKA’ grew and had good plant health in 2017. However, their plant health declined in 2020 having only a plant health rating of 6. In 2022, all Blush™ *Nandina domestica* ‘AKA’ died. Obsession™ *Nandina domestica* ‘SEIKA’ didn’t grow under these conditions.

Table 4. Two-way ANOVA of *Liriope* varieties and Plant Age in testing area 2.

Liriope					
Overall ANOVA					
	DF	Sum of Squares	Mean Square	F Value	P Value
Liriope	1	0.66667	0.66667	1	0.42265
Plant Age	2	1.33333	0.66667	1	0.5
Model	3	2	0.66667	1	0.53524
Error	2	1.33333	0.66667		
Corrected Total	5	3.33333			
At the 0.05 level, the population means of *Liriope* are not significantly different **At the 0.05 level, the population means of Plant Age are not significantly different**					

Table 4 shows the Two-way ANOVA table to determine if the *Liriope* varieties and plant age have an effect on the plant health. From the table, it can be seen that at a 95% level of confidence, having different varieties of *Liriope* and plant age have no significant effect on plant health. This means that even if different varieties of *Liriope* were planted in the bio-retention swale, regardless of the plant maturity, the plant health will be the same.

Table 5. Two-way ANOVA of *Rhaphiolepis* varieties and Plant Age in testing area 2.

Rhaphiolepis					
Overall ANOVA					
	DF	Sum of Squares	Mean Square	F Value	P Value
Rhaphiolepis	1	4.16667	4.16667	25	0.03775
Plant Age	2	0.33333	0.16667	1	0.5
Model	3	4.5	1.5	9	0.10164
Error	2	0.33333	0.16667		

Corrected Total	5	4.83333			
At the 0.05 level, the population means of *Rhaphiolepis* are significantly different **At the 0.05 level, the population means of Plant Age are not significantly different**					

Table 5 shows the Two-way ANOVA table to determine if the *Rhaphiolepis* varieties and plant age have an effect on the plant health. From the table, it can be seen that at a 95% level of confidence, having different varieties of *Rhaphiolepis* has a significant effect on plant health, and plant age has no significant effect on plant health. This means that there are *Rhaphiolepis* varieties that are more suitable under bio-retention swale conditions. The result also shows that regardless of plant age, the plant health of *Rhaphiolepis* in the bio-retention swale is expected to be similar.

Table 6. Two-way ANOVA of *Nandina* varieties and Plant Age in testing area 2.

Nandina					
Overall ANOVA					
	DF	Sum of Squares	Mean Square	F Value	P Value
Nandina	1	37.5	37.5	3.57143	0.19936
Plant Age	2	21	10.5	1	0.5
Model	3	58.5	19.5	1.85714	0.36878
Error	2	21	10.5		
Corrected Total	5	79.5			
At the 0.05 level, the population means of *Nandina* not significantly different **At the 0.05 level, the population means of Plant Age not significantly different**					

Table 6 shows the Two-way ANOVA table to determine if the *Nandina* varieties and plant age have an effect on the plant health. From the table, it can be seen that at a 95% level of confidence, having different varieties of *Nandina* and plant age have no significant effect on plant health. This may mean that even if different varieties of *Nandina* were planted in the bio-retention swale, the plant health will be the same regardless of the plant maturity. As observed in Figure no. 7, the different varieties of *Nandina* showed that the plants didn't thrive in testing area 1. The

ANOVA suggests that even if other *Nandina* varieties are planted in this testing area 1, these varieties will not thrive as well.

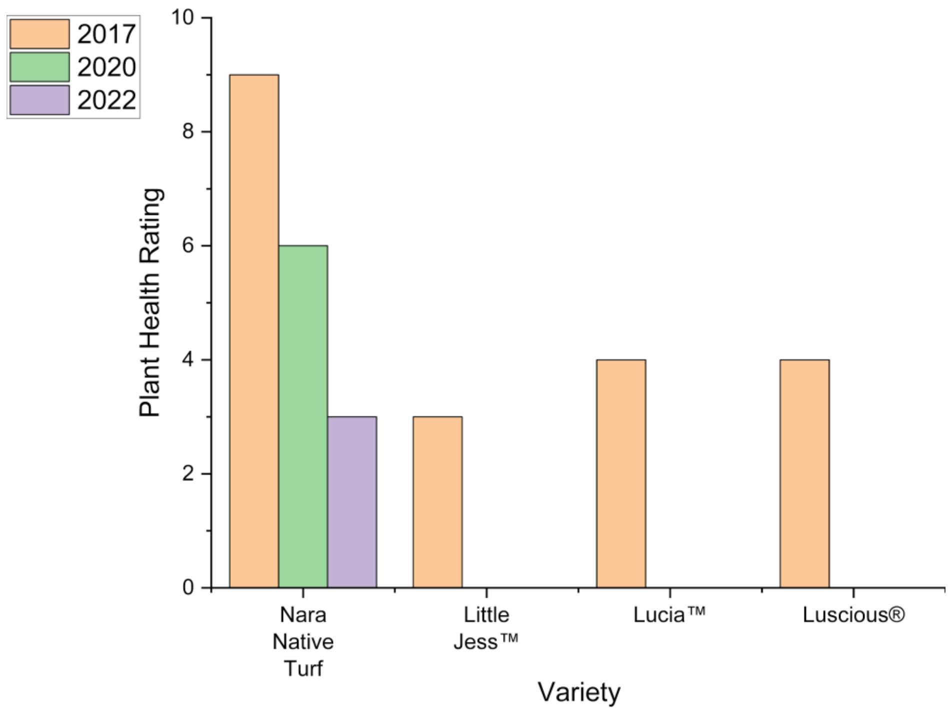

Figure 8. Plant health rating of different native varieties in the bio-retention swale.

Four native varieties were planted in bio-retention swale conditions and their plant health was evaluated when the plants reached 2, 5, and 7 years old. As seen in Figure 8, Nara Native Turf had good plant health when the plants were two years old (2017). However, their health declined through time having only a plant health rating of 3 when the plants were seven years old (2022). The Pearson correlation coefficient as seen in Table 7 further supports this observation. At a 90% level of confidence, the plant age of Nara Native Turf has an inverse effect on its plant health. This may be due to the fact that this Nara Native Turf is only recommended to be planted on periodic wet feet while testing area 2 is permanently waterlogged during the experiment. These other native varieties in Figure 8 didn't thrive under these conditions and died after reaching two years old.

Table 7. Pearson correlation table of Nara Native Turf in testing area 2.

Zoysia			
Pearson Correlations			
		Plant Health	Plant Age
"Plant Health"	Pearson Corr.	1	-0.9934
	p-value	--	0.07319
"Plant Age"	Pearson Corr.	-0.9934	1
	p-value	0.07319	--
2-tailed test of significance is used			

Table 8. Two-way ANOVA of *Dianella* varieties and Plant Age in testing area 2.

Dianella					
Overall ANOVA					
	DF	Sum of Squares	Mean Square	F Value	P Value
Dianella	1	0.16667	0.16667	1	0.42265
Plant Age	2	16.33333	8.16667	49	0.02
Model	3	16.5	5.5	33	0.02956
Error	2	0.33333	0.16667		
Corrected Total	5	16.83333			
At the 0.05 level, the population means of Dianella are not significantly different					
At the 0.05 level, the population means of Plant Age are significantly different					

Table 8 shows the Two-way ANOVA table to determine if the *Dianella* varieties and plant age have an effect on plant health. From the table, it can be seen that at a 95% level of confidence, having different varieties of *Dianella* has no significant effect on plant health. However, the plant age of *Dianella* varieties has an effect on plant health. As observed in Figure 8, the plant health declined, and the plants eventually died as they aged.

Table 9. Pearson correlation table of Luscious® *Tristaniopsis laurina* 'DOW10' in testing area 2.

Tristaniopsis			
Pearson Correlations			
		Plant Heath	Plant Age
"Plant Heath"	Pearson Corr.	1	-0.91766
	p-value	--	0.26015
"Plant Age"	Pearson Corr.	-0.91766	1
	p-value	0.26015	--
2-tailed test of significance is used			

Meanwhile, Table 9 shows the Pearson correlation of Luscious® *Tristaniopsis laurina* 'DOW10' in testing area 2. This shows that plant age and plant health have a negative relationship. However, the p-value for this correlation is over 0.05 so this negative correlation is statistically insignificant.

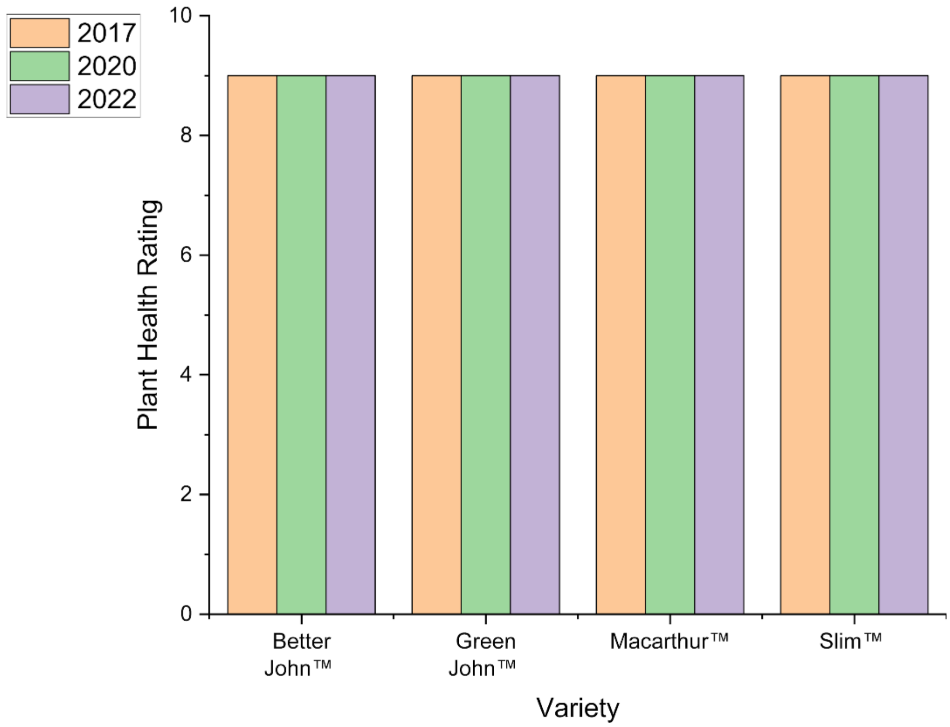

Figure 9. Plant health rating of different native *Callistemon* varieties in the bio-retention swale.

Four Callistemon varieties were planted in bio-retention swale condition and their plant health was evaluated when the plants reached 2, 5, and 7 years old. These Callistemon were observed to live well under these conditions. Their plant health didn't decline as they age and was maintained at 9.

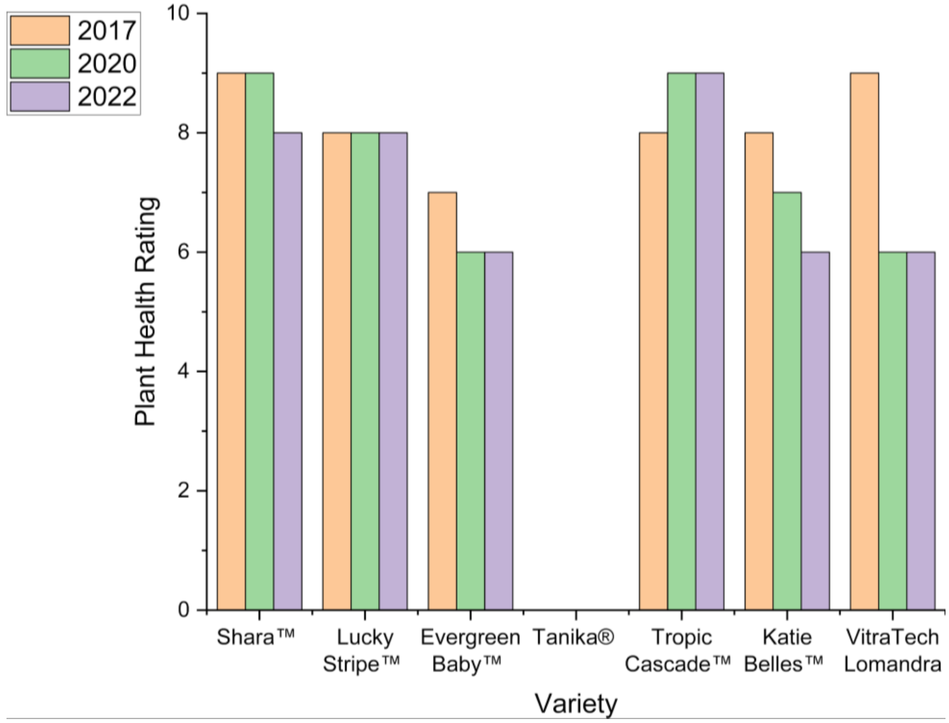

Figure 10. Plant health rating of different native *Lomandra* varieties in the bio-retention swale.

Seven Lomandra varieties were planted in the bio-retention swale and their plant health was evaluated when the plants reached 2, 5, and 7 years old. Figure 10 shows the plant health rating of the different Lomandra varieties. From the figure, it can be seen that Tanika® Lomandra longifolia 'LM300' didn't thrive under these conditions and died before even reaching 2 years old. Meanwhile Shara™ *Lomandra fluviatilis* 'ABU7' and Lucky Stripe™ Lomandra hystrix 'LMV200' both exhibited good plant health over the course of the experiment. Evergreen Baby™ *Lomandra labill*. 'LM600', Katie Belles™ Lomandra hystrix 'LHBYF', and VitraTech Lomandra (a selection from naturally occurring swamp Lomandra) all exhibited a minor decline in plant health as they aged. The surprising one is the Trophic Cascade™ Lomandra hystrix 'LHWP' which improved its plant health as it aged.

Table 10. Two-way ANOVA of Lomandra varieties and Plant Age in testing area 2.

Lomandra					
Overall ANOVA					
	DF	Sum of Squares	Mean Square	F Value	P Value
Lomandra	6	163.2381	27.20635	44.51948	1.64E-07
Plant Age	2	2.66667	1.33333	2.18182	0.15553
Model	8	165.90476	20.7381	33.93506	4.33E-07
Error	12	7.33333	0.61111		
Corrected Total	20	173.2381			
At the 0.05 level, the population means of Lomandra are significantly different					
At the 0.05 level, the population means of Plant Age are not significantly different					

Table 10 shows the Two-way ANOVA table to determine if the Lomandra varieties and plant age have an effect on plant health. From the table, it can be seen that at a 95% level of confidence, having different varieties of *Lomandra* has a significant effect on plant health. This supports the observed pattern in Figure 10 with different *Lomandra* varieties exhibiting different plant health as they aged. However, the plant age of *Lomandra* varieties has no significant effect on plant health.

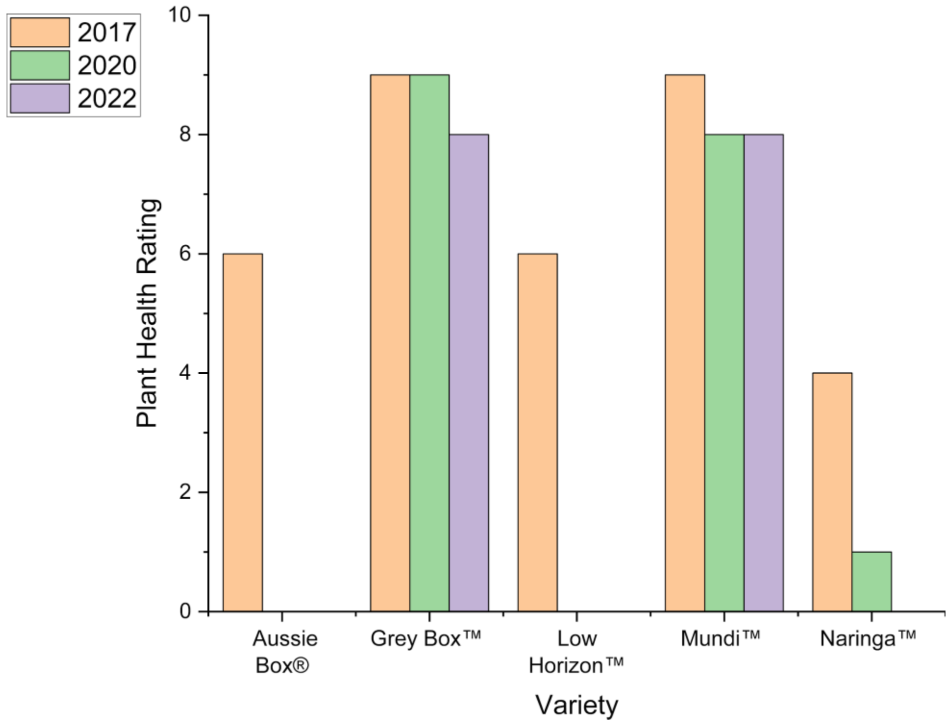

Figure 11. Plant health rating of different native *Westringia* varieties in the bio-retention swale.

Five *Westringia* varieties were planted in a bio-retention swale and their plant health was evaluated when the plants reached 2, 5, and 7 years old. Grey Box™ *Westringia fruticosa* ‘WES04’ and Mundi™ *Westringia* fruticosa ‘WES05’ were observed to thrive under these conditions. Meanwhile, Ozbreed Aussie Box® *Westringia* ‘WES08’ and Low Horizon™ *Westringia fruticosa* 'WES06' were observed to have relatively good plant health but eventually died before reaching the age of five. Naringa™ *Westringia* ‘WES01’ was observed to have poor plant health at the age of 2 but still survived and reached the age of 5 but eventually died before reaching the age of 7.

Table 11. Two-way ANOVA of *Westringia* varieties and Plant Age in testing area 2

Westringia					
Overall ANOVA					
	DF	Sum of Squares	Mean Square	F Value	P Value
Westringia	4	157.73333	39.43333	16.54545	6.18E-04
Plant Age	2	38.93333	19.46667	8.16783	0.01168
Model	6	196.66667	32.77778	13.75291	7.91E-04
Error	8	19.06667	2.38333		
Corrected Total	14	215.73333			
At the 0.05 level, the population means of Westringia are significantly different					
At the 0.05 level, the population means of Plant Age are significantly different					

Table 11 shows the Two-way ANOVA table to determine if the *Westringia* varieties and plant age have an effect on the plant health. From the table, it can be seen that at a 95% level of confidence, having different *Westringia* varieties and plant age have a significant effect on plant health. This means that there are specific *Westringia* varieties that can live better in bio-retention swales, while the plant age affects the plant health of these varieties.

C. Survivability of various plant types in floodplains.

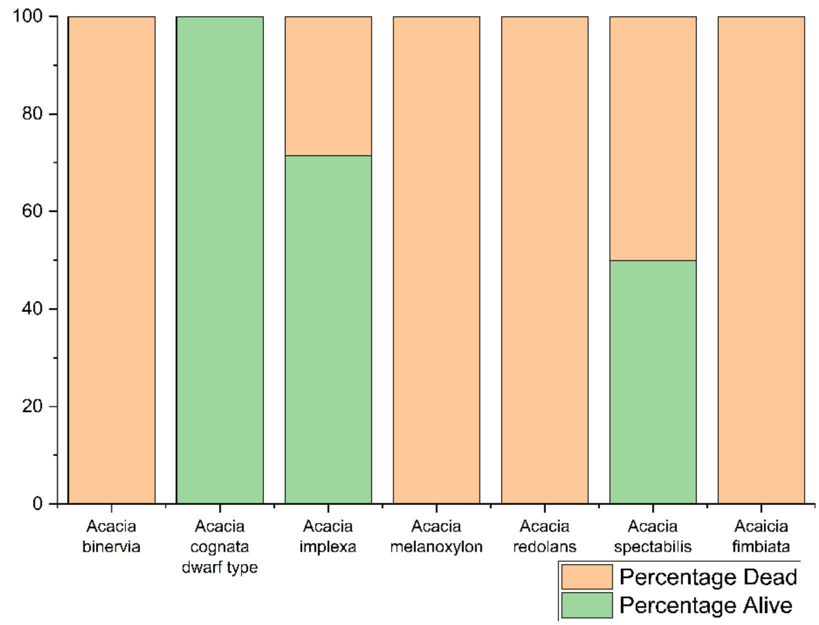

Figure 12. The survival rate of *Acacia* varieties in testing area 3.

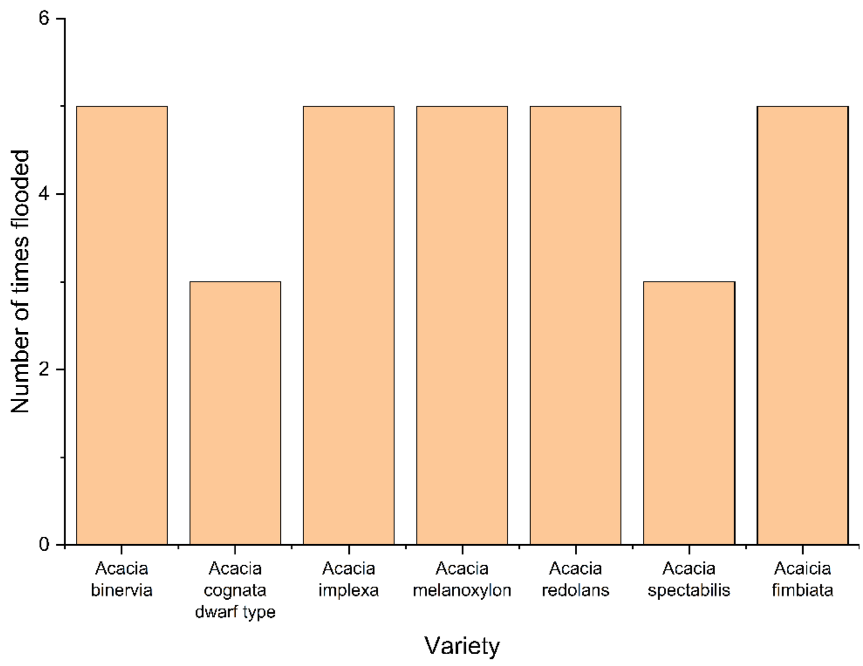

Figure 13. Number of floods experienced by *Acacia* varieties in testing area 3.

Seven *Acacia* varieties were planted in the floodplain. As seen in Figure 13, five varieties experienced flooding five times, while *Acacia cognata* (dwarf type) and *Acacia spectabilis* experienced flooding only three times. *Acacia redolens* were mature plants when the flooding came. Most plants survived the first flood. However, almost half are killed by the second flood. When the third flood came, all the plants were killed. Meanwhile, both *Acacia fimbriata* and *Acacia binervia* each have four plants planted in the floodplain.

The plants were semi-mature when the flooding came. The two varieties exhibited the same behaviour when exposed to flooded conditions. Two of each variety survived the first three floods, but the next floods killed the remaining plants. *Acacia melanoxylon* plants were semi-mature plants when the flooding came. However, all three *Acacia melanoxylon* plants did not survive.

Acacia implexa is the variety that survived the five floodings that came. Out of the seven mature plants of this variety in the floodplain, five survived. The two plants that did not survive only died during the last flood. *Acacia spectabilis* have a 50% survival rate, with two plants surviving the three floods while the other two died. The lone *Acacia cognata* (dwarf type) plant survived the three floods with some evident browning but has been regrowing well. From Figure 12, only three *Acacia* varieties have survival rates greater than zero. These are *Acacia cognata* (100%), *Acacia implexa* (71.43%), and *Acacia spectabilis* (50%).

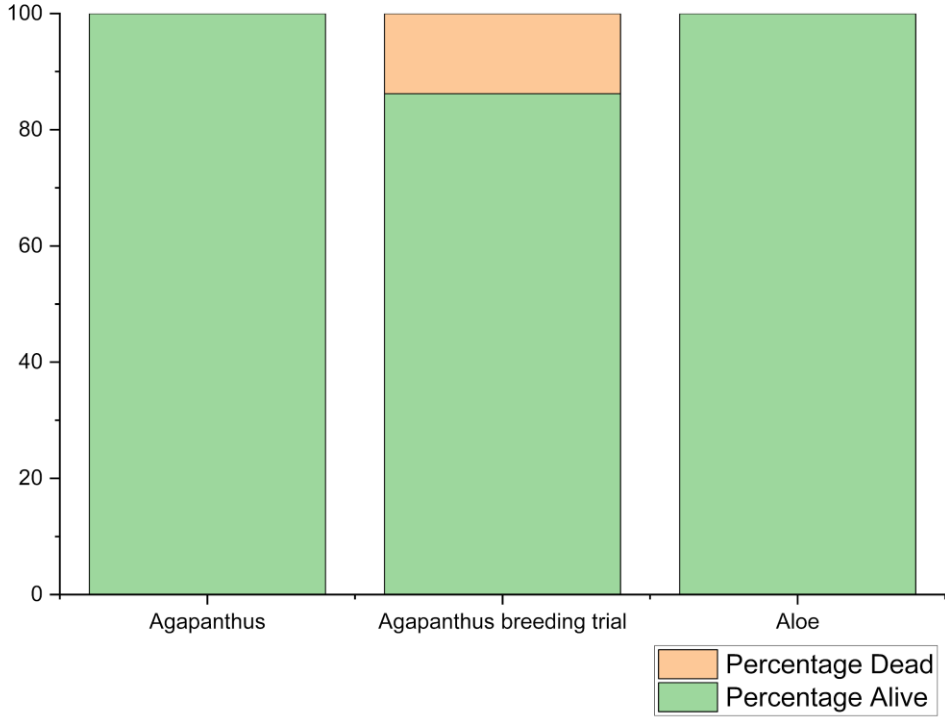

Figure 14. Survival rate of *Agapanthus* and *Aloe* varieties in testing area 3.

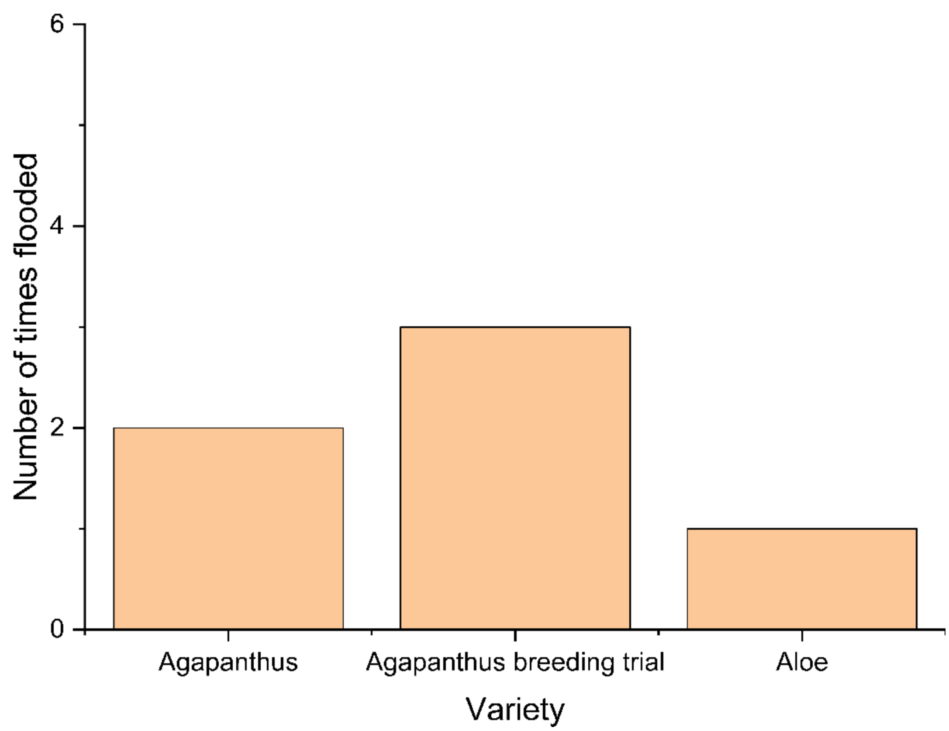

Figure 15. Number of floods experienced by *Agapanthus* and *Aloe* varieties in testing area 3.

There were two varieties of *Agapanthus* planted in testing area 3. The first variety is the common *Agapanthus* with six mature plants. As seen on Figure 15, they have been flooded twice, and all six survived, however the common plants were very large types, so perhaps larger types survive the flood better. The second variety is the *Agapanthus* breeding trial, composed of twenty-nine mature plants. This variety experienced flooding thrice, resulting in three dead or dormant plants.

From Figure 14, the common *Agapanthus* has a 100% survival rate while the *Agapanthus* breeding trial only has an 86.21% survival rate. As there were a number of very ultra-compact and weaker plants in the breeding trial, it is not unexpected that some of these died. Meanwhile, only one variety of *Aloe* was grown in the area. This variety experienced one minor flooding and all fifteen mature plants survived having a 100% survival rate.

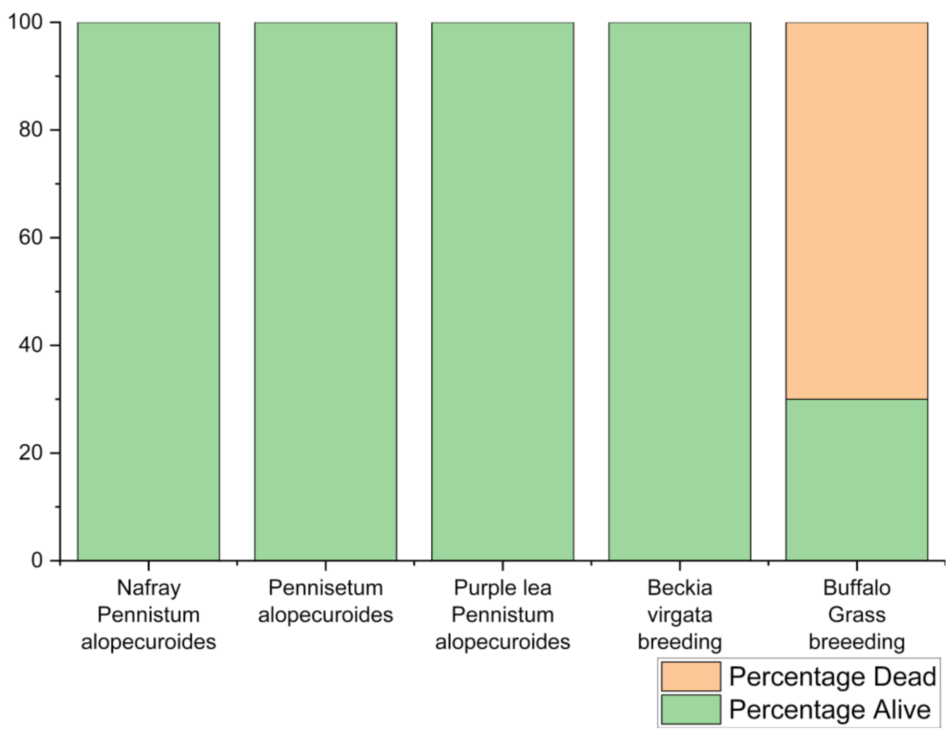

Figure 16. Survival rate of *Pennisetum alopecuroides*, *Buffalo*, and *Beckia* varieties in testing area 3.

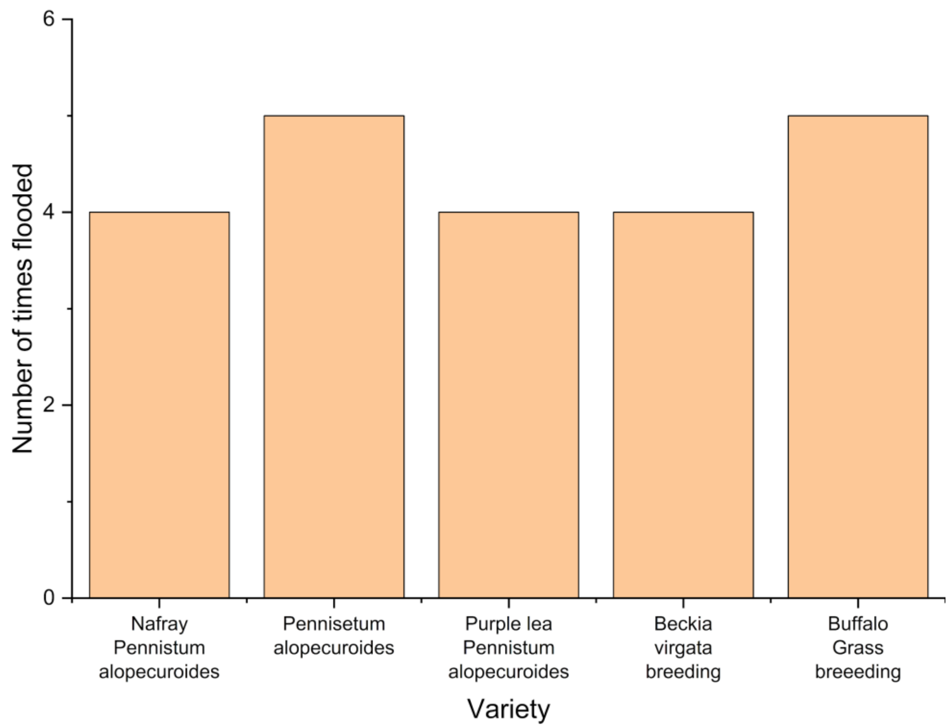

Figure 17. Number of floods experienced by *Pennisetum alopecuroides*, *Buffalo*, and *Beckia* varieties in testing area 3.

Three varieties of *Pennisetum alopecuroides* or swamp foxtail were grown in the area. Nafray *Pennisetum alopecuroides* have more mature plants compared to the other two varieties. As seen in Figure 17, both the Nafray *Pennisetum alopecuroides* and Purple lea *Pennisetum alopecuroides* were flooded four times while the common *Pennisetum alopecuroides* were flooded five times.

Although all varieties have been flooded numerous times, all plants for each variety have survived with a total of eight for Nafray *Pennisetum alopecuroides*, twenty for *Pennisetum alopecuroides*, and ten for Purple lea *Pennisetum alopecuroides*. From Figure 16, all *Pennisetum* *alopecuroides* varieties have a 100% survival rate. In another section where a large number of Nafray was planted and had 4 floods, most died. However, these were young plants, and were planted after the second flood, and were still small when the largest and worst flood occurred, with most dying at this stage. This pattern was also observed by previous studies by Zaidi et al. (2004), Stokes (2008), and Gattringer et al. (2017) where they concluded that young plants are more likely to die when subjected to flood than more mature plants.

One *Beckia* variety can also be seen in area 3, the *Beckia virgata* breeding. This unreleased variety has been flooded four times. All five mature plants survived, having a 100% survival rate. Meanwhile, the *Buffalo* varieties grown in the area had 10 types, specifically, the *Buffalo* Grass breeding made up of young plants. It can be found in a very low area which makes it sit under the water for a long time, similar to the *Liriope*.

It has been flooded five times and out of ten plants, the majority were dead or dormant, and only three survived the flooding. This shows that *Buffalo* has a very low survival rate of 30% over 10 types. This also provides evidence that the survivability of *Buffalo* in floods is very dependent on its breeding and can be highly variable.

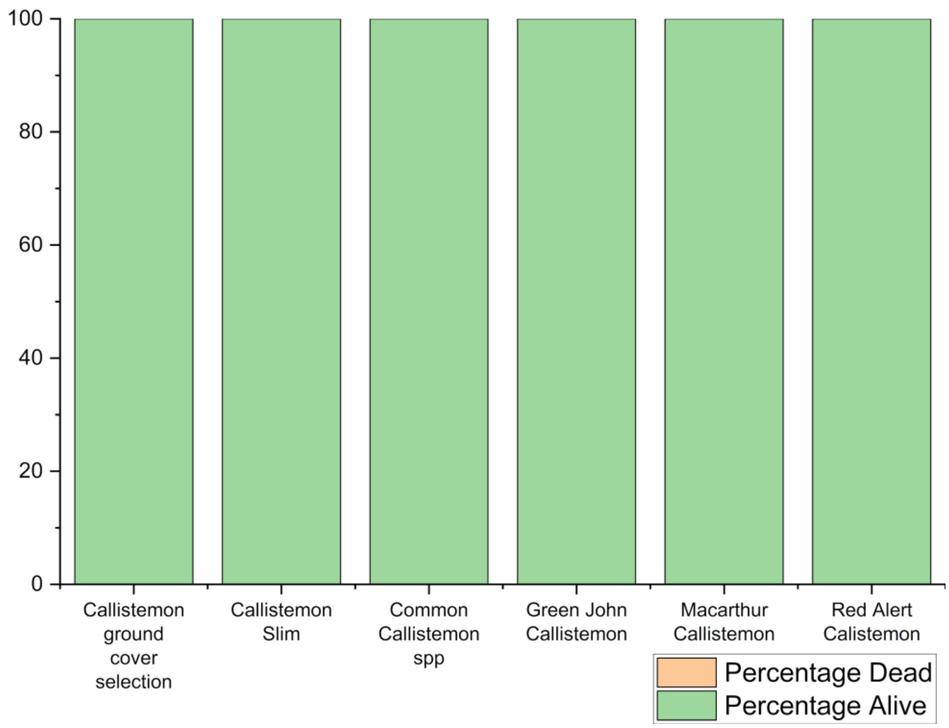

Figure 18. The survival rate of *Callistemon* varieties in testing area 3.

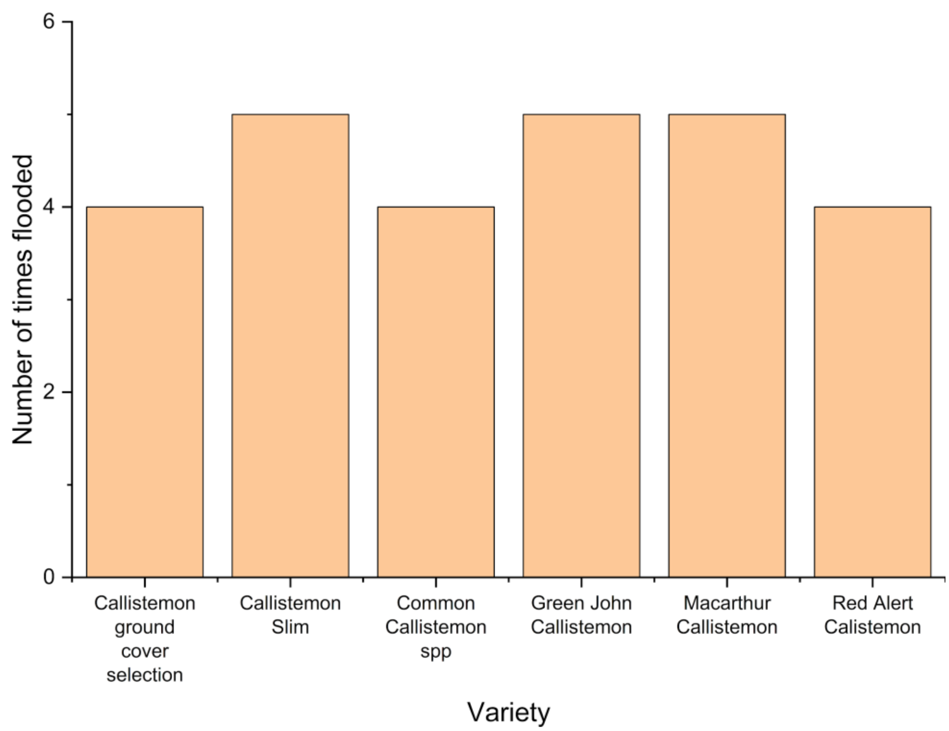

Figure 19. Number of floods experienced by *Callistemon* varieties in testing area 3.

Six varieties of *Callistemon* or bottlebrush were planted in the floodplain area, all having mature plants. Two varieties were planted in low areas, including *Callistemon* Slim and Green John *Callistemon*. The Green John *Callistemon* variety was seen as very healthy-looking as well as the Red Alert *Callistemon*.

From Figure 19, three varieties experienced flooding four times including *Callistemon* ground cover selection, Common *Callistemon* spp, and Red Alert *Callistemon*. The *Callistemon* Slim, Green John *Callistemon*, and Macarthur *Callistemon* varieties experienced five floods. All plants from the six varieties survived the flooding, and this shows that *Callistemon* can be grown under these conditions because of the 100% survival rate that *Callistemon* plants exhibited during the testing.

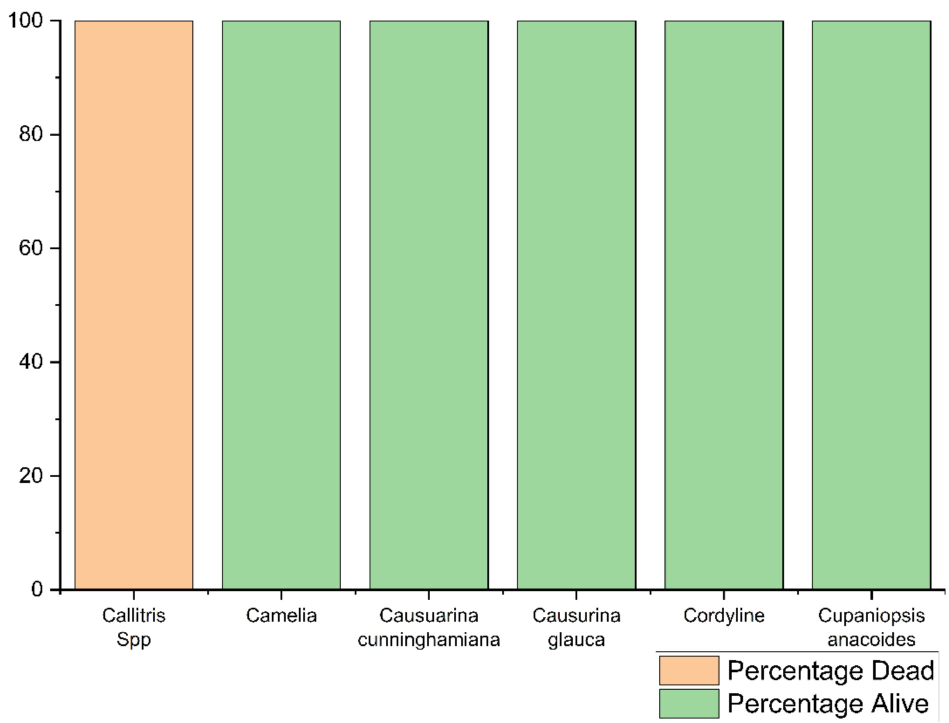

Figure 20. Survival rate of *Callitris*, *Camelia*, *Casuarina*, *Cordyline*, and *Cupaniopsis* varieties in testing area 3.

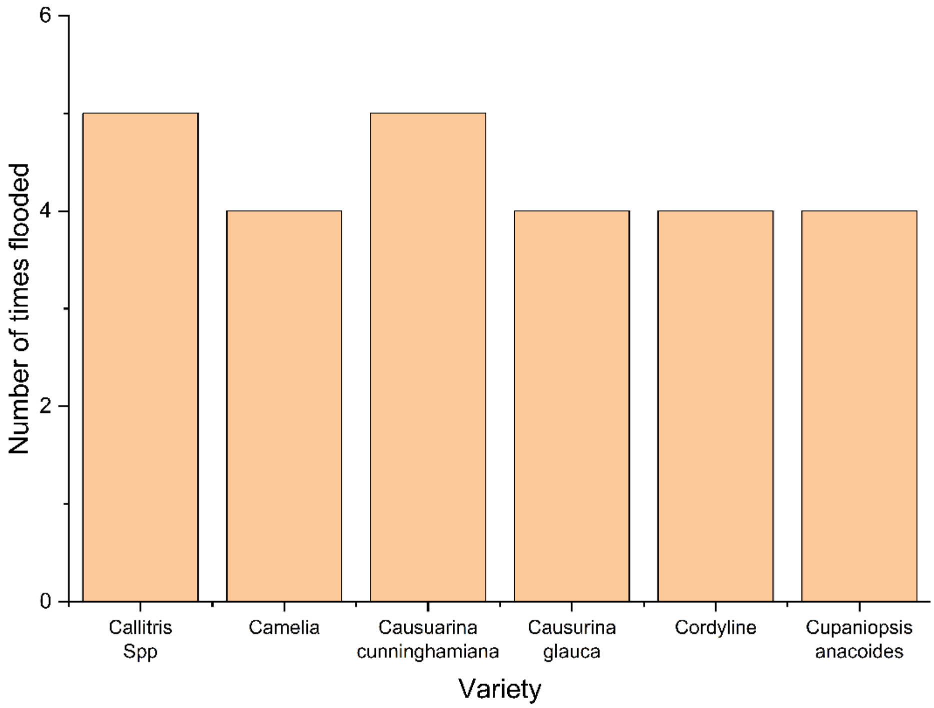

Figure 21. Number of floods experienced by *Callitris*, *Camelia*, *Casuarina*, *Cordyline*, and *Cupaniopsis* varieties in testing area 3.

The *Callitris* planted for this area has only one variety, consisting of one mature plant. This variety experienced five floods and did not survive thereafter. Meanwhile, five mature plants composed the only *Camelia* variety grown in the floodplain area. Unlike the previous variety, all five plants of this variety survived the four floods.

Two *Casuarina* types were grown in this area. Both types have mature plants. The *Casuarina cunninghamiana*, despite being planted in a very low area, all survived five floods. All *Casuarina glauca* survived as well even after experiencing four floods.

One type of *Cordyline* was planted in the area. Despite experiencing four floods, all three mature plants of this variety survived. Also, only one type of *Cupaniopsis* was grown in the area, specifically *Cupianopsis anacoides*. All plants were semi-mature and most of them experienced four floods. However, some plants experienced either two or three floods. Regardless, all survived the floods they experienced.

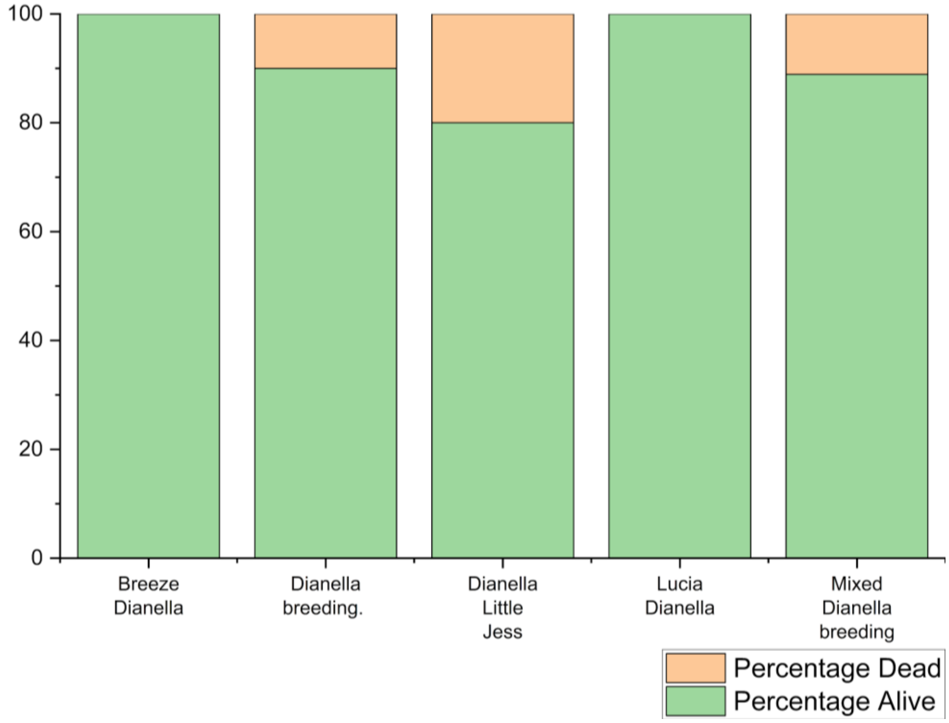

Figure 22. Survival rate of *Dianella* varieties in testing area 3.

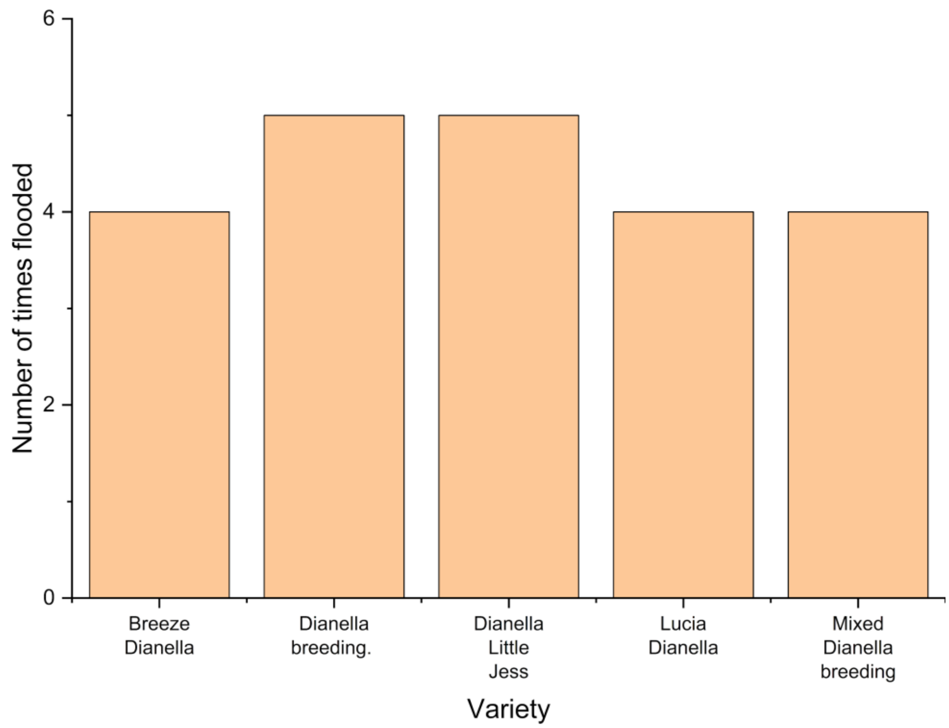

Figure 23. Number of floods experienced by *Dianella* varieties in testing area 3.

Five varieties of matured *Dianella* plants were raised in the floodplain. Three varieties endured four floods. The Breeze *Dianella* and Lucia *Dianella* varieties all survived and clean foliage after the flood was observed. The Mixed *Dianella* breeding variety, although having nine plants with brown foliage, showed clear signs of regrowth. Only three out of twenty-seven plants of this type showed signs of death and dormancy.

On the other hand, two varieties experienced five floods. The *Dianella* breeding (mainly *Dianella caerulea*, or cross breeds) variety showed signs of discolouration but also showed indications of growth. Out of thirty plants, twenty-seven of this variety have survived the flooding. The other variety, which is *Dianella* Little Jess, has a total of one hundred plants grown in a very low area. Twenty of them were suspected to be dormant and were expected to grow in the next month.

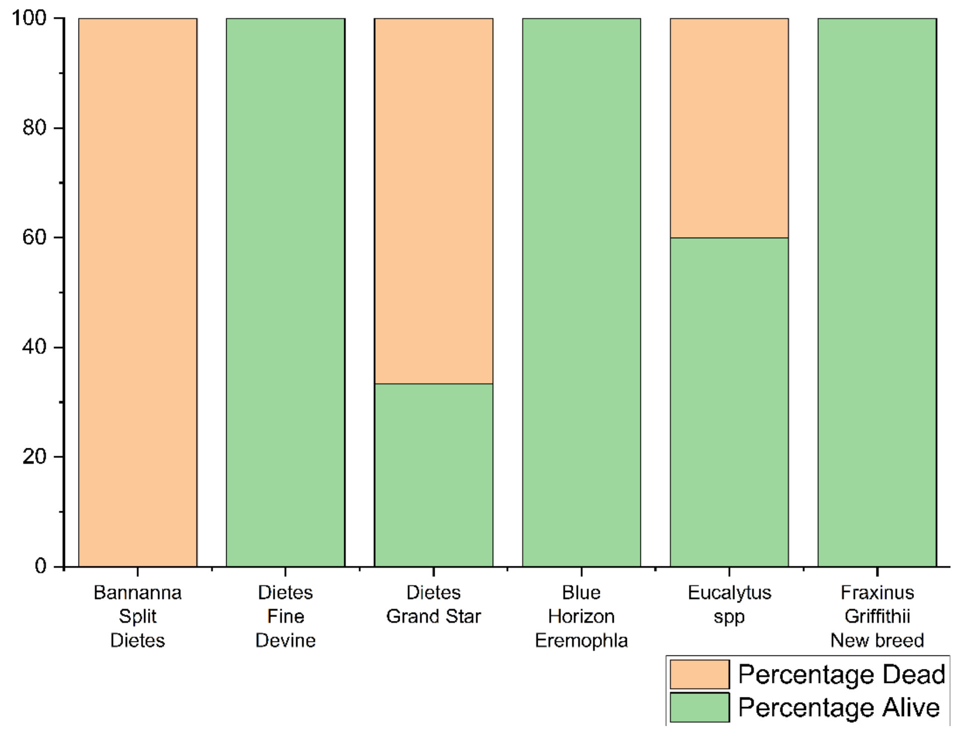

Figure 24. Survival rate of *Dietes*, *Eremophila*, *Fraxinus*, and *Eucalyptus* varieties in testing area 3.

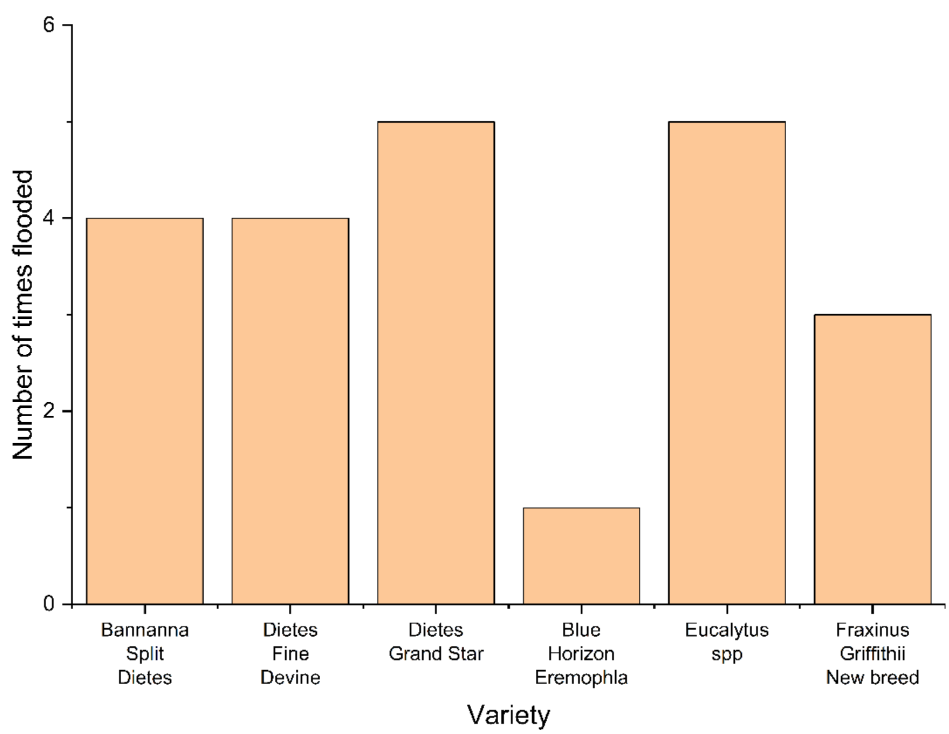

Figure 25. Number of floods experienced by *Dietes*, *Eremophila*, *Fraxinus*, and *Eucalyptus* varieties in testing area 3.

The *Dietes* plants had three varieties of mature plants in the area. One variety, *Dietes* Grand Star, experienced five floods, and only five out of fifteen plants survived. Five of them were also observed to be sick but were still regrowing multiple green shots. The two other varieties experienced four floods. The twenty-five plants of the *Dietes* Fine Devine variety had all survived, while all three of the Bannanna Split *Dietes* variety died or became dormant. The Bannanna Split *Dietes,* although displaying signs of regrowth at first, were discovered to be very brown and dormant at the time of evaluation.

The *Eremophila* and the *Fraxinus* varieties, both with only one type, are found in the area. The Blue Horizon *Eremophila* variety experienced one flooding, while the *Fraxinus* Griffithii New breed, which consisted of smaller plants approximately two years old, experienced three. All plants from both types were alive even after the flooding. On the other hand, the *Eucalyptus spp* experienced five floods. After the flood, only two out of three of the *Eucalyptus spp* were dormant or dead.

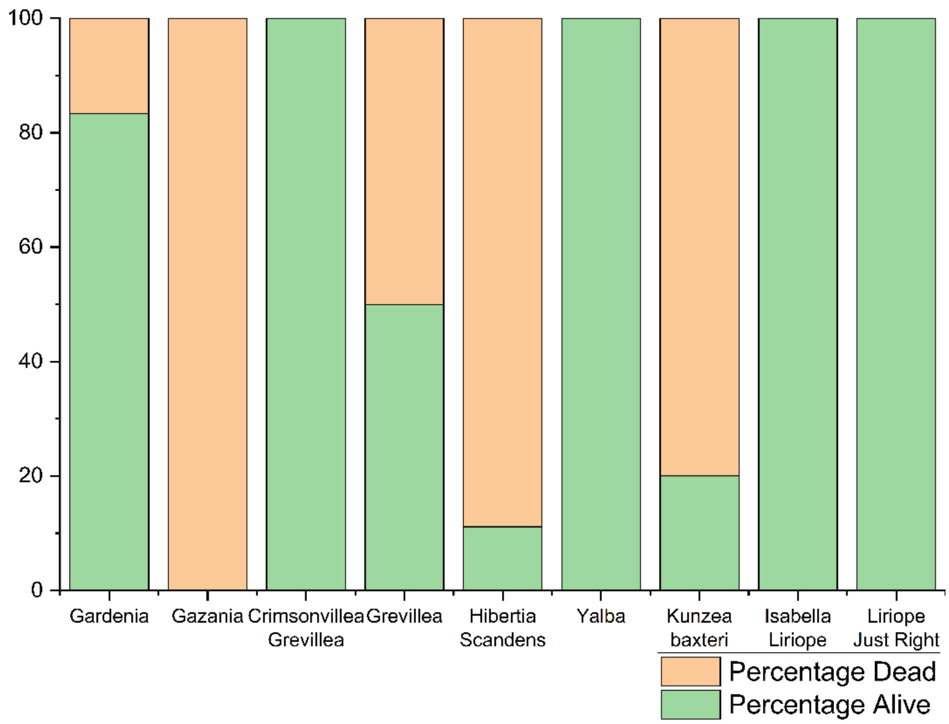

Figure 26. Survival rate of *Gardenia*, *Gazania*, *Grevillea*, *Hibbertia*, *Imperata*, *Kunzea*, and *Liriope* varieties in testing area 3.

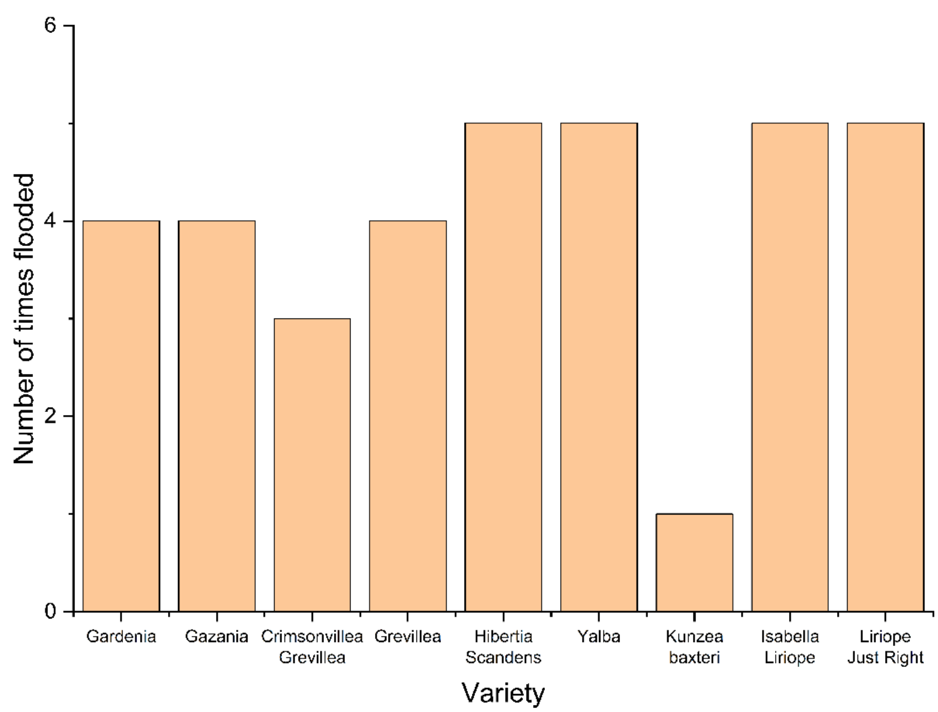

Figure 27. Number of floods experienced by *Gardenia*, *Gazania*, *Grevillea*, *Hibbertia*, *Imperata*, *Kunzea*, and *Liriope* varieties in testing area 3.

Gardenia varieties experienced four floods. After the flood, only one was dormant or dead from the *Gardenia* variety. The *Gazania* variety in the area consisted of mature plants. These plants experienced four floods, and most became dormant during the first flooding. Although they grew again after the first flooding, most of the plants died after the second flood, and only a few survived. After the four floods, none remained alive.

The *Hibbertia scandens* variety of the *Hibbertia* plant was grown 2.5 metres above the lowest area where the *Liriope* were planted. While these are all mature plants, only one out of nine survived after experiencing five floods. On the other hand, the Yalba variety of the *Imperata* all thrived after five floods. It was observed they had grown into one mass as rhizomes and spread together.

The *Kunzea baxteri* variety consisted of semi-mature plants, where only one out of five survived after experiencing one flood. The survivor plant of the said type was always observed to be the healthiest and still looks well until the most recent observation. No browning was also seen, even after experiencing the last big flood. This is evidence that given the right genetics, even plants that die easily in floods, can potentially be bred to survive.

Two types of both *Grevillea* and *Liriope* were grown in the floodplain. The first variety, the Crimsonvillea *Grevillea*, experienced three floods, while the second variety, the Common *Grevillea*, experienced four floods. All plants were considered mature plants at the time of evaluation. However, only plants of the first variety remained alive after experiencing the flooding. None survived from the second variety.

Meanwhile, the *Liriope* variety has two types that experience five floods. The Isabella *Liriope* variety consisted of semi-mature plants while the *Liriope* Just Right variety consisted of mature plants. Both were planted on the very low part of the floodplain since it was proven to thrive after water submersion tests that were done previously. All plants from both varieties survived after experiencing the floods.

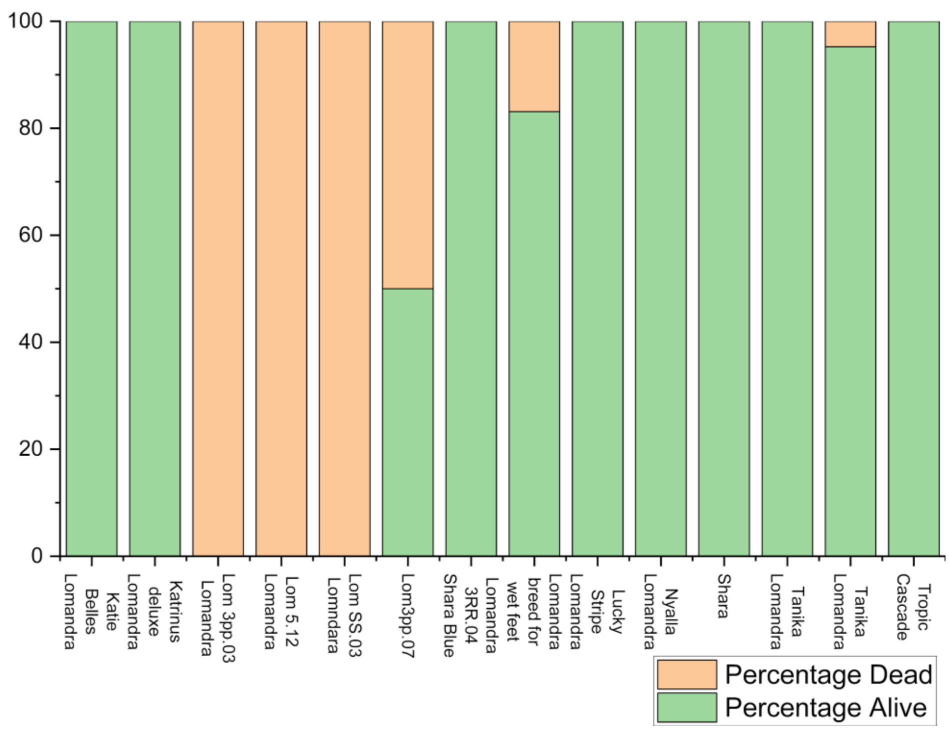

Figure 28. Survival rate of *Lomandra* varieties in testing area 3.

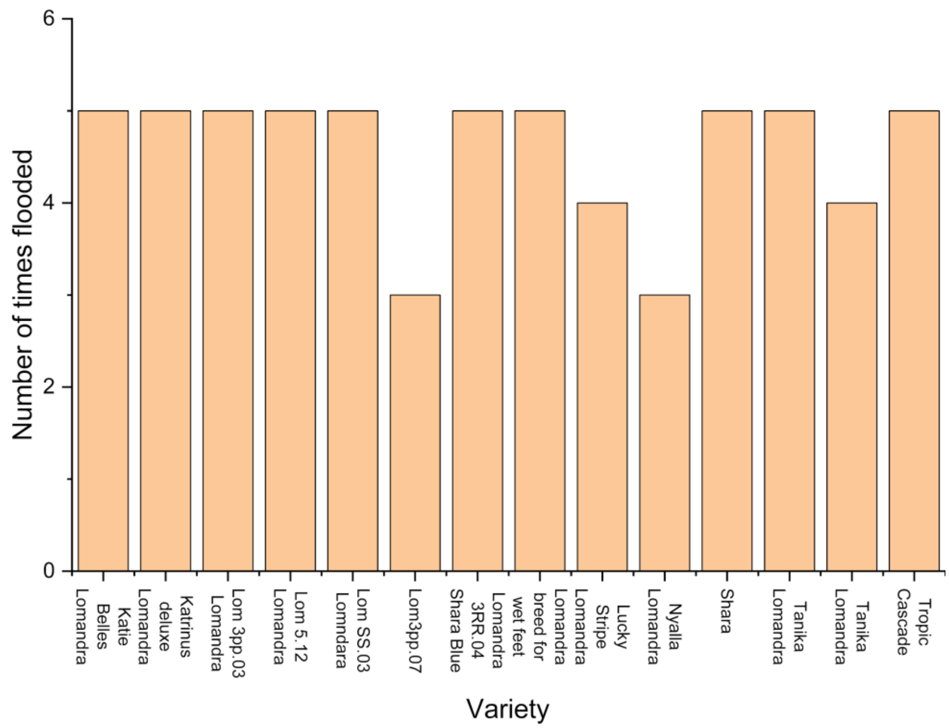

Figure 29. Number of floods experienced by *Lomandra* varieties in testing area 3.

The greatest number of plant varieties found in the floodplain area was the *Lomandra* plant which has fourteen varieties. Twelve varieties were mature plants, while the Lom3pp.07 and Lucky Stripe *Lomandra* were semi-mature plants. Meanwhile, nine varieties of the *Lomandra* have all survived after experiencing the floods. All nine varieties experienced five floods except the Lucky Stripe *Lomandra*, Lom3pp.07 and Nyalla *Lomandra* which experienced four, three, and three floods, respectively.

On the other hand, all the plants from the three varieties died after the first wet feet trial and after five floods, namely Lom 3pp.03, Lom 5.12, and Lom SS.03. Meanwhile, 59 out of 71 plants of the *Lomandra* breed for wet feet in the general breeding trial thrived after five floods. Since they were just wet and not flooded, all plants from this type did well during the first wet feet trial.

One set of the Tanika variety has one dormant plant after experiencing four floods, resulting in twenty survivor plants. Additionally, it was observed that the Trophic Cascade type which was represented in large numbers thrived well in the drainage swale flood plain, which was generally wet, while the Shara type also in large numbers was placed at a very low area and always stayed green throughout the observation.

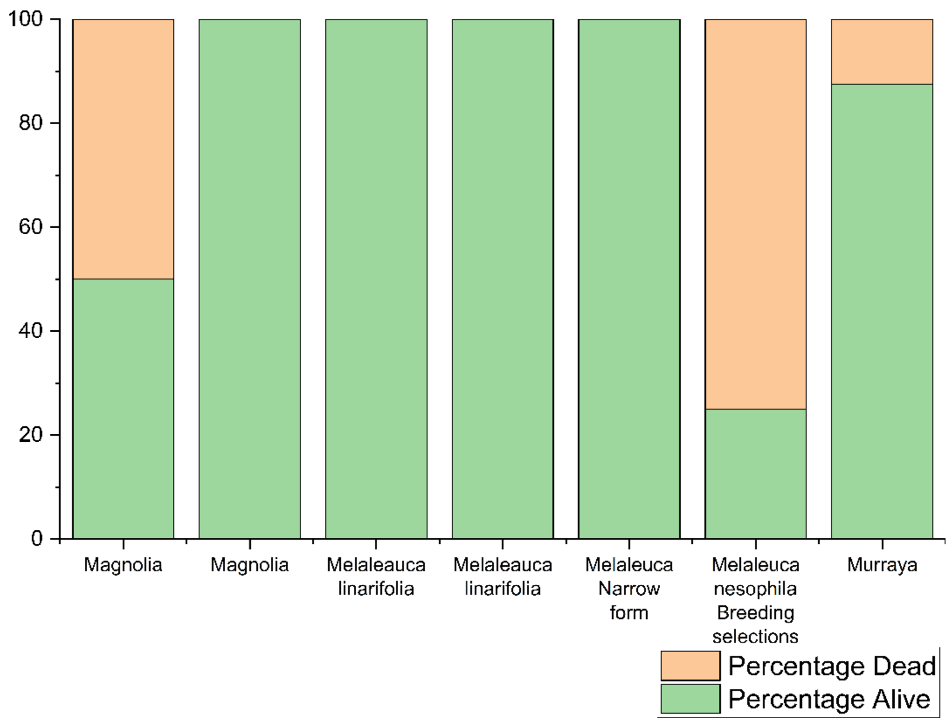

Figure 30. Survival rate of *Magnolia*, *Melaleuca*, and *Murraya* varieties in testing area 3.

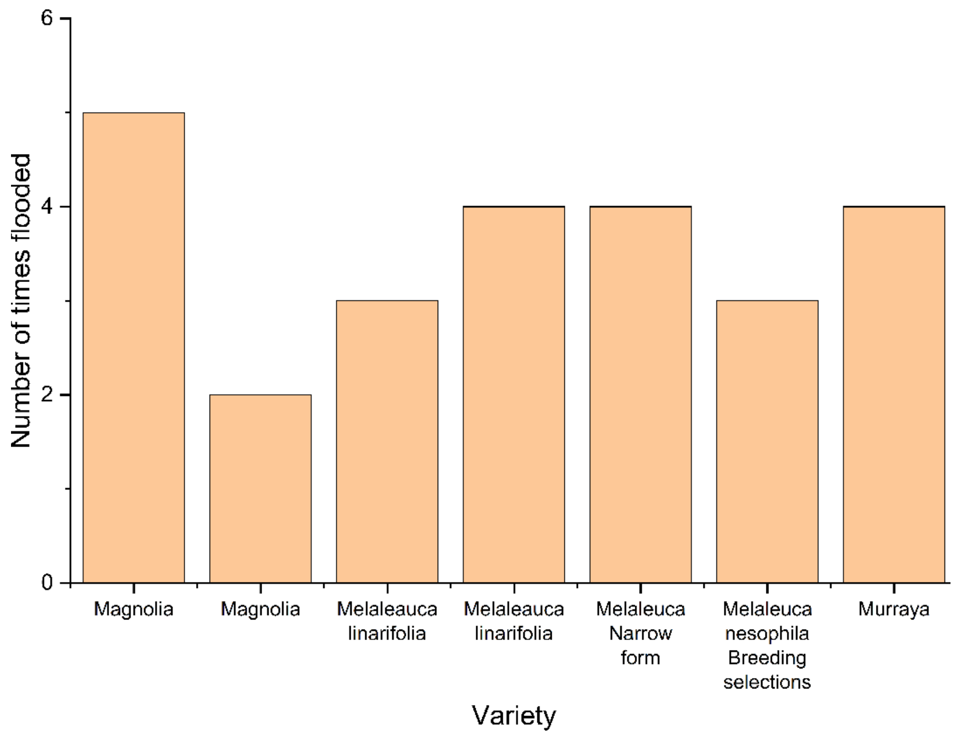

Figure 31. Number of floods experienced by *Magnolia*, *Melaleuca*, and *Murraya* varieties in testing area 3.

Two sets of the common *Magnolia* were placed in the floodplain area. The first set was smaller plants with an average height of 70 centimetres and was only planted for six months. Only half of this type survived after five floods. The second set was all matured plants and all had thrived after two floods.

There are four types of the *Melaleuca* plants and all were mature plants except the *Melaleuca nesophila* Breeding selections which are semi-mature plants. While the three other types having mature plants, all survived after the flooding, only one of the *Melaleuca nesophila* breeding selection types thrived after three floods.

Observations show that some browning was seen after the last big flood and that the only survivor plant could be seen as the healthiest since the start of the observation. Additionally, the common *Murraya* found in the floodplain are all mature plants. After four floods, most plants had thrived and only one was observed to be dead or dormant.

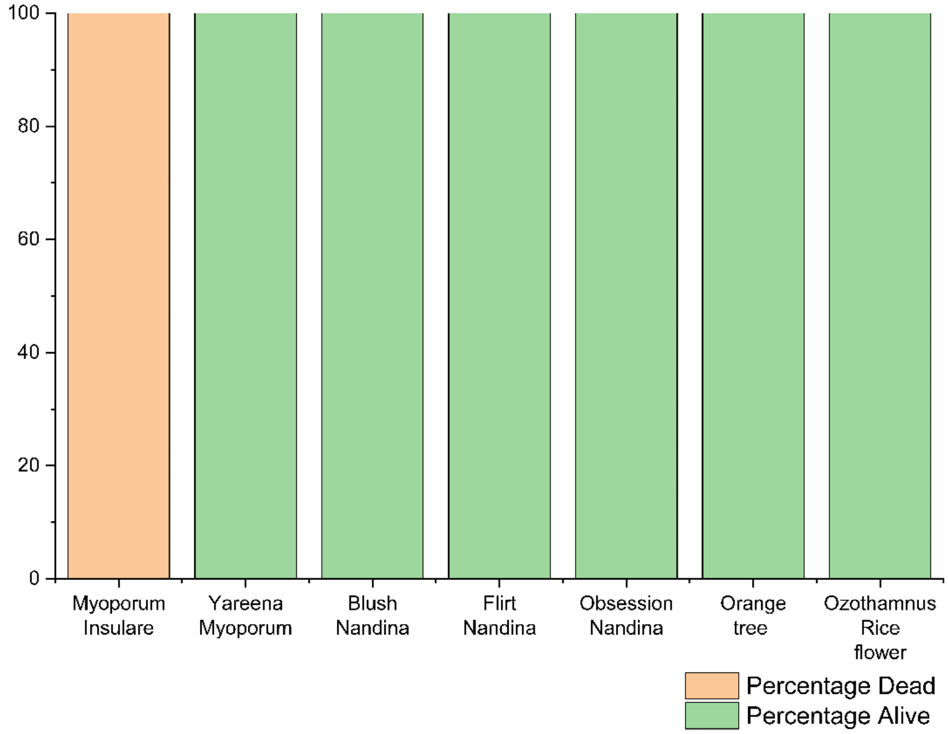

Figure 32. Survival rate of *Myoporum*, *Nandina*, Orange, and *Ozothamnus* varieties in testing area 3.

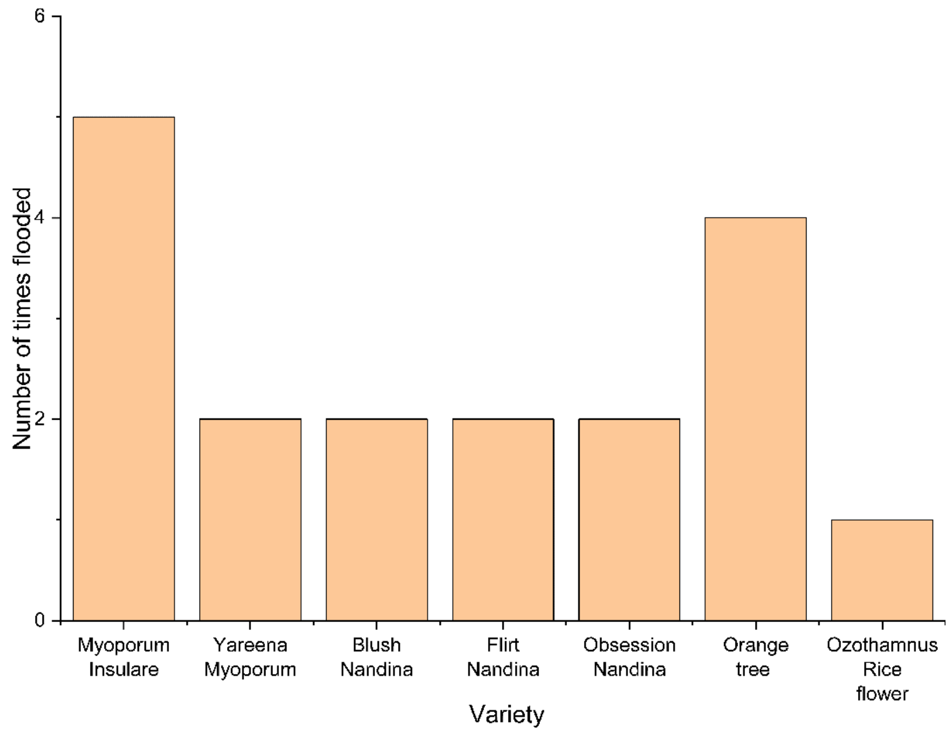

Figure 33. Number of floods experienced by *Myoporum*, *Nandina*, Orange, and *Ozothamnus* varieties in testing area 3.

There are two types of *Myoporum* observed in the floodplain. Both types are mature plants. However, the first variety, the *Myoporum insulare* has undergone five floods and none thrived. Only one survived after the first two floods but also died after the third. The other type, Yareena™ *Myoporum*, had only one plant and survived after experiencing two floods.

Three varieties of *Nandina* were also placed in the area, namely Blush *Nandina*, Flirt *Nandina* and Obsession *Nandina*. All three varieties consisted of mature plants and all survived after experiencing two floods.

There are also orange tree and *Ozothamnus* Rice flower varieties found in the floodplain area. The orange tree variety were mature plants, and all survived after four floods. Meanwhile, the *Ozothamnus* Rice flower type was also a mature plant and seemed to be looking good and flowering well after experiencing one flood.

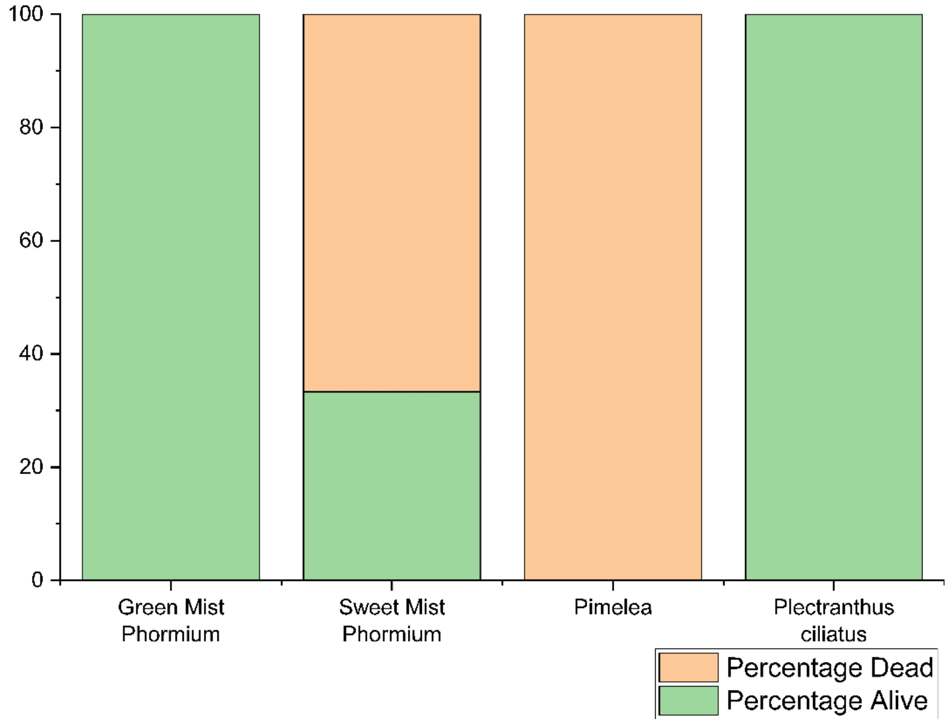

Figure 34. Survival rate of *Phormium*, *Pimelea*, and *Plectranthus* varieties in testing area 3.

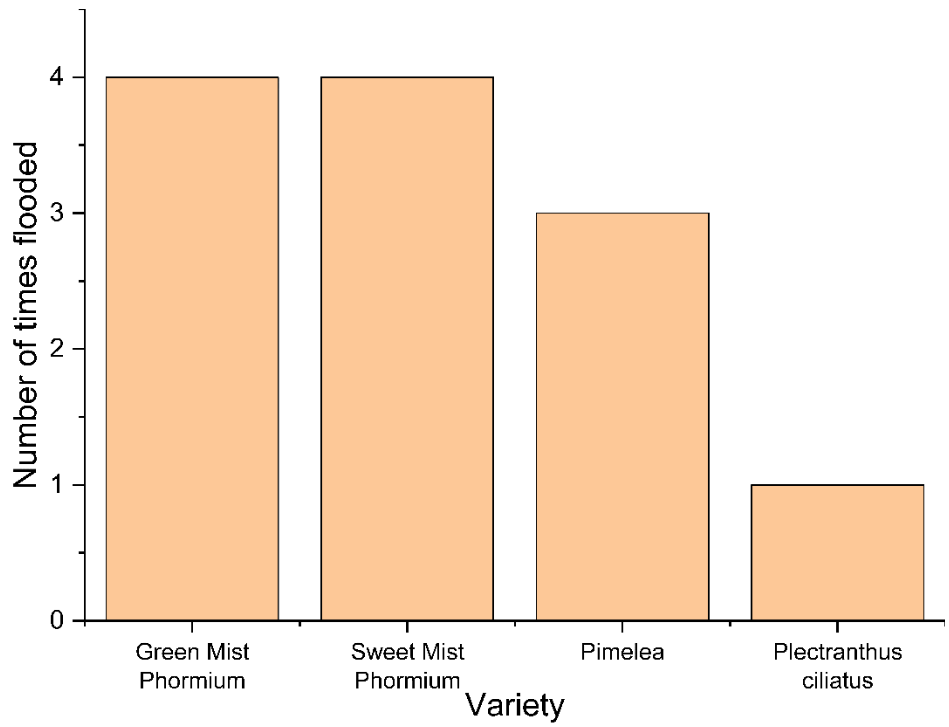

Figure 35. Number of floods experienced by *Phormium, Pimelea,* and *Plectranthus* varieties in testing area 3.

Two types of mature *Phormium* plants were grown in the floodplain area. However, each yielded different results. Although having different leaf colours, both share the same genetics, since the Green Mist *Phormium* type is a mutation of the Sweet Mist *Phormium* type. Meanwhile, the Green Mist *Phormium* showed positive results, where all plants of this type survived after four floods. On the other hand, the Sweet Mist *Phormium* had one survivor plant after four floods. It is also observed that Green Mist *Phormium*s are generally tougher than bronze foliage *Phormium*s.

Pimelea and *Plectranthus ciliatus* were also put in the floodplain area. All these plants were mature plants. However, only the *Plectranthus cillatis* variety survived and was still observed to look good even after experiencing flooding.

Figure 36. Survival rate of *Raphiolepis*, *Westringia*, and *Zoysia* varieties in testing area 3.

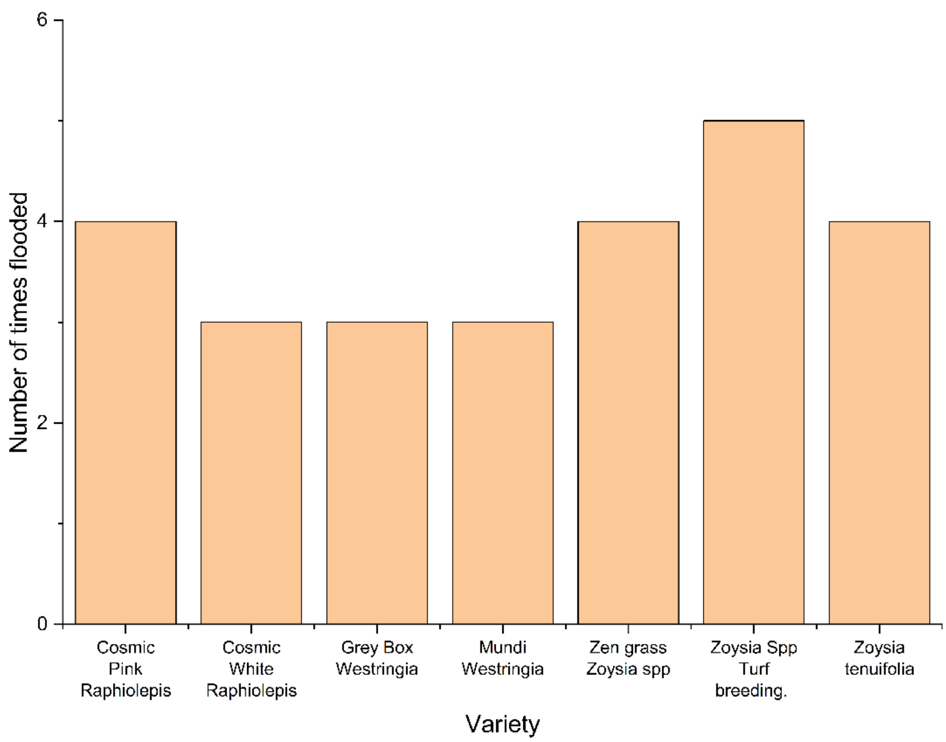

Figure 37. Number of floods experienced by *Raphiolepis*, *Westringia*, and *Zoysia* varieties in testing area 3.

Two *Rhaphiolepis* varieties were observed in these floodplains. One Cosmic Pink plant and two Cosmic White plants were planted and survived the floods. This means that *Rhaphiolepis* can handle excessive surface moisture and survive under these conditions. Two *Westringia* varieties were considered in this study. Both varieties survived three floods with a 100% survival rate. The plants observed were mature.

Three *Zoysia* types were planted in the floodplain. Zen grass and *Zoysia* tenuifolia experienced flooding four times. Meanwhile, *Zoysia* spp (for turf breeding) experienced flooding five times. All the Zen grass survived the floods, and the grass became a thick mat and stayed green after the flooding occurred.

One *Zoysia tenuifolia* died during the flooding. However, the remaining plants that survived were sick-looking and had very few new shoots. The *Zoysia spp.* (for turf breeding) had 6 plants that survived the flooding. However, 9 plants died. These plants were placed in a very low area and sat underwater for a very long time. This shows that flood survivability depends on the variety, and is evidence that breeding for Zoysia flood survival is important.

A turf grower survey, and large turf growing areas were evaluated, with both *Empire Zoysia* and *Nara Native Zoysia* surviving all floods well. *Couch turf* also survived well. *Buffalo grass* results were mixed, and survival was dependent on the variety and age. *Kikuyu* in general survived the floods poorly. Note: turf harvesting after the floods was not evaluated.

Table 12. Pearson correlation table of the plants in testing area 3.

Floodplains			
Pearson Correlations			
		Number of times flooded	% Survival Rate
"Number of times flooded"	Pearson Corr.	1	-0.19743
	p-value	--	0.0668
"% Survival Rate"	Pearson Corr.	-0.19743	1
	p-value	0.0668	--
2-tailed test of significance is used			

Table 12 shows the Pearson correlation table for the plants in testing area 3. It shows that at 90% level of confidence, the number of times flooded and the % survival rate of these plants has a negative relationship. This means that regardless of what plant experiences flooding, the smaller the number of floods the plant experiences, the better chance the plant will survive.

Chapter V

Conclusion and Recommendations

Conclusion

The negative impact of rapid urbanisation has been enormous on our environment. Because of this, there is an enormous loss of biodiversity, erosion problems, nutrient shedding, waterlogging, and other problems occurring, especially in urban areas. To tackle these problems, careful landscape planning is needed. This entails finding suitable plants that can withstand extreme conditions while helping to reestablish the biodiversity in the area. This study provided key results to help landscape planners what plants to grow in wet feet conditions.

This study examined the survivability of different landscape plants in extreme wet conditions. There were three testing areas considered in this study. The first area consisted of heavy clay-type soil which was kept saturated with water with runoffs or irrigation. Different *Lomandra* varieties were planted in this area. It was observed that Evergreen baby and Shara were the two *Lomandra* varieties that thrived under wet feet conditions in heavy clay-type soils. The two varieties exhibited a 100% survival rate in all the trials conducted in testing area 1.

Another experiment was conducted in testing area 1 where two treatment methods against root rot diseases were evaluated. Tanika *Lomandra longifolia* plants were planted in testing area 1. There were three setups. The first setup was the control setup. 1 g/L Phyto guard and 4 mL/L of Rhizovital were given to Tanika plants in the second setup. The plants in the third setup received 1.7 mL/L of Agri-Fos. It was found that using Phyto guard and Rhizovital can increase the survival rate of Tanika plants in wet feet conditions with root rot diseases by up to 62.5%.

Meanwhile, the second testing area was a plot that mimics bioretention swale conditions. The plant health of the plants on three occasions – 2017, 2020, and 2022. It was observed that different varieties of *Rhaphiolepis*, *Lomandra*, and *Westringia* can have different plant healths when planted in bio-retention swale conditions.

It was also observed that plant age has an inverse correlation with plant health in most plants planted in the bio-retention swale. Very young *Pennisetum* died whilst older *Pennisetum* all lived. Table 13 shows the varieties that thrived in permanently wet conditions of soils mimicking a bioretention swale with constant water runoff. Table 14 shows those varieties that had acceptable quality after being planted under the same conditions.

Table 13. Varieties that thrived in permanently wet conditions of soils mimicking bioretention swale with constant water runoff.

Just Right® *Liriope muscari* 'LIRJ'
Cosmic White™ *Rhaphiolepis indica* 'RAPH01'
Grey Box™ *Westringia fruticosa* 'WES04'
Mundi™ *Westringia fruticosa* 'WES05'
Shara™ *Lomandra fluviatilis* 'ABU7'
Trophic Cascade™ *Lomandra hystrix* 'LHWP'
Lucky Stripe™ *Lomandra hystrix* 'LMV200'
Better John™ *Callistemon viminalis* 'LJ1'
Green John™ *Callistemon viminalis* 'LJ23'
Macarthur™ *Callistemon viminalis* 'LC01'
Slim™ *Callistemon viminalis* 'CV01'
Amethyst™ *Liriope muscari* 'LIRTP'

Table 14. Varieties that had acceptable quality after being planted in permanently wet conditions of soils mimicking bioretention swale with constant water runoff.

Evergreen Baby™ *Lomandra labill*. 'LM600'
Amethyst™ *Liriope muscari* 'LIRTP'

The last testing area was a floodplain where different plants were grown. The plants in this testing area experienced multiple floods. The survival rate of the different plants was recorded. The results showed that most of the plants planted in the floodplain survived the numerous floods and thrived and grew into mature plants. However, there are few plants that did not thrive under this condition. Table 15 shows the list of plants to avoid when planting in floodplains.

Table 15. Plants that did not thrive when planted on floodplains.

Acacia binervia	Lom 3pp.03 *Lomandra*
Acacia melanoxylon	Lom 5.12 *Lomandra*
Acacia redolens	Lom SS.03 *Lomandra*
Acacia fimbriata	*Myoporum Insulare*
Callitris Spp	*Pimelea*
Bannanna Split™ *Dietes*	
Gazania	

This study recommends the following plants listed in Table 16 when planting in wet feet conditions, floodplains, and bio-retention swales.

Table 16ss. List of plants that were observed to thrive in multiple examples in wet feet conditions,

Agapanthus	*Casuarina cunninghamiana*	Katrinus deluxe *Lomandra*	Obsession™ *Nandina*
Aloe	*Casuarina glauca*	*Lomandra* 3RR.04 Shara Blue	Orange tree
Nafray *Pennisetum alopecuroides*	*Cordyline* floodplains, and bio-retention swales. (Note; If permanent water runoff see table 13.)	Lucky Stripe™ *Lomandra*	Green Mist® *Phormium*
Pennisetum alopecuroides	*Cupianopsis anacoides*	Nyalla® *Lomandra*	*Plectranthus cillatis*
Purple lea *Pennistum alopecuroides*	Breeze® *Dianella*	Shara™ *Lomandra*	Cosmic Pink™ *Rhaphiolepis*

Baeckea virgata breeding	Lucia® *Dianella*	Tanika® *Lomandra*	Cosmic White™ *Rhaphiolepis*
Callistemon ground cover selection	*Dietes* Fine Devine	Trophic Cascade	Grey Box *Westringia*
Callistemon Slim	Blue Horizon™ *Eremophila*	*Magnolia*	Mundi *Westringia*
Common *Callistemon spp*	*Fraxinus griffithii* New breed	*Melaleuca linariifolia*	Zen grass *Zoysia spp*
Green John™ *Callistemon*	*Yalba*	*Melaleuca* Narrow form	*Nara Native Turf*
Macarthur™ *Callistemon*	Isabella® *Liriope*	Yareena™ *Myoporum*	*Empire Zoysia*
Red Alert™ *Callistemon*	*Liriope* Just Right	Blush™ *Nandina*	
Camelia	Katie Belles™ *Lomandra*	Flirt™ *Nandina*	

Recommendation

This study provided significant data regarding which landscape plants to use in wet feet conditions. Future studies should be conducted regarding the mechanism of how these plants adapt and survive these conditions. Since the data gathered in this study were based on real situations, studying the effect of wet feet conditions on various experimental situations can further give insight into the maximum and optimum wet feet conditions that each plant can withstand.

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