Edaphic Zoning and Species-Site Matching to Assist Re-vegetation of Indigenous Species at the Styx Mill Reserve

A dissertation submitted in partial fulfilment of the requirements for the Degree of Bachelor of Forestry Science with Honours

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2014

Abstract

The Styx Mill Reserve is located in Belfast, Christchurch and is managed by the Christchurch City Council. Who aim to re-establish indigenous vegetation to large proportions of the area. These efforts have been successful in some sections of the Reserve; but large areas of the Reserve remain in grass and other weeds. The purpose of this investigation was to evaluate the presence of 5 hypothesised edaphic[1] zones in a 10 ha study area, with a future aim of matching establishment practices to these edaphic sites. Findings indicated that all zones have significantly different vegetation and soil characteristics. Consequentially methods of native re-vegetation must be different in each zone if successful re-establishment of native species is to occur.

Based on confirmed edaphic zones and client input, a site matched management plan and species list for one zone was developed. This aimed to increase the health and survival rates of plantings. Site modification followed techniques used at sites with similar conditions that have had successes in establishing woody vegetation. The effect of hydrogel on heath and survival levels was also trialled. To assess species suitability, five species were selected based on their abilities to survive the site conditions. Due to a combination of frost damage and ungulate browse, only totara survived and demonstrated good health scores. The frost factor is difficult to mitigate, hence species affected severely by frost are not recommended. The browse issue is easier to mitigate and it is felt that the two species heavily browsed, but not frosted are likely to be suitable. This resulted in ribbonwood, totara and kōhūhū being recommended. The time period did not allow assessment of the hydrogel treatment. Insufficient trial numbers exist to continue trials assessing future growth and survival rates over a longer time scale.

Key words: Re-vegetation, Edaphic, Indigenous, Ecology, Forestry, Hydrogel, New Zealand, Styx Mill Reserve

[1] Edaphic; ecology of, produced by, or influenced by the soil (Oxford Dictionary)

Acknowledgements

I would like to acknowledge the assistance of the following Christchurch City Council staff; Joe Cartman, John Parry, Trevor Partridge and Antony Shadbolt. Larry Burrows (Landcare Research) and Trevor Partridge (CCC) provided valuable advice about the vegetation sampling and species selection.

The project was supervised by Dr Mark Bloomberg (School of Forestry, University of Canterbury). This project was funded on a 50/50 basis by the University of Canterbury summer scholarship programme and the Styx Living Laboratory Charitable Trust.

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1. Introduction

The Styx Mill Reserve is a park located in Belfast, Christchurch. The total area of the Reserve is 60 ha; this study is focused on a 10 ha study area located in the middle region of the Reserve (Figure 1). The purpose of this report is to identify different edaphic zones within the Reserve and using this knowledge, match species and management plans to at least one of the edaphic zones to facilitate the ecological restoration of the Reserve.

The area is located in an old channel of the Waimakariri River and has been significantly modified by farming practices and excavation of storm water storage ponds. There have been successful efforts to re-establish native vegetation to sections of the Reserve, but large areas of the reserve remain in pasture grass and introduced weeds. Although some of these areas have been planted with indigenous vegetation they are struggling to establish dominance on the sites.

To stratify an area into edaphic zones there needs to be an accurate understanding of the specific land characteristics in the area (Hoopes & Hall, 2002). The differences in these characteristics combined with differences in vegetation define the edaphic zones. Styx Mill Reserve is situated in a naturally variable and human modified environment (Basher, 2000; Brown & Webber, 1992). Due to this there is expected to be significant differences in soil characteristics. The Reserve is primarily located in a depression and has varied micro-topography (Christchurch City Council, 2013). These variations are expected to influence vegetation types present at the site, giving clear indication of edaphic zoning and influencing the future species choice for re-vegetation (T.Partridge, personal communication, 3/12/2013).

The second part of this report will focus on the implementation of a zone specific management plan and the selection and the trial of five species that are believed to be suitable, in one specific edaphic zone.

2. Back ground and literature review

2.1 General overview

New Zealand is considered one of the biodiversity hot spots of the world, partially due to the high level of endemic species and associated globally unique ecosystems (Myers, Mittermeier, Mittermeier, da Fonseca, & Kent, 2000). The value of this biodiversity cannot be overstated and there is a responsibility to ensure the survival of the multiple species and environments that this is composed of. This value links into our economy, quality of life and our identity as a nation (Department of Conservation & Ministry for the Environment, 2000).

The New Zealand Biodiversity Strategy (2000) clearly outlines the responsibilities and actions needing to be taken to maintain and enhance these values. The third goal: "halt the decline in New Zealand's indigenous biodiversity" which includes restoring and maintaining natural ecosystems, is of particular relevance to this project (Department of Conservation & Ministry for the Environment, 2000).

The Christchurch City Council (CCC) published a series of goals in their "Ecological Strategy" publication (2008), which included a goal to enhance and maintain biodiversity within the City boundary (Christchurch City Council, 2008). The Styx Mill Reserve is one of these areas that this goal applies to.

The establishment of native vegetation at the Reserve by the CCC started in 1986 when the CCC became the Reserve managers. Since then significant areas of native vegetation have been established (Styx Living Laboratory Charitable Trust, 2010). However, establishment difficulties believed to be related to frost, desiccation and inter-species competition have resulted in failures in some areas (A.Shadbolt, personal communication, 19/11/2013).

2.2 Why is edaphic zoning important?

Edaphic zoning delineates areas based on the environmental constraints, limitations and potentials of the environment that are expressed through site ecology. If significantly different edaphic zones do exist, it is an indication that there are significant differences in the constraints and limitations of the site. To establish vegetation successfully an understanding of these limitations is desirable, as it allows more accurate species-site selection and implementation of relevant management activities.

2.3 Previous research

2.3.1 Edaphic zoning

A literature study of the area highlighted a lack of data on the Styx Mill Reserve. No literature with sufficient detail to create the proposed edaphic map exists for specific grass, weed and soil data at the Styx Mill Reserve (Basher, 2000). However, a generalised large scale soil mapping data for the Belfast area does exist (Basher, 2000; Landcare Research, 2011). The Reserve is situated in an old Waimakariri river bed believed to be flood plain surface dating from <300 years (Brown & Webber, 1992). The basic soil type is classified as a Te Kakahi stony sandy loam which is a poorly drained flood plain soil formed of fine sediment and gravels (Landcare Research, 2011). This classification does not provide details on the localised soil variations with the Reserve area. The area has been significantly modified by historical land clearing, continued agricultural use and more recently the excavation of storm water storage ponds (A.Shadbolt, personal communication, 19/11/2013), which renders the existing mapping largely irrelevant.

2.3.2 Site-species matching for ecological restoration

Examining the available data revealed informal and formal species lists and planting practices for the Canterbury district (Basher, 2000; A.Shadbolt, personal communication, 19/11/2013), however no official specific planting lists or planting practices were found to exist for the Styx Mill area. The wider studies for the Canterbury regions were modified through consultation with a senior CCC botanist to develop a suitable species list for the study area (T.Partridge, personal communication, 3/12/2013)

2.3.3 Assessment of suitable management practices

The selection of species to match site conditions is a key consideration to achieve successful establishment (Davis & Meurk, 2001). This is often difficult in situations where the objective includes establishing ecologically and historically relevant species into a modified area. Achieving full re-establishment of final forest composition in one planting event is unlikely to be successful, with many species requiring the modified conditions provided by other individuals (Padilla & Pugnaire, 2006). Because of this pioneer-type species that match the site characteristics are suggested for initial establishment. Consideration should be paid to the origin of genetic material to be used; this can have both ecological importance and can assist in establishment through environmental evolved genetic material (Porteous, 1993). Although no specific plantings list exist for the zones identified wider studies incorporating areas with similar characteristics do exist. Based on this, these wider studies for the Canterbury regions were modified through consultation with a senior CCC botanist to develop a suitable species list (T.Partridge, personal communication, 3/12/2013).

Weed management

Native vegetation is often out-competed by introduced species resulting in decreased survival and growth rates; as a result the importance of controlling inter-species competition is high (Davis & Meurk, 2001). This factor can be particularly high in areas that suffer from moisture deficits. Removal of short weedy vegetation in immediate vicinity of the planting can also mitigate frost damage. Typically vegetation competition control in New Zealand is managed with herbicides. For pre-plant competition control, chemical treatment is recommended, specifically knock-down type treatments with no residual effects, such as glyphosphate based spray. Due to indigenous vegetation being highly sensitive to chemical sprays, it is important that pre-plant sprays are residual free. (Harrington & Gregory 2009; Harrington & Schmitz 2007; Porteous, 1993) However due to; a lack of information on the effect of herbicides on native species, the high sensitivity of natives, the wider range of vegetation types present in the same vicinity, and inaccuracy of application, chemical sprays are not always suitable for post plant competition control (Harrington & Gregory 2009; Harrington & Schmitz 2007) . For post-plant weed control, wood mulch around the base of planted species is effective at reducing competition. This also removes the risk of damage to plants that is very high when post-plant weed control is done mechanically or chemically (Porteous, 1993).

Deep ripping/cultivation

Deep ripping is the use of a tractor-towed tine to rip and disturb a trench through the soil, usually to a maximum depth of one metre. The selected vegetation is then planted in or near the ripped area. This is done to; increase drainage, increase aeration, provide channels to intercept surface run off (increasing moisture content in the vicinity of planted trees) and allow the roots to penetrate further into the soil increasing access to resources (Guild, 1971; Madeira, Melo, Alexandre, & Steen, 1989). This can greatly increase the chance of survival of recently planted vegetation (Milligan, 2000). The effects of deep ripping are most significant in shallow, compacted (dense) and stony soils (Guild 1971; Prior, 1963), these are very similar to those in the Styx Mill Reserve (Prior, 1963). It is believed that although the species differ significantly to this study the effects of deep ripping will be similar. Deep ripping also facilitates planting of vegetation on difficult sites.

Control of pests

Browsing damage is a significant factor in the failure of establishment of native vegetation (Clarkson & Peters, 2012). This can either be through domestic or feral animals. Domestic browse is best controlled by exclusion, with permanent fencing being considered the only long term efficient option. Control of feral animals is more problematic with ungulates often being particularly difficult to control (Porteous, 1993). Techniques to control these include; trapping, poisoning, shooting, physical barriers and repellents (Clarkson & Peters, 2012; Porteous, 1993). Research in the Styx Mill Reserve area revealed that due to public use, domestic animals and town boundary limits, the most viable options are physical barriers and repellents (A.Shadbolt, personal communication, 19/11/2013).

Use of hydrogels

Hydrogels are hydrophilic gels that have the ability to absorb and hold large quantities of water (Xindong et al., 2011). The application of hydrogels to soils can increase the moisture content of the soil over increased periods of time (Silberbush, Adar, & De Malach, 1993). Although there is a large amount of literature available there are disparities in results with soil types, plant types and application technique appearing to be influential on the final effect. When incorporating hydrogels into soils the best results are obtained through mixing the gels into the soil (root zone) rather than in layers or bands (Kjelgren , Cleveland , & Foutch 1994). Although this method is more time consuming, the increase in effectiveness justifies the cost. Different soil types have significant effects on the effectiveness of hydrogels. Clay soils show smaller increases (1.8 x normal) in available water content than loam (2.2 x normal) and sandy loam soils (3.2 x normal) (Abedi-Koupai, Sohrab, & Swarbrick, 2008). The sandy loam soil type is likely to be most similar to the soil type present at Styx Mill Reserve (Landcare Research, 2011).

3. Research Objectives

3.1 Edaphic zoning

Problem statement

Establishment of native plant species at the Styx Mill Reserve is limited by biotic and abiotic site limitations, therefore it is important to match species and establishment techniques to the relevant zones. Although a data review was carried out in 2000 by Basher ("Styx River Catchment Data Review; Geology, Soils, Vegetation and Land Use"), including recommendations to match species to sites using a corresponding species list. There appears to be limited understanding and classifications of the site characteristics at a micro-scale. Potential exists to implement a micro-scale edaphic classification for the area which would assist in making future establishment decisions. This involves delineating zones by vegetation and physical land attributes to provide insight into management techniques and species selections for the proposed zones.

Research question

The purpose of this research is to assess if there is sufficient edaphic variation to differentiate the five hypothesised edaphic zones in the area. The null hypothesis is that the hypothesised zones have similar edaphic properties, with the alternative being that the hypothesised zones have different edaphic properties.

3.2 Establishment and site-species matching

Problem statement

The CCC is having difficulties in achieving effective re-vegetation of indigenous species at the Styx Mill Reserve. This is largely due to challenging site conditions and establishment plans of limited specificity to the area. Previous attempts at re-vegetation have sometimes resulted in poor survival rates and stalled growth rates. The Styx Mill Reserve Trust (in conjunction with the CCC) is planning to plant a four hectare block of the Reserve in the near future and want to achieve higher growth and survival levels than is being achieved using current establishment techniques. The purpose of this study is to attempt to develop a site matched establishment plan to trial ecologically relevant pioneer plants with nurse qualities. Five species will be selected for this trial based on field experiences (T.Partridge, personal communication, 3/12/2013) and available publications focusing on re-vegetation in similar areas (Basher, 2000).

Research question

The purpose of this research is to assess if some of the selected species have better establishment characteristics (survival and health) than other selected species. The null hypothesis is that all species will have equal health and survival levels at the end of the trial period, with the alternative being that the health survival levels of the species will differ at the end of the trial period.

3.3 Hydrogel testing

Problem statement

The low soil moisture content of the Sand/silt zone makes it likely that it will be difficult to establish even hardy vegetation. To increase establishment rates, artificially maintaining higher soil moisture is recommended. Due to the scale of planting and associated cost, the typical option of irrigation is not considered to be viable. Hydrogel is a product that can increase the soil moisture holding capacity of the soil over longer periods of time. However, past trials using hydrogels have returned highly variable results, so a trial to assess effectiveness in increasing health and survival rates in the specific application is being executed.

Research question

The purpose of this research is to assess if using Broadleaf P4 hydrogel (Broadleaf Industries Inc, 2000) at the recommended levels has a noticeable effect on health scores of the trialled species. The null hypothesis is that the hydrogel treatment will have no noticeable effect on health levels and survival, with the alternative being that the hydrogel treatment will have a noticeable effect on health and survival levels.

4. Edaphic zoning

4.1 Introduction

As previously described, the delineation and confirmation of edaphic zones within the Reserve has a high value for making future management decisions. This section provides background on the processes used to assess edaphic variation within the Styx Mill Reserve and will report and discuss the results found during the study, with consideration to the implications that these may have on future re-vegetation of indigenous species.

4.2 Methods

4.2.1 Identification of zones

The ArcGIS program (ERSI, Redlands, Ca, 909) was used to create an accurate map and identify different edaphic zones with the Styx Mill Reserve. This was done using Christchurch post-earthquake (2011) 0.1 m resolution photos (NZ Aerial Mapping, 2011) to provide a high resolution base map, with park boundaries identified using a Christchurch City Council (CCC) boundary map. A LiDAR layer was used to accurately assess elevation and topography (Christchurch City Council, 2013). Combined use of this map and field observations of vegetation types resulted in the identification and delineation of five areas believed to be separate edaphic zones. The delineation of zones was based on generalised vegetation assessment with observable vegetation differences present. The observable features were; colour, height and general type of the vegetation present (Appendix 1). The area was stratified into separate edaphic zones classified as; Sand/silt, Stream, Meadow, Swamp and Fill zone (Figure 1). This allowed the use of a random sampling within each stratum.

To create locations of sampling points (where all data is collected), random points within each edaphic zone were generated using the random points feature in ARC map. For larger zones (>2 ha) ten points were used, for the smaller zones (< 2 ha) five points were created. This resulted in 10 data collection points for the Sand/silt and Fill zones and five for the Meadow, Stream and Swamp zones. The sampling points were located using a GPS unit with associated northings and eastings. The edaphic zones and sampling point locations are shown in Figure 1.

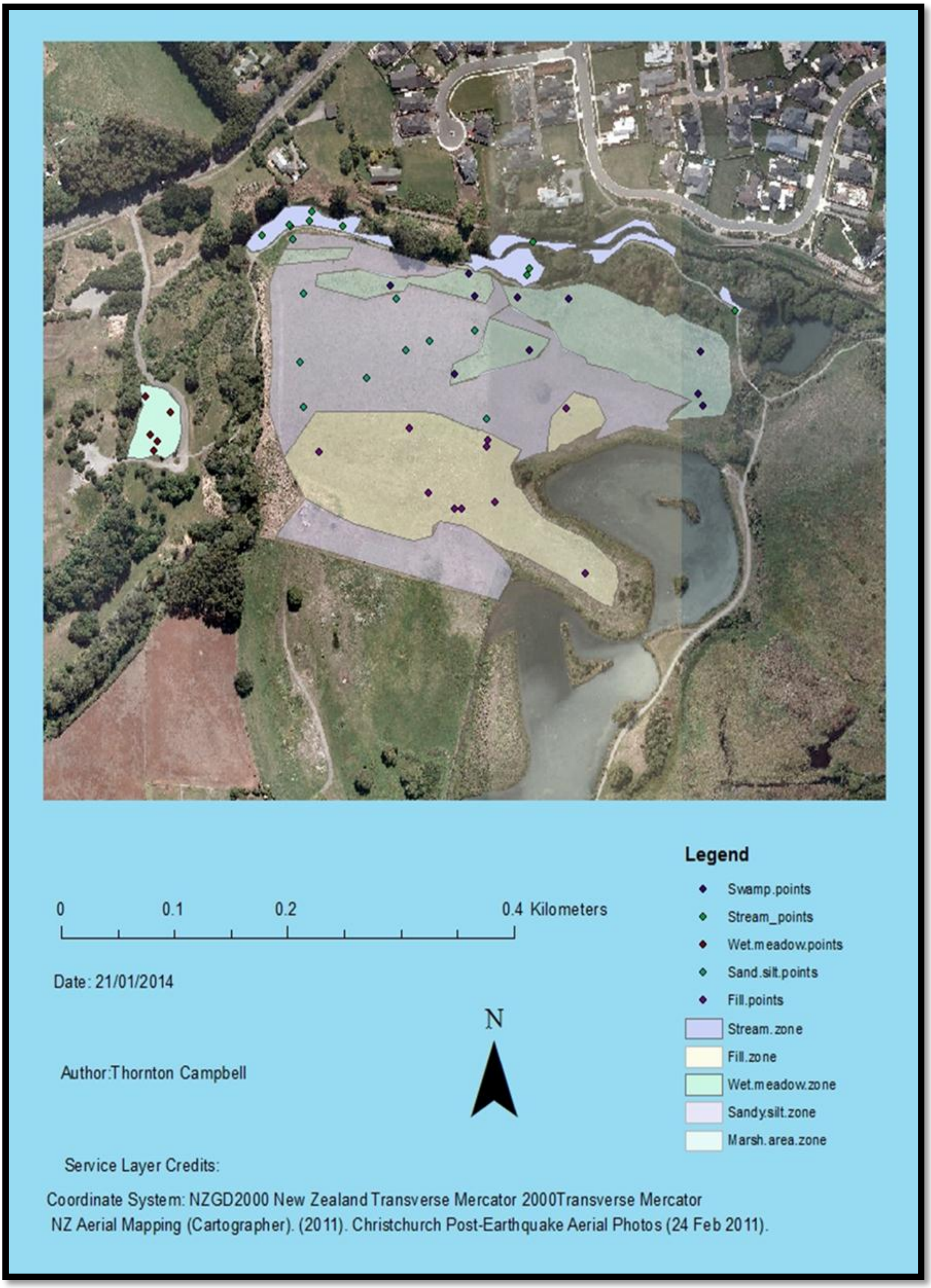

Figure 1: Study focus area and hypothesised edaphic zones and data sampling points.

The basic stratification of the area into initial sub-groups also served the purpose of reducing over-sampling of larger areas and under-sampling of smaller areas that can occur when conducting sampling of non-stratified areas (Carter & Gregorich, 1993). As the stratified edaphic zones are believed to be homogeneous this allows the use of a completely random plot location design within each stratum (Carter & Gregorich, 1993), as was used in this case.

4.2.2 Vegetation assessment

Debate exists over the most effective method of assessing vegetation characteristics, with trade-offs existing between accuracy, speed and relevance of data (Becker & Crockett, 1973; Morrison, Le Brocque, & Clarke, 1995; T.Partridge, personal communication, 3/12/2013; Stohlgren, Bull, & Otsuki, 1998).

For plot based sampling techniques each plant species has an optimum plot size to accurately represent it (Morrison et al., 1995). It is important to match plot size to the area as if the plots are too large frequency counts will be biased and contain a disproportionate number of species; if too small there may be an understated level of some species (Hurst & Allen, 2007). It is suggested that in most cases making an estimate of the plot size that will provide the best overall result and using this plot size for all species/areas is adequate. It also necessary to do this if comparable statistical values are to be achieved (M.Burrows, personal communication, 12/12/2013).

The Modified – Whittaker plot, based on an exhaustive search for plant species in a 70x50m plot, is described as being the benchmark for vegetation sampling (Stohlgren et al., 1998). However the low species diversity, resource limitations and the level of data required resulted in the use of the local frequency quadrat technique being used in this study. The National Vegetation Survey recommended the use of 4.5mx4.5m plots (Hurst and Allen 2007). These are designed for large scale land forms and due to local knowledge (T.Partridge, personal communication, 3/12/2013), it was decided that 1mx1m plots would be sufficient.

Due to the species composition present, a $1m^2$ plot divided into 25 smaller equal sized 0.2m x 0.2m subplots was used (T.Partridge, personal communication, 3/12/2013). The frequency count is displayed by a percentage measurement; this is calculated by the number of subplots that a species is found in multiplied by four (4 x 25 =100). A species is considered in the subplot if any part of the plant (roots, leaves, shoots) is found within the subplot. The subplot count can then be easily converted to a percentage of total area. This method is considered fast and accurate for this area (T.Partridge, personal communication, 3/12/2013).

4.2.3 Soil assessment

It was important to sample soils in each edaphic zone, because although there is a soil map and assorted data available, the detail is not at the level required to accurately delineate an edaphic zoning system.

Four soil augers per plot location were taken in a triangular pattern, with three points at 1.5 m spacing from the central point (located in the middle of the vegetation sample). This was done to correctly assess soil characteristics by accounting for variability that may exist over short distances due to the stony composition of the soil.

To assess the properties of the soil, augers were taken to a depth of 1 metre (where possible) and data were recorded in the changes of; texture, colour, moisture, structure, soil mottling and rock content.

To assess soil moisture levels present at the sites, three points at 1 metre distances from the sample plot centre were measured using a hand held Hydrosense metre (Campbell Scientific, Logan, Utah 84321 - 1784). This was done after recent rainfall so that differences in soil moisture would be more defined.

To account for potential variability between samples the following characteristics were recorded; slope, aspect, erosion, disturbance, land form, animal activity and any other potentially influential features. The elevation of each point was also recorded, using the LiDAR layer data for the area (Christchurch City Council, 2013).

4.3 Results

4.3.1 Vegetation assessment - species count

ANOVA analysis revealed significant differences between species count per plot (Figure 2) in some of the areas ($P = 4.6$ E-6). Using a Tukey analysis it was found that the sites to have significant differences were the Meadow and Fill zones ($p = 3.4$ E- 6), Sand/silt and Fill zones ($p = 2.1$ E- 4), Swamp and Meadow zones ($p = 0.013$) and Stream and Sand/silt ($p = 0.01$). The Fill zone recorded the least number of species while the Meadow zone recorded the highest number of species.

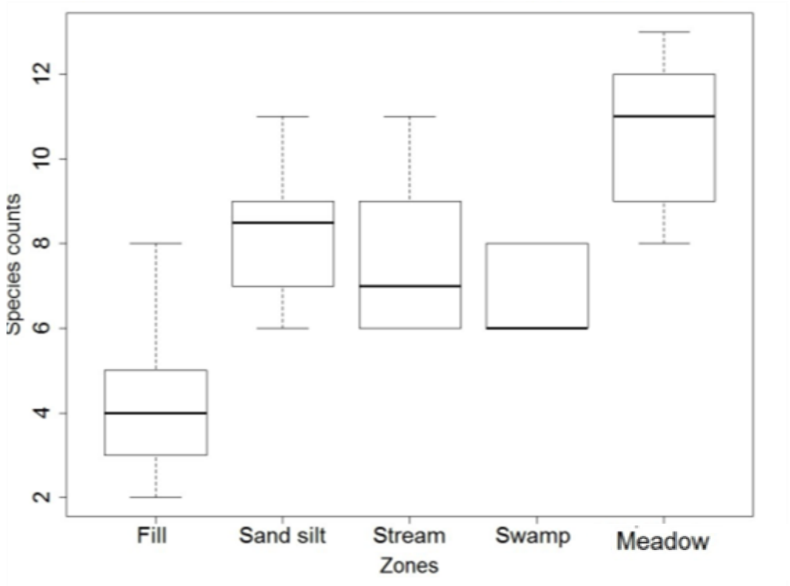

Figure 2: Species count per plot for each edaphic zone displaying; median, quartiles and minimum-maximum values.

4.3.2 Moisture content

ANOVA analysis revealed significant differences between some of the areas at a 95% confidence level, P = 2.2 E-16. The Fill zone had very low moisture content with the Sand/silt zone also being low. The Meadow and Swamp zones both recorded high water contents and the Stream zone recorded very high moisture levels (Figure 3). Using a Tukey analysis it was found that all the areas were significantly different at a 95% level except Swamp versus Meadow zones. Note that values above 60% for soil moisture are exceptionally high (Stream, Swamp and Meadow).

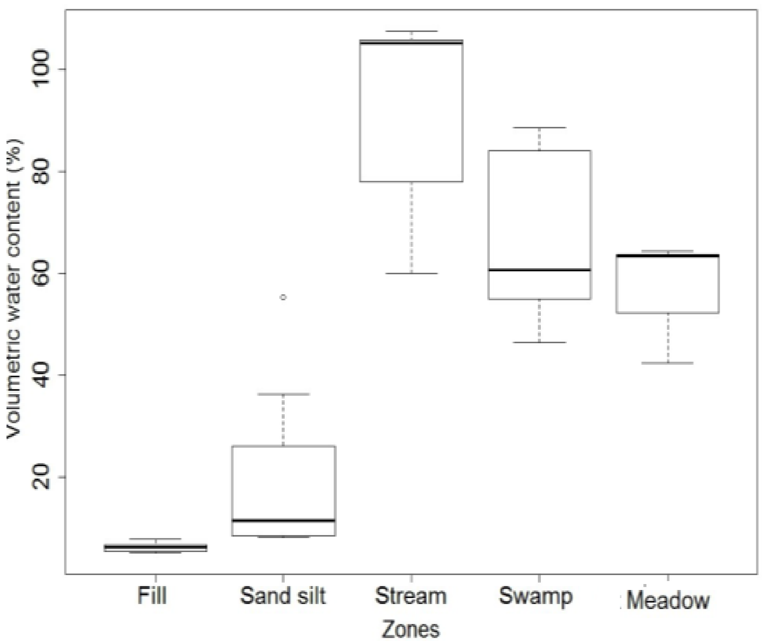

Figure 3: Volumetric water content for each edaphic zone displaying; median, quartiles and minimum-maximum values.

4.3.3 Vegetation height

It was initially believed that differences in vegetation height could be used as an indicator of site characteristics, but due to some zones being heavily grazed this result would be significantly biased and inaccurate.

4.3.4 Species Frequency counts and descriptions

The frequency measurement (Table 1) indicates how many subplots (25 subplots / plot) the individual species was found in (as a percentage). The top three dominant species from each area were chosen for this analysis. Although the standard deviations for each species in each zone were high, all areas displayed a different range and frequency of species. Table 2 shows how different species have significantly different habitat ranges based on the plants tolerance for moisture and soil quality. The large differences in range and frequency of species indicated the existence of different edaphic zones.

Table 1: Top three abundant species per zone

Species	Frequency (%)	Standard deviation (%)
Fill Zone	**n = 10**	
Vulpia (Hair grass)	88	17
Browntop (grass)	47	34
Yarrow	34	40
Sand/Silt Zone	**n = 10**	
Browntop (grass)	52	38
Yarrow	52	36
Sweet vernal (grass)	32	31
Meadow Zone	**n = 5**	
Creeping Bent (grass)	72	31
Self-heal	50	19
Butter Cup	45	38
Stream zone	**n = 5**	
Butter Cup	95	7
Yorkshire Fog (grass)	58	21
Lotus	46	33
Swamp zone	**n = 5**	
Lotus	62	50
Sweet vernal (grass)	47	13
Rushes	35	21

Table 2: Species habitat description

Species	Species Habitat Characteristics
Browntop	Medium – low fertility soils, present on a wide range of moisture conditions but more common on dryer soils (Lambrechsten, 1975).
Buttercup	Tolerant of wet soil conditions, and are often found in soils that are poorly drained (Harrington, 2014).
Creeping bent	Prefers moist localities on very diverse soil types (Lambrechsten, 1975).
Lotus	Commonly found in moist low-fertility soils (Charlton, 2012).
Rushes	Wet land plants reliant on moist conditions and tolerant of very moist conditions (Johnson, 2012).
Self-Heal	Typically found in moist to wet conditions, but can also tolerate dryness (Harrington, 2014).
Sweet vernal	Tolerates an extremely wide variety of soil and moisture conditions. Most common on dry soils with low – medium fertility (Lambrechsten, 1975)
Hair grass	Usually present on dry, open and infertile soils (Lambrechsten, 1975).
Yarrow	Drought tolerant species found in a wide range of conditions (Harrington, 2014).
Yorkshire Fog	Tolerates a wide range of soils including peat type soils (usually very moist) (Lambrechsten, 1975).

4.3.5 Elevation

All sites were located on river terraces. Differences in elevation did exist between edaphic zones (Table 3). It should be noted that in this study the relevance of these elevations is strongly related to the zones vertical distance from the water table (estimated at 8.5 metres to 9 metres).

Table 3: Land form of the edaphic zones

Zone	Sand/silt	Stream	Meadow	Swamp	Fill
Land form	Terrace	Terrace	Terrace	Terrace	Terrace
Elevations	10.4m – 11.6m	8.5m – 9m	10.4m – 11.6m	9.2 – 10m	11.6m – 12.6m

4.3.6 Description of edaphic zone soil characteristics

Soil characteristics were found to be significantly different for each zone. This included depth, moisture, rock content and composition.

Table 4: Soil characteristics grouped by zones

Sand/silt	Loamy A horizon with little or no humic layer. A horizon ranged from 5 - 15 cm, gravelly loam base ranging from 5- 25 cm. The loam A horizon layer had a moderate level of stones and soil was dry with little moisture. Not as rocky or dry as the fill zone.
Stream	Wet peaty top layer present in most auger sites to 15cm—(30cm-1m) depth, particularly those closer to the stream. Usually based on gravel (30-70cm) and rock layers. Some sites were located close to the path and it is believed that this may have skewed the result of these samples. All samples encountered free water, with some showing evidence of mottling.
Meadow	Significant horizon structure, with a shallow peaty humic layer (2-3 cm) followed by loamy top soils ranging from 15 - 20 cm. A very sandy layer occured between 15 -40 cm depth, this was usually based on a gravelly sandy layer (down to 90cm). It was common for this layer to be water logged and free water was present. This soil is moist in all layers.
Swamp	Loam top soil 15-20 cm deep based on a stony layer (20-35 cm), this was often based on a sandy loam layer (35 - 90cm) under which a stony sand layer with free water was often found. The soils at this site are highly variable, with some auger points having multiple assessable horizons while others were shallow and difficult to penetrate. Generally located in slight depressions and lower elevations which explains the free water found.
Fill	Shallow stony loam with maximum depth 30 cm, averaging 17 cm. Soils were very dry with no humic layer being recorded. Soil horizons were almost non-existent and many auger sites had large stones present on the surface.

4.3.7 Summary

The following describes key edaphic and botanical differences for the five sampled areas (summarised in Table 5).

Fill

These are the sites that are partially constructed from fill from the ponds. The natural soil is composed of heavier gravel loam with a maximum depth of 30 cm reached, averaging 17 cm. This site exhibited very low moisture content due to the site's higher elevation, shallow soil depth and significant stone content.

The Fill zone displayed the lowest number of species per plot averaging 4.4 species. The dominant species was low stature, very hardy species such as hair grass, browntop and yarrow. The limiting factor here is the shallow stony soil and associated low moisture retention.

Meadow

This zone has well defined soil horizons with a thin humic layer (3 cm), loamy A horizon (15-20cm) and a sandy layer (15-40cm) based on water logged gravels (90cm+). This area has higher moisture content than the Fill zone, but not as high as the stream zone and was located at medium elevations.

This site demonstrated the highest species count, averaging 10.6 species / plot. The dominant species were aggressive moisture-reliant species such as creeping bent, self-heal and buttercup. This was linked to the site's good moisture and soil characteristics with the limiting factors on establishing new vegetation likely to be plant competition.

Sand/silt

This zone has a shallow moderately stony loam A horizon (5-15cm) on a gravel base (5-25 cm). This results in poor moisture-holding capabilities and is significantly drier than all zones except the fill site. This zone was also located at relatively higher elevations further reducing the moisture availability.

This zone displayed an intermediate number of species with 8.3 species per plot. This was very similar to the Stream zone. The vegetation present is predominantly dry-land grass species such as browntop and sweet vernal, and a high frequency of yarrow. The limiting factors for re-establishing native vegetation are likely to be the poor soil-moisture characteristics with plant competition being an additional factor. Although at a higher elevation than other areas, the lack of large vegetation and open nature of the area may make it susceptible to frost events.

Stream

This is used to describe the area in the immediate vicinity of the Styx River. This site had a deep peaty surface horizon (15 – (30-100cm)) usually based on gravel (30-70cm) and rock layers. It had a high moisture content with free water present at almost all plots (A horizon) and low elevation. The high moisture content was linked to the close proximity to the water table/stream. The low elevation has the potential to increase the risk of frost damage.

There was a similar species count in this area to the Sand/silt zone (mean = 7.8 species/plot), although the reason for this may be a lack of soil aeration due to permanent water logging and the presence of dominant vegetation which can out-compete other plant species. The dominant species were moisture tolerant species such as buttercup, Yorkshire fog and *Lotus.* The limiting factors for this area are the weed species present, which may create high levels of competition and saturated soils, potentially affecting the ability to establish native species.

Swamp

The swamp zone had a loam top soil 15-20 cm deep based on a stony loam layer (20-35 cm), this was based on a sandy loam layer (35 - 90cm) under which a stony sand layer with free water is often found (35-90 cm). The soils at this site were highly variable, with some auger points having deep soils with distinct horizons while others were shallow and difficult to penetrate. The soils had high moisture contents, second only to the saturated Stream zone.

The site had a relatively low species count (6.8 species / plot). The dominant species are *Lotus,* sweet vernal and rushes. Limiting features are likely to be the high moisture content with these areas displaying ponding after rain and competition from moisture tolerant dominant species such as rushes.

Table 5: Summary of key edaphic and botanical differences for the five sampled areas

Zone	Soil type	Moisture content	Vegetation type	Elevation
Sand/silt	Thin loam (5 – 15cm) based on gravel (5 - 25cm).	Low 19%	Average 8.3 species/plot Dominant species - browntop, yarrow, sweet vernal.	Medium 10.4m - 11.6m
Stream	Peaty A horizon (15 – (30-100 cm)) on gravel (30 – 70 cm) saturated soil.	Saturated 91%	Average 7.8 species/plot Dominant species - buttercup, Yorkshire fog, *lotus*.	Very low 8.5m – 9m
Meadow	Significant layering moist loam (15-20cm) on a sand (15-40 cm) then gravel base (15-100cm).	High 57%	Average 10.6 species/plot Dominant species - creeping bent, self-heal, buttercup.	Medium 10.4m – 11.6m
Swamp	Highly variable – moist loam or peat (20cm) on stony loam (25-30cm), sandy loam layer (35-90cm) on stony sandy layer with free water.	High 67%	Average 6.8 species/plot Dominant species - *Lotus*, sweet vernal and rushes.	Low 9.2m - 10m
Fill	Shallow dry stony loam max depth reached 30 cm average 17 cm.	Very Low 6%	Average 4.4 species/plot Dominant species – hair grass, browntop, sweet vernal.	High 11.6m- 12.6m

4.4 Discussion

Although the Arcmap-GIS technique was accurate enough for locating random points, inaccuracies in delineation of edaphic zones resulted in some random points being located on sites within zones that were more similar to other zones. Zone boundaries were modified to more accurately reflect differences in soils and vegetation between the plots.

The most practical statistical test for both the volumetric water content and species counts per plots was an ANOVA analysis coupled with a Tukey analysis. This allowed the accurate analysis of the data for each zone and the portrayal of any differences between zones. This analysis method was suitable because the ANOVA analysis is based on numerical data sets, the sampling technique meant that each sample was independent and random and although sample sizes were small, the data distributions were believed to be sufficiently normally distributed. The only issue is that the *volumetric water content* population variances were not similar across all group levels; this is primarily concerning the Fill zone data, with the other zone variances being similar. However due to the differences visible graphically it is believed that the conclusion reached was correct and this population variance effect was minimal. Issues can exist with different samples sizes as occurred in both of these assessments, however in this case the sample variances are the same or smaller for the larger sample groups, indicating that this issue is very unlikely to be an issue (Quinn & Keough 2002).

As was expected, the areas with the more favourable conditions showed higher species/plot counts than areas with less favourable conditions. This was also expressed in the vegetation types present, with large differences in plant types indicating significantly different environments. Environmental conditions were expressed (and assessed) through both the soil characteristics and soil moisture content.

Although the soil characteristics do vary significantly, the soils that were present at all sites (except the stream zone) are consistent with the previously mapped soil unit Te Kakahi stony sandy loam. What varied however was the; amount of stones present, soil types underlying the top soil (A horizon) and the elevation in relation to the local water table, which affected both drainage and soil formation.

The stoniness of the soil has the ability to reduce the moisture holding capacity of the soil. The Fill zone was notably stonier than the other three zones with the Meadow and Stream zones having largely stone-free top soils and the Sand/Silt site being moderately stony. It is thought that this will have contributed to the sparser and hardier nature of the plants found in both the Fill and Sand/Silt zones (more so in the Fill zone).

The penetrable soil depth (depth to a resistant stony layer) varied greatly between the sites, with the Meadow and Stream zones having greater depth than the other zones.

It should be noted that the soil moisture is not just controlled by the soil characteristics but also the topography. The lower the elevation in relation to the water table the higher the soil moisture content, with the very low-lying Stream zone being saturated, and the Swamp and Meadow zones exhibiting free water at lower levels. The Sand/silt zone exhibited poor moisture levels compared with the Meadow zone due to being at a higher relative elevation to the stream. The Fill zone at higher elevations showed very poor moisture levels.

Soil moisture is considered to be a limiting factor in three of the five zones, with the Stream zone being limited by too much water and therefore suffering from a lack of aeration, while the Sand/silt and Fill zones suffer from a moisture deficit which limits the vegetation type and abundance. The only zones where moisture is not a limiting factor is the Meadow and Swamp zones. The most likely limiting factor at the Meadow zone is likely to be vegetation competition with the high number of plants, the competitive nature of the species present and good growth conditions resulting in high competition levels.

5. Site matched management plan

5.1 Introduction

The second section of this report is focused on selecting site-matched species and developing a management plan that is suitable for the selected focus area. Based on the client's preference the zone focused on is the Sand/silt zone. As a result, this section focuses on the trialling of five species within the Sand/silt zone of the Reserve; it also assesses the effectiveness of a hydrogel product on plant survival and health. Results are reported and discussed, with the key focus being on implications that these results have on future re-vegetation of indigenous species in this edaphic zone.

5.2 Methods

5.2.1 Trial area

The edaphic zone selected for the trial is the Sand/silt zone delineated by the previous chapter. The decision was based on the client's preference, with the area being of current focus and with limited planting history. The key restricting factors for re-establishing native vegetation identified in section 4, are poor soil-moisture characteristics, inter-species plant competition and frost damage. The sample area selected for the trial is a cross-section of the zone measuring 120 metres long by 9 metres wide. The area has permanent sheep fencing. The area zone captures the edaphic variation present in the zone and results will be analysed to assess potential environmental effects.

5.2.2 Species selection

The species chosen for the trial were selected based on ecological relevance and the suitability of the species as colonisers and nurse species considering the site limitations. These are chiefly considered to be; low soil moisture, inter-species competition and frost (T.Partridge, personal communication, 3/12/2013). Based on this five species were selected; *Melicytus ramiflorus* (J.R.Forst/G.Forst 1776), *Pittosporum tenuifolium* (Gaertn, 1788), *Coprosma robusta* (Raoul, 1844), *Plagianthus regius* (Hochr, 1907) and *Podocarpus totara* (D.Don, 1832).

5.2.3 Site preparation

The trial area was ripped six weeks before planting to 0.5 metres deep with a one metre interval between furrows. To prevent over-aeration, soil was partially re-compacted by running the tractor tyre over the furrow.

Chemical spraying of the existing pasture was done with Roundup (Monsanto, St. Louis, Missouri, USA) four weeks before planting. This was effective in killing all vegetation before the planting day. The advised spray application technique is localised spot weed control centred on the individual plant zone, with a 0.5 metre kill diameter. This minimises the work required and is equally efficient at negating weed competition (Davis & Meurk, 2001). However, because of the closer proximity of seedlings (one metre) in this experiment a blanket spray of the area was done.

Planting occurred on the 27th of April; although this is slightly earlier than recommended (Milligan, 2000; Porteous, 1993), site conditions were favourable with soil moisture being considered sufficient. 200 of each species were trialled (1000 trees total). This provided adequate numbers for statistical power. Planting was at one metre intervals in the ripped lines with the species completely randomised. Planting was done using community work personnel.

To counter hare and rabbit browse, it was requested that a protein-based repellent would be applied in the nursery before planting and at subsequent one month intervals for three months. The initial repellent treatment did not happen and was discovered one week later and rectified 11 days after planting. Monthly repellent sprayings did not occur either.

To assess effectiveness of hydrogel application on health levels, 50 per cent of each species received the hydrogel treatment. This was also randomly assigned. The gel was poured into the planting hole, mixed with the soil and the tree was planted on top of the material as recommended. The hydrogel treatment was applied using the recommended levels as set by the manufacturer (Broadleaf Industries Inc, 2000). This resulted in 0.2 litres of hydrated material for the smaller individuals (broadleaf, mahoe, ribbonwood and kōhūhū and 0.4 litres for the larger totara seedlings.

5.2.4 Assessment technique

To assess species health a four class categorical classification system was developed. One week post plant a damage score system was also implemented using a similar classification.

Table 6 : Health score description

Score	Health score description
"0"	Completely dead with no chance of recovery.
"1"	Wilted or missing a large proportion of leaves, remaining leaves not healthy, chance of recovery does exist.
"2"	Foliage missing or partially damaged by frost, majority of foliage healthy, very good chance of survival.
"3"	Plant may be missing a small amount of foliage but remaining foliage is completely healthy, full survival expected.

Table 7 : Damage score description

Score	Damage score description
"3"	Completely defoliated or cut at base.
"2"	Missing large proportion of leaves, chance of recovery does exist.
"1"	Missing some foliage, very good chance of survival.
"0"	Plant may be missing a small amount of foliage.

5.2.5 Assessment dates

A planting health assessment was conducted one week after planting. After this both health and damage assessments were conducted at 4 week intervals. This resulted in a trial period of 16 weeks. For an overview of key dates view Appendix 2.

5.3 Trial results

5.3.1 Planting success

The trial aimed to establish five species with 200 of each species. Establishment error resulted in unequal numbers, subtotals are; broadleaf (184), mahoe (184), kōhūhū (173), ribbonwood (186), totara (197), totalling 924 individuals. Of this count, 50% of each species were meant to receive hydrogel treatment. The final number was different with treatment levels at (count then percentage); broadleaf (82: 45%), mahoe (77: 42%), kōhūhū (66: 42%), ribbonwood (85: 38%), totara (105: 53%). Overall treatment rate with hydrogel was 45%.

On planting day less than 1% of the trees exhibited poor health. This was comprised of seven mahoe which exhibited severely wilted leaves (health score “1”) and two ribbonwood exhibiting stem damage due to poor handling but expected to survive (health score “2”).

5.3.2 Species health results

Figure 4 displays health levels for the individual species over the course of the trial. Figure 5 displays the proportions of species that were considered “healthy individuals”. A healthy individual is considered to have a very good chance of survival, represented by the “2”-“3” scores. Based on this the result break down will be represented by “success” being in the“2”-“3” score with “0” and “1” scores indicating failure.

At the four week measurement broadleaf and mahoe showed the largest decrease in health scores (66% and 75% success), ribbonwood and kōhūhū also showed declines (82% and 90% success). Totara was unaffected.

The eight week measurement showed a very large decrease in health for both mahoe and broadleaf (3% and 8% success). Both ribbonwood and kōhūhū showed large decreases in health (49% and 63% success), while totara was unaffected. A large proportion of the score “0” mahoe and broadleaf individuals exhibited severe frost damage with burnt and wilted leaves. In severe cases frost damage also affected plant stems. Other trialled species also displayed slight frost damage to leaf tips, although not to a serious level.

The 12 week measurement showed a further decrease in health for mahoe, now almost non-existent (2% success). Broadleaf displayed similar patterns at 5% success. Ribbonwood had a large decrease from the week eight measurements (17% success) and kōhūhū showed a lesser decline (57% success). Totara showed the largest decrease in health recorded for that species over the trial, however it was still minor with no individuals below “2”.

The 16 week measurement showed a health score decrease to almost “0” for all species except kōhūhū (4% success) and totara (unaffected).

Figure 4 displays the health scores of the individual species across the assessment period. The assessment period covered 16 weeks from planting, with assessment at four week intervals, using the four point assessment previously described.

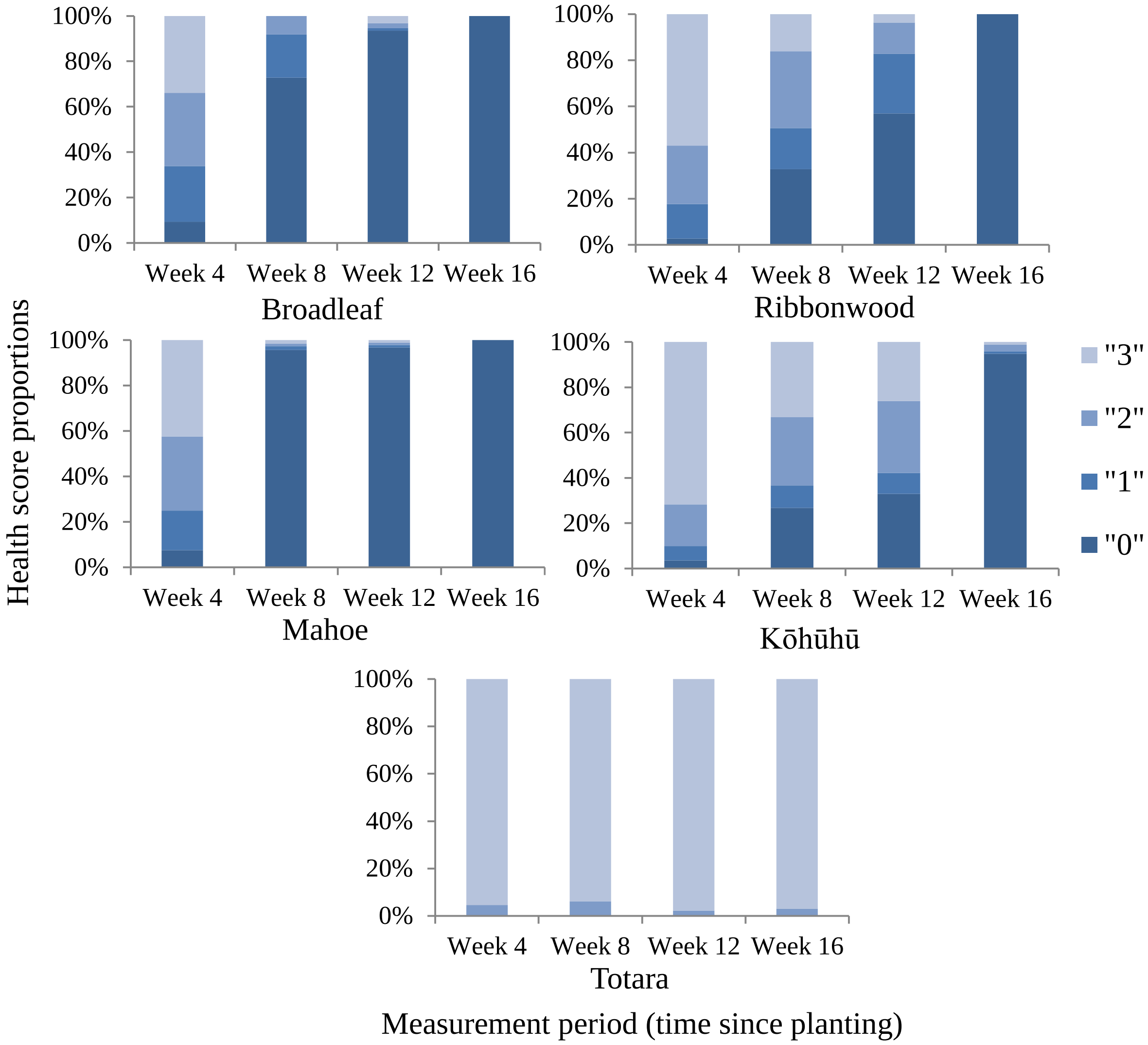

Figure 4: Health levels over a 16 week assessment period for each trialled species.

Success rates by health score

The general trend in Figure 5 is a large decrease in the health of four of the five species (totara being the exception) across the 16 week assessment period. Groupings exist, with a very similar, very large decrease in acceptable health levels in mahoe and broadleaf between the fourth and eighth week assessment periods. This coincides with the large frost event shown in Figure 7. The kōhūhū and ribbonwood individuals followed a different pattern to in mahoe and broadleaf displaying a more gradual decrease over the total time period. Totara showed very little decrease acceptable health percentages over the time period. It is probable that the slight decrease in acceptable health is recording error (believed to be ±2%).

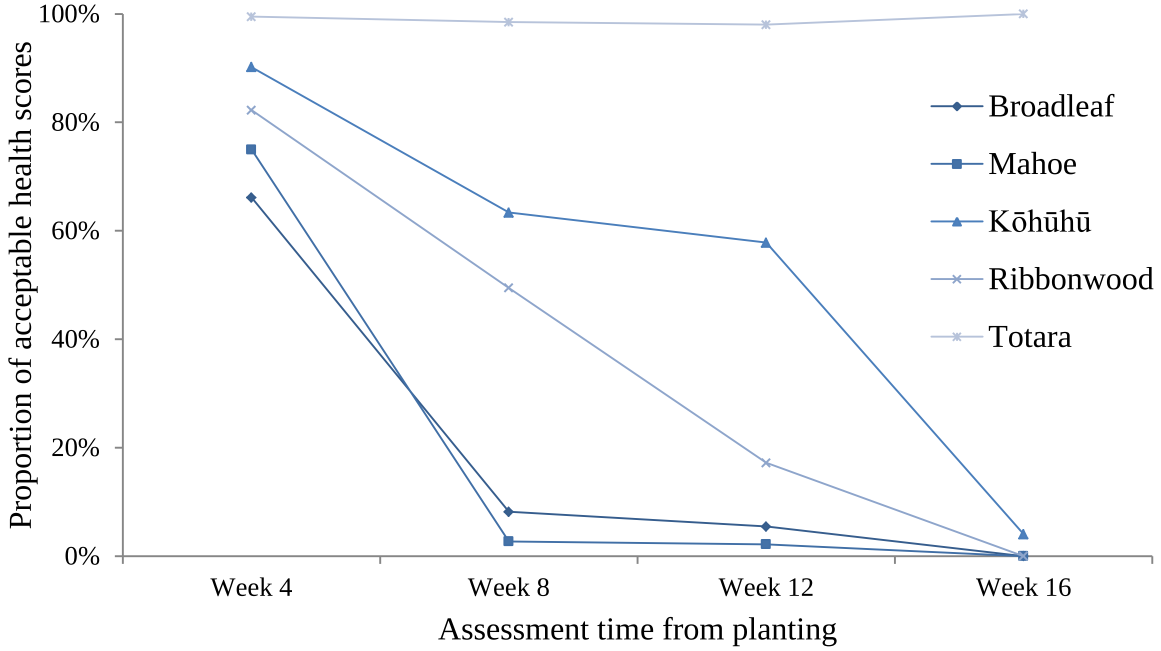

Figure 5: Acceptable health proportion over the time period

5.3.3 Overall result

The final result was clear, with four of the five of the species having overall health values of "0" (kōhūhū had nine individuals above "0"). The totara plantings had almost all plantings in the "3" (fully healthy category). This finding was confirmed significant by a Chi squared test (P = 1.6 E-12). The difference between species was confirmed to be all species versus totara, with no significant differences noted between the other species confirmed using a Tukey analysis (P > 0.05).

5.3.4 Factors influential on health scores

To understand causes of failure, two factors that were felt to be significantly influential were assessed. These factors are ungulate browse and frost damage. However the data collected made it difficult to make statistical inferences concerning the overall health relationship with these factors, with inconsistent measurements and subsequent relationships in data, between species being noted.

5.3.5 Species browse result

The first health assessment revealed that browse damage from hares was going to be a more significant factor than initially predicted. Based on this a browse/damage score was developed. This was assessed over the 16 week period as the general health score and uses a similar four point scale (Table 7). Figure 6 shows browse data grouped by species and assessment date.

As with the previous health data the assessment will be grouped. Damage scores of “2” and “3” will be grouped together as failure, as damage to this level renders the individual unsuitable.

The week four data shows an increase in damage across all species. The most affected species is broadleaf (34% failure); this is followed by ribbonwood and mahoe (16% and 15% failure) and kōhūhū (10% failure). Mahoe showed some damage, while totara showed very little damage (2% failure).

Week eight data displays a large increase in damage across all species except totara, with a similar ranking of species. Broadleaf was the most damaged (80% failure), while kōhūhū, ribbonwood and mahoe were at similar levels (45%, 41% and 44% failure).

The week 12 data displayed a smaller increase in damage. Broadleaf (95% failure), kōhūhū and mahoe were tightly grouped (48% and 47% failure). Ribbonwood showed the largest decrease (64% failure) and totara remained stable.

Week 16 data, kōhūhū (95% failure) and totara (0% failure) are only surviving species; the other three species have been browsed to non-existence.

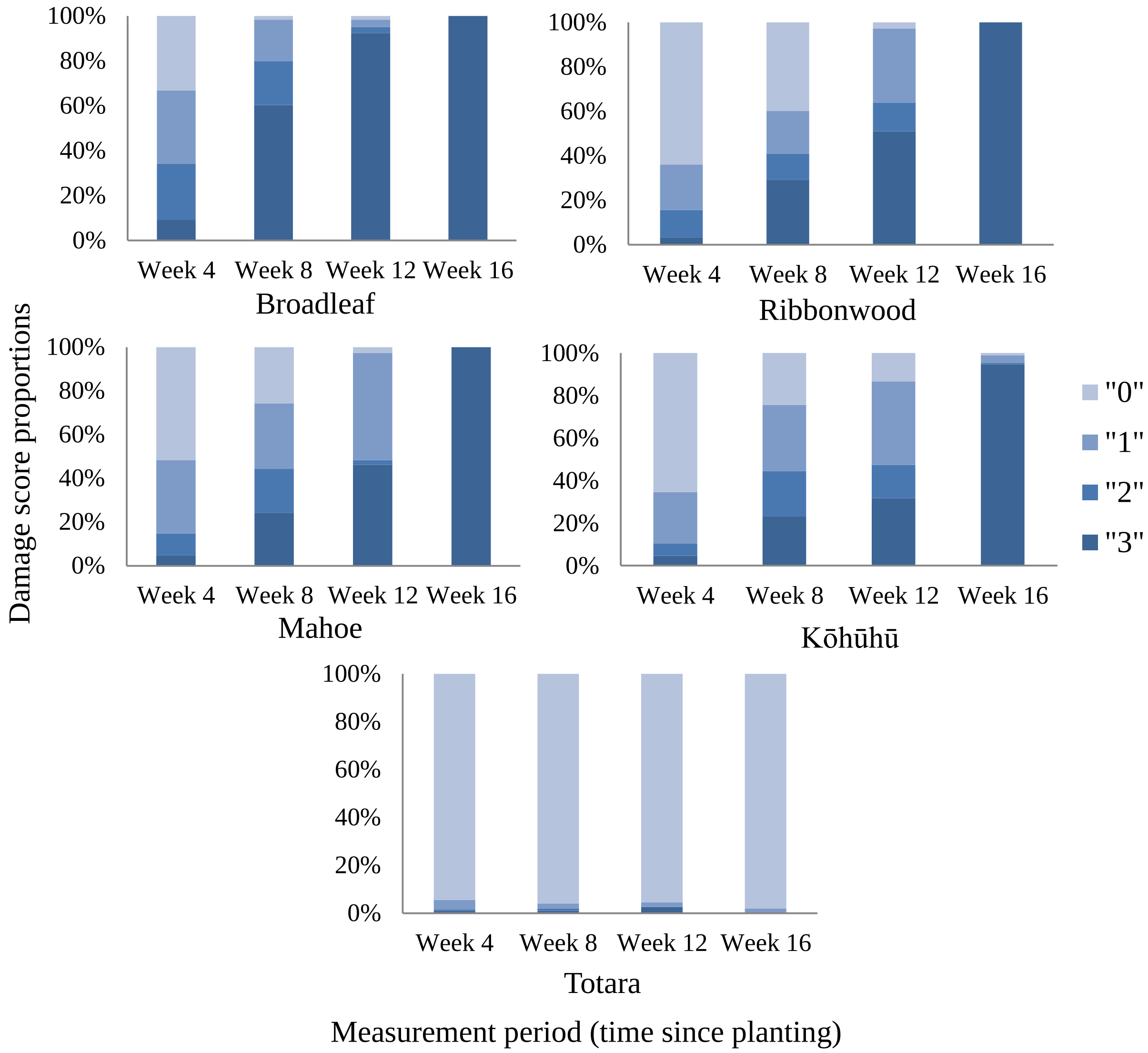

Figure 6: browse damage on foliage and stem material

5.3.6 Minimum temperature data assessment

Frost damage was previously noted as an establishment issue in the Reserve. To assess if this had an effect on the trial outcome, the minimum Christchurch temperatures over the course of the trial were examined.

The first significant frost event (circled) occurred five days after the four week assessment; this event occurred after a month of moderate to warm minimum temperature levels. Two more frost events were noted over the course of the experiment at 10 and 14 weeks.

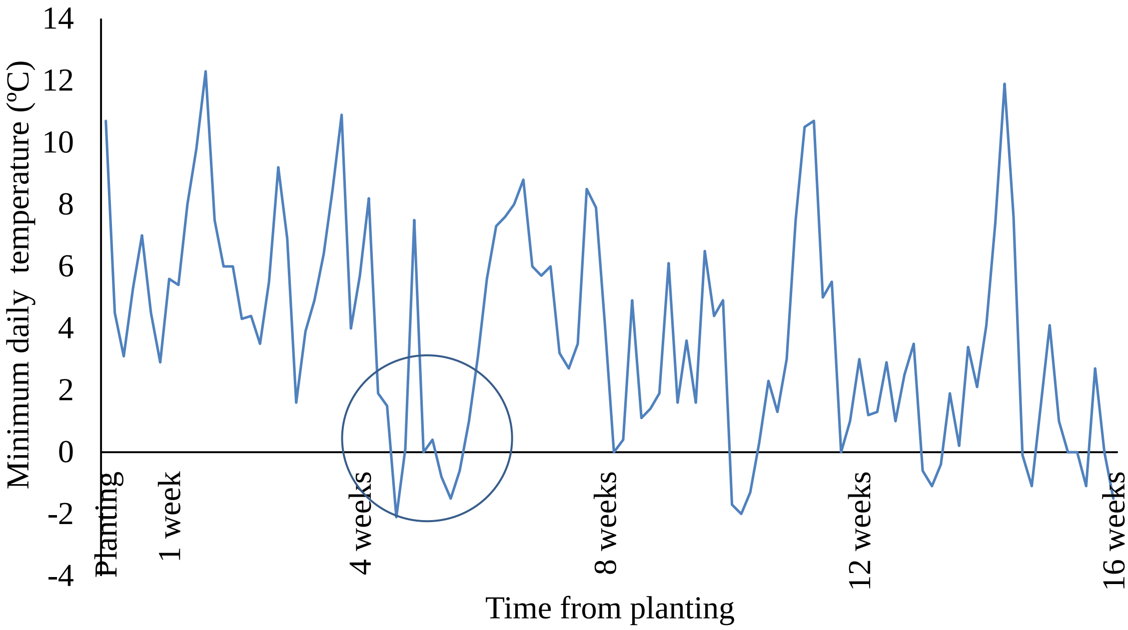

Figure 7: Minimum temperatures in Christchurch during trial duration (NIWA, 2014)

Assessment of health showed that after this event (Figure 5: week 8), there was a marked decrease in acceptable health levels of broadleaf and mahoe species. This health decrease to mahoe and broadleaf was observable in burnt, wilted leaves. Low numbers of ribbonwood, kōhūhū and totara did exhibit slight frost damage to the tips of leaves but not to a significant level.

5.4 Discussion

5.4.1 Site preparation and planting assessment

The site preparation was implemented on the specified time scale, with the four week time lag used for the pre-plant spray successfully clearing the vegetation cover and the six week lag for ripping allowing adequate settling of the soil. Although issues with planting quality by the Department of Corrections workers were raised, the final result was acceptable. With almost all the planted individuals were healthy, with a small number of mahoe dying as a result of transplant stress. The seedling trees supplied by the Council nursery were all healthy and of an acceptable size. Application of the hydrogel treatment was done to the acceptable standard.

5.4.2 Statistical analysis

A Chi squared test coupled with a Tukey analysis was suitable to assess the health and browse score data sets. It was suitable because of the ordinal nature of the health and browse data values, the size of the predicted results (> five) and the independence of each individual sampled points to each other (Quinn & Keough 2002).

5.4.3 Key factors

The final result was believed to be influenced by two main factors; feral animal browse and frost damage. Although water stress is believed to be a key factor in survival rates at this site, the time period of the study did not fall in any time of water deficit. Therefore this factor and the effectiveness of the hydrogel treatment cannot be assessed.

5.4.4 Browse damage

In the planning stages there was little mention of damage to previous plantings from ungulates in the park. However, on multiple trips both hares and rabbits were seen in the area. The original management plan developed with the Council involving the application of protein-based repellent to prevent browse damage did not occur as specified. The initial application was applied 11 days after planting, the first missed application was identified due to observable damage levels and the planned monthly applications did not occur.

Of the five species planted, only totara was unaffected by browse, which is a typical characteristic (Bergin & Kimberley, 2014). All the other seedlings recorded serious damage and is believed to have been the key component in the complete failure in survival of the ribbonwood and kōhūhū seedlings. It is also likely to have been the causation of failure of the mahoe and broadleaf if frost had not been an issue. Prior to the key frost event mahoe and broadleaf showed similar damage scores to ribbonwood and kōhūhū, indicating susceptibility.

Although some kōhūhū (4%) survived browsing this is not thought to be linked to the species behaviour, but the planting technique implemented by some of the workers. The kōhūhū seedlings were short (<20cm) and overzealous hole digging and planting often resulted in trees being situated partially below ground level. This seemed to provide some protection against browse.

The worst average damage incidence was registered between weeks 12 and 16. This resulted in all remaining individuals except totara being browsed to a fatal level. This may be due to heavy browse from sheep in the surrounding paddocks reducing grass cover surrounding the planting zone.

The protein repellent technique is a recommended browse reduction technique and it is felt that if the prescribed applications had been carried out, the browse level would be far lower. However it is recommended that in future more permanent lower maintenance browse control methods are employed. This could either be protective cages or more intensive control operations.

5.4.5 Frost damage

Initial communication with the Council indicated that frost was an issue with vegetation establishment in the area. To avoid this, a range of species believed to be frost resistant was selected and pre-plant spraying was conducted. Mahoe was the exception to this. Mahoe was selected because of a lack of data at the site and an interest from the Council (T.Partridge, personal communication, 3/12/2013) in its behaviour in an exposed environment.

Although attempts were made to mitigate frost damage, it still was a significant factor in survival. This was revealed by the first key frost event of the year (Figure 7). The high damage levels are believed to be linked to the relatively large change in temperature, going from milder minimum temperatures in the 5 to 8 °C range in the week prior, to -1 and -2°C levels over eight days. A rapid change in temperature such as this, is recognised as being more severely damaging than a gradual temperature decrease over time (Sakai, 1960). Significant frost damage was observed on mature broadleaf trees in established areas within the park, suggesting that this frost event was of a significant nature (Appendix 3).

Preventing frost damage via fast, basic and minimal site modification is a difficult and expensive task and therefore it is advised that pioneer species which are severely affected are not used. Based their proven frost susceptibility, broadleaf and mahoe species are not recommended as pioneer species for this site.

5.4.6 Hydrogel

Over the course of the trial there was no difference noted between plantings with or without hydrogel treatments. However it is felt there is inadequate evidence to come to a conclusion on the effectiveness of this treatment, as no prolonged dry period was recorded during the trial period. Due to the large scale failure of establishment it is recommended that further testing is done using solely the totara plantings over a significant dry period.

6. Weaknesses in experimental design

Edaphic zoning

A potential issue with the data gathered is the origin of some of the vegetation in some of the zones. This is linked to the site modification; with some sites having the majority of the species artificially planted instead of being naturally occurring. This could have been an issue in the Sand/silt zone, where a large majority of the species are planted pasture species. This could add significant bias to the assessment, with the potential for species abundances and type to not actually represent the site characteristics existing. This factor has been ignored in this study because the species that exist at this site were selected to succeed in this environment and have done with little maintenance. This indicates that they are good matched for the environment and are believed to provide a good indication of the site. It could however have exacerbated the difference in vegetation between zones.

Species and hydrogel trials

Upon data examination it became obvious that although the same assessment technique (scoring 0-3) was used to assess health and damage factors for each species, there were large disparities regarding the health/damage relationship between species. The disparities in data are linked to the different tree forms, which made equal assessment difficult. Although statistical analysis on the relationship between health and damage could not be conducted, the overall effect is negligible on the final conclusions and recommendations.

Although health data was gathered, there was a shortage of recorded data to indicate cause of death. Because of this, damage scores and frost events had to be used to assess cause of death. Although it is felt the correct conclusions were drawn they are based on inferences and observations rather than statistical testing.

Ideally a larger number of species would have been used to provide a larger range of potential species for the site. However this was not viable due to plot size and funding constraints while achieving statistical power.

The trial duration only addresses establishment over the autumn to late winter assessment period. It has been recognised that issues with establishment at this site are linked to moisture deficiencies over the summer period. Based on this, this study cannot assess the successfulness of differing species during this time period, or the effect of the hydrogel treatment of increasing health and growth rates.

Control plots for the management plan do not exist and it is assumed that failure to address the factors mitigated in the management plan (soil moisture and weed competition) will result in far lower growth and survival rates. Observed site data indicated this and literature supports this from a non-site specific view point.

The failure to apply the protein repellent at the correct dates is a key issue in assessing the viability of the management plan. However it did allow the recommendation of a lower maintenance pest management plan to be made.

7. Conclusions

There is sufficient evidence in both vegetation and soil characteristics to confirm that the five different edaphic zones initially hypothesized do exist. Due to these different zones being present, it is believed that each will need differing management techniques in order to achieve successful and relatively rapid re-vegetation with indigenous species.

During the establishment trial in the Silt/sand zone; ribbonwood, totara and kōhūhū revealed promising characteristics as pioneering species within the site over the trial period. All three appearing to frost resistant, although only totara was naturally browse resistant. Mahoe and broadleaf are not considered suitable for the site, as to modify the site to reduce frost damage is considered not feasible given the situation and a reluctance to engage in serious land modification.

The key issue concerning the large scale failure is considered to be the pest management strategy. The hare repellent was applied late and although a slight decrease in damage rates was observable in the period, after this it cannot be verified as effective. To achieve effective re-vegetation of any species (except unpalatable species such as totara), there will have to be more extensive measures taken against browse damage. If this was done; ribbonwood, totara and kōhūhū would be recommended as pioneer species for this site.

Although totara could effectively be used as a sole pioneer species for the site, it does not meet the goal of creating a native mixed species forest for the Reserve. Hence a better site management plan to negate browse damage allowing other less browse resistant species to be planted into the area is recommended.

Although recommendations can be made on initial establishment during the autumn-winter period, the trial cannot provide data to assess species health during the summer period. This is important as during the summer period there is a high chance of tree desiccation and subsequent failure. For all species except totara, this data cannot be collected from this site due to the extreme hare damage. This also reduces the potential to assess the effectiveness of hydrogel on health and survival rates. Although there is strong confidence placed in the selection criteria, it is recommended that further studies are conducted on the ability of the three recommended species at this site over the summer period.

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9. Appendix

Appendix 1

Example of visible ecological differences that facilitated initial hypothecations of proposed edaphic zones:

Swamp zone

Meadow zone

Stream zone

Fill zone

Sand/silt zone

Appendix 2

Key trial events and dates

Date	Event
8-10.01.2014	Soil and soil water assessment
13-17.01.2014	Vegetation assessments
17.03.2014	Ripping occurred
26.03.2014	Spraying occurred
27.04.2014	Planting date
4.04.2014	planting assessment
8.05.2014	Protein repellent spray application
20.05.2014	4 week assessment
20.06.2014	8 week assessment
18.07.2014	12 week assessment
10.08.2014	16 week assessment

Appendix 3

Mature broadleaf tree (age 20 years plus) in a low lying section of the Styx Mill Reserve exhibiting moderate to heavy frost damage (winter 2014).