An evaluation of the establishment, early growth, and nutritive value of native New Zealand shrubs'

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Abstract

Agriculture in New Zealand faces many challenges including a need to develop more environmentally focused production systems to help address issues including the need to revegetate step erosion prone hill country, improve indigenous biodiversity and improve water quality. In the past New Zealand has experienced increasingly unpredictable and severe weather which has resulted in severe damage, for example, the 2004 flooding event in the lower north island (Fuller, 2005). New Zealand has a large portion of land that is classed as hill country or steep land, much of which is also classed as highly erodible. These highly erodible areas are vulnerable to high intensity rainfall events; revegetation could help mitigate or reduce the effects of erosion.

The species that are currently used in erosion control on farms are often poplars and willows due to their ability to stabilise hill slopes and ease of planting. Native species are not often used in erosion control projects, potentially due to planting difficulties but more likely due to a lack of consistent and long-term information (Phillips, 2005). Species chosen for the present study have been shown to have benefits for erosion previously, as well as being preferred in some ungulate diets. These species were *Hoheria populnea, Griselinia littoralis*, *Pittosporum crassifolium*, *Coprosma robusta*, *Pseudopanax arboreus*, *Coprosma repens*, *Melicytus ramiflorus*, and *Salix kinuyanagi*. *S. kinuyanagi* is used as the control species in the present study due to its existing uses in slope stabilisation and forage supplementation on farms in New Zealand. The research objective of this study was to fill the gaps in the knowledge on certain native species and corroborate what is already known from the literature with results from this study, and assess their potential uses as forage.

To achieve this objective several species were assessed at two sites: Massey University Dairy No. 4, and Pongaroa Station, Mahia. Measurements included height and stem basal diameter at the start of the trial in July/August 2019 and following summer in March 2020, sampling leaf and edible stem (<5mm) for nutritional content and assessing vigour and survival at the end of the first summer following planting.

Survival and early growth at Massey No.4 were higher than at Mahia. Potential reasons for the differences in survival, and growth at Massey No.4 and Mahia, include unplanned browsing damage that occurred early on in the trial at Mahia, as well as the potential effects of the different aspects of the sites. Mahia had a north-facing aspects which has been shown to have effects on soil moisture, soil temperature etc. whereas the Massey No.4 site has a south-facing aspect. The nutritional traits of the native species tested compared favourably to *S. kinuyanagi,* which is utilised on as a browse shrub in New Zealand. Crude protein was highest in *H. populnea* for both stem and leaf material while metabolisable energy was highest in *P. arboreus* for stem and leaf samples. *C. robusta* foliage had similar metabolisable energy and crude protein to *S. kinuyanagi*.

Several species including *H. populnea*, and *C. robusta* showed good early growth suggesting they have potential to be effective species for mitigating erosion on hill slopes. However, further testing over time and at further sites is required to make firm conclusions about the potential for these shrubs as browse species.

Keywords: Native species, Forage, Ungulate, Palmerston North, Mahia, Nutrition,

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Dedication

I would like to dedicate this thesis to Talia, whose path was interrupted far too soon.

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List of abbreviations

N ……………………………………...Nitrogen (%)

P……………………………………Phosphorus

ME…………………………………Metabolisable Energy (MJ/kg)

CT…………………………………Condensed Tannins

NDF………………………………..Neutral Detergent Fibre (%)

ADF………………………………..Acid Detergent Fibre (%)

CP…………………………………Crude Protein (%)

SBD………………………………..Stem Basal Diameter

RCD………………………………Root Collar Diameter

DM………………………………...Dry Matter

DOMD ……………………………Digestibility of organic matter in the DM (%)

1. Introduction

New Zealand is a highly agricultural country, years of tradition are however giving way to more intensive practices, and with that comes the need for more feed for stock. The agricultural sector have accepted that droughts are a regular natural hazard that can have severe impacts not only on animal health but economically as well (Mol, Tait, & Macara, 2017). These extended dry periods and droughts often require supplementary feed to be brought in. While there has been research performed on the values of some native species in terms of nutrition, there has been little done concerning the potential for native species to be used as a viable fodder alternative. The importance of understanding the value of native species has never been greater as the potential uses as a supplementary forage in extended dry periods are poorly understood.

Current uses of native species on farms are restricted to uses such as shade, and revegetation projects on land that has been retired or is no longer productive. The Manawatu-Wanganui area has the largest area of land classed as highly erodible (2545.44km^2), the entire country has a total of 14,125km^2 of highly erodible land (Stats NZ, 2019). These figures show the scale of the problem and while this project is not studying the effect of native species on erosion, using hill slopes for the growth of native species provides an alternative to forestry or complete retirement of pastures. When making this transition to the use of native species as forage there are many aspects which need to be considered. These include the suitability for erosion control, growth requirements for native species, tolerances to different conditions, nutritional value, and productivity of selected species.

Main avenues of research will include the productivity of the species as well as nutritional values of the selected species as a potential forage for sheep and beef. The primary research question for this project can be phrased as is there a difference in productivity and nutritive value between species when planted on hill slopes. Also discussed will be any differences found between Manawatu ecotypes and Hawkes Bay ecotypes.

This project began in July of 2019 as a year-long project. Two trial sites were planted for this project, the first site with 8 treatments is in Paddock 25 on Massey Dairy farm No. 4. The second site has five treatments on the Pongaroa Station on the Mahia peninsula. Currently there is a gap in the knowledge concerning how nutritious native plant species are and how they could fit into modern farming practices in New Zealand. The species studied are *Hoheria populnea* (*H. populnea* or lacebark), *Griselinia littoralis* (*G. littoralis*), *Pittosporum crassifolium* (*P. crassifolium*), *Coprosma robusta* (Karamū), *Pseudopanax arboreus* (*P. arboreus*), *Coprosma repens* (Taupata), *Melicytus ramiflorus* (Māhoe), and *Salix kinuyanagi* (Willow). Each of these were selected based on the available knowledge of palatable species, growth, and availability. The Kinuyanagi willow species is used as the control or comparative species as this is already in use as supplementary herbage. In order to provide a realistic and comparison in terms of nutritional value perennial ryegrass is included in nutritional values. These values show a clear comparison for easier understanding of the nutritional value of native species.

2. Literature Review

This section will provide a thorough assessment of the current literature relevant to the research undertaken for this thesis. This review will address the background information needed for this research surrounding the land use capability system (LUC), followed by a section dedicated to the forage qualities and defensive adaptations shown by native New Zealand plants. A section for each species then follows reviewing the known literature surrounding each individual species. As there is varying degrees of research for each species, consistent information was not always available.

2.1. Introduction

Native plant species have had very little use in respect to their potential as forage in agriculture in New Zealand. This literature review will assess current information surround nutritional qualities found in native plant species with the purpose of this review being to examine the current literature surrounding the foliage nutritional traits of seven species of native flora. The seven species to be examined in this review are *Hoheria populnea, Griselinia littoralis, Pittosporum crassifolium, Coprosma robusta, Pseudopanax arboreus, Coprosma repens* and *Melicytus ramiflorus.* The aim of this review is to provide a detailed summary of the literature on these species in respect to the nutritional content such as protein, fibre, metabolisable energy, tannins, and forage quality of these species. This review will be ordered by species although, this review will not go into depth regarding root structure and biomass. It is however, expected that some species may not have large amounts of information available or that the information be largely dated as there was a surge in interest around the 1970's and 1980's which declined for some years. The classification systems used throughout this thesis requires further explanation. This includes the Land Use Capability classification system which will be explained in the following section.

2.2. Land use capability system

Throughout this section the Land Use Capability system or LUC system is explained here so as to provide better understanding of the two sites. The LUC system was designed to help achieve sustainable land management as well as aid farmers and others using land for agricultural or horticultural purposes (Lynn et al., 2009). Each designation is decided based on the interpretation of data in the Land Resource Inventory (LRI). This data is in turn based on field assessments of vegetation, erosion potential, soils, landforms and more. By providing an easily understandable system by which quick evaluations regarding potential uses for land within a polygon the system becomes widely accessible by those making use of the land.

The site's class is assigned according to the potential long-term use capabilities as opposed to short term activities (Lynn et al., 2009). The advantages of this include the accurate classifications of site characteristics. For example, if a site was classified according to its short-term potential, then intensive cropping or agriculture could change the site classification from 3e3 to a 5e3 (a detailed explanation is shown in section 2.2.1) within a short time frame, particularly if the soil was vulnerable to erosion and gullying. Class 6 and 7 land is often only suitable for grazing or forestry uses whereas class 8 land requires extreme conservation efforts (Lynn et al., 2009). Neither site used in this project has a class 8 rating. By grouping the land according to its general capability for sustained production, the limitations from factors such as topography, soil types, and climactic factors are included in the original analysis and do not require re-evaluations to be undertaken.

2.2.1. Layout of LUC classes

This LUC system has three parts to each designation. The first section is the main class, these range from numbers one through to eight in increasing degrees of physical and agricultural limitations (Lynn et al., 2009). Essentially this scale is a rating of the land in terms of best to worse with eight being the 'worst' class of land. Land that has a greater number and therefore more limitations is often only suitable for forestry or in some cases, complete restoration back to woody vegetation (Lynn et al., 2009). The second part to this classification is the subclass. This letter section of this system describes the primary limitation of the area. There are four limitations that are used within this system, including erodibility (e), climate (c), soil (s), and the wetness (w) (Lynn et al., 2009). The final section in the classification system is the LUC unit. This number describes the versatility of the site and areas are grouped together into polygons with similar conservation needs, for example some areas may be completely unsuitable for any commercial purposes, including forestry and total soil conservation is needed (Lynn et al., 2009). As each number increases the versatility of the land decreases. These land classes given to sections of land are the most accurate way of assessing the long-term land management necessary to preserve the current site conditions. As LUC classifications move from the most versatile to the least the arable uses, the most suitable uses tend towards more vegetation cover to the stage where only woody vegetation and conservation of the land is the only possible practice.

2.3. Forage quality and defensive adaptations

Native plant species in New Zealand have several mechanisms of defence which can affect forage quality. These include the divaricating growth form found in many native shrubs is thought to be a defence mechanism for protection against moa browsing although this has been hard to prove due to the lack of extant moa. Divaricating growth forms can be restricted to purely juvenile forms or can continue into adult stages. Some studies such as that from Bond, Lee, and Craine (2004) examined the feeding habits of extant ratites such as emu and ostrich to establish how the moa might have fed and determined that the combination of divaricating growth, small leaved species, and spines found on some plants all contributed to the mitigation of damage caused by browsing herbivores. According to Bee et al. (2009), defence mechanisms can occur when a species is more palatable than the surrounding foliage. Things like spines, chemicals, and even behavioural aspects where a plant may grow amongst less palatable species all defence mechanisms used to discourage browsing. The latter of these in particular as it was discovered that plants are more likely to be browsed if found in an area containing other palatable species (Bee et al., 2009). In other words, the forage selection by browsing animals was determined by the surrounding forage quality.

While defence by divarication is useful against ratite browsers, it is infinitely less so against mammalian browsers and the actual feeding action is decidedly different, it is a shearing motion rather than whiplash tugging which makes the divaricating adaptation less useful than it may have once been. The spines are useful in that they reduce the rate of feeding and prevent defoliation completely. It has been acknowledged by McGlone and Clarkson (1993) that the faster the growth rate of a plant is then the less beneficial it would be for a plant to invest energy in defence mechanisms (Coley, Bryant, & Chapin, 1985). It is therefore more likely that a plant growing on a nutrient poor site or an area which could be considered a stressful environment might dedicate more energy towards defence rather than growth (Coley et al., 1985).

2.4. Hoheria populnea (Houhere or lacebark)

Relatively little is known regarding *H. populnea* in respect to its suitability as forage for animals, particularly the nutritional content of which only one source gives a weight by weight percentage of leaves. Sims, Smith, Morris, Ghori, and Carnachan (2018), found that *H. populnea* leaves had a protein content of 2.6% w/w. This was calculated by multiplying the nitrogen content by 6.25 as devised by Mariotti, Tomé, and Mirand (2008). This conversion factor using the nitrogen content allows native species to have protein content (Mariotti et al., 2008) without actually measuring it. While there is no New Zealand information concerning *H. populnea* as forage for grazing, there are related species found in Australia which have been used as a source of herbage including *Lavatera plebia* which comes from the same sub family of Malvoideae (Mitchell, 1982). Browsed in situ in New Zealand is *Hoheria glabra* (Forsyth, Coomes, & Nugent, 2003) which was noted to be absent outside exclosure plots but found inside where deer were unable to browse which suggests palatable members of the Hoheria genus. Concerning productivity or growth potential of *H. populnea* Marden, Lambie, and Rowan (2018), showed there was exponential growth of stem basal diameters (SBD) over time which is a good measure of establishment and productivity. Knowledge does exist on the traditional medicinal & weaving uses of the plant in Māori culture, however, to date the species has mainly been used for ornamental use and for traditional medicine (Mitchell, 1982; Sims et al., 2018).

The species germinates rapidly and shows no decrease in germination after desiccation (Bannister, Bibby, & Jameson, 1996). This species also shows positive qualities when considering it for erosion management and soil stability (Marden et al., 2018). It appears that there is no other information available on nutritional properties of this species.

2.5. Griselinia littoralis (Pāpāuma or Broadleaf)

G. littoralis as it has been recorded to be highly selected and a preferred species in native New Zealand forests where it comprises an average of 22.04% of deer diets (Nugent, Fraser, & Sweetapple, 1997). In fact *G. littoralis* has been stated as the largest component of the diet of both red and fallow deer (Forsyth, Richardson, & Menchenton, 2005; Nugent, 1990). It has also been suggested that a large percentage, perhaps as high as 50% of the diet, of fallow deer was from litterfall with this percentage changing dependant on the forest type (Nugent, 1990). Preferences that deer display are affected by foliar traits

(Forsyth et al., 2005). The higher the levels of acid detergent fibre and acid detergent cellulose found within a plants leaves, the lower preference (Forsyth et al., 2005). Consistent with these findings are those from Bee et al. (2011) who found that cellulose and fibre were good indicators for predicting palatability. Further, Bee et al. (2011), reported that phenolics were a good predictor of palatability in woody species such as *G. littoralis*, with lower the levels of total phenolics (concentrations of which were determined by tannic acid equivalents) and condensed tannins (as catechin equivalents), being associated with higher palatability (Bee et al., 2011).

Coomes, Kunstler, Canham, and Wright (2009), reported relatively average concentrations of phosphorus but lower nitrogen levels in the leaves compared to the other short angiosperms (*Coprosma lucida, Carpodetus serratus, Fuchsia excorticate, Neopanax colensoi, Coprosma foetidissima)* that were tested. Forsyth, Coomes, Nugent, and Hall (2002), found that phosphorus content was a significant indicator of preference for nine species consisting of deer and feral goats when analysing the palatability of 379 indigenous plant species. This species also displays a low concentration of foliar lignin, which was found to be preferred by deer over high foliar lignin concentrations (Bee et al., 2011; Forsyth et al., 2005; Nugent, 1990).

Metabolisable energy is dependent on digestibility, for example high digestibility indicates high metabolisable energy (Waghorn, 2007). It has been suggested *G. littoralis* would have a high metabolisable energy due to its quite high digestibility (Forsyth et al., 2002) although this has not been directly measured. Because of the high palatability of *G. littoralis* it is reasonable to conclude that the foliar nutritional traits (as seen in Table S1 from Kurokawa, Peltzer, and Wardle (2010) and in Coomes et al. (2009)) within the leaves are consistent with preferred concentrations of lower fibre, cellulose, phenolics, and lignin and higher phosphorus (Forsyth et al., 2002; Kurokawa et al., 2010).

Pollock (1986) found that *G. littoralis* is quick to establish if there is minimal browsing, although it will not tolerate prolonged drought conditions.

2.6. Pittosporum crassifolium (Karo)

Commonly known as Karo, *Pittosporum crassifolium* is another species of which there is limited information. Freschet, Bellingham, Lyver, Bonner, and Wardle (2013), found that the variability in leaf nitrogen content could be explained (R^2=0.86) by a combination of soil nutrient availability, light, and disturbance. They also showed large variability in leaf phosphorus concentrations, larger than *Coprosma macrocarpa* and *Melicytus ramiflorus* (Freschet et al., 2013). Wardle, Bellingham, Bonner, and Mulder (2009) showed that *P. crassifolium* had one of the lowest concentrations of foliar nitrogen content, but the second highest percentage of polyphenolics out of the twelve species (*Melicytus ramiflorus*, *Macropiper excelsum*, *Planchonella costata*, *Coprosma repens*, *Melicope ternata*, *Corynocarpus laevigatus*, *Asplenium oblongifolium*, *Brachyglottis repanda*, *Coprosma macrocarpa*, *Pittosporum crassifolium*, *Metrosideros excelsa*, and *Pseudopanax lessonii*) tested and lower percentages of fibre and cellulose than many other species (Wardle et al., 2009).

Kardol et al. (2014), showed that when ungulates were unable to browse, the growth of *P. crassifolium* was much improved compared to that of the control areas. This suggests that there was enough browsing from ungulates to cause differences in *P. crassifolium* growth. It should be noted there were effects on growth found attributed to soil bulk density changes (Kardol et al., 2014). Wardle et al. (2009), reported low fibre, cellulose, and polyphenolic percentages of 28.9%, 14.9%, and 2.14% respectively in plant litter indicating the potential for good digestibility, and by extension, potentially high metabolisable energy. Foliage phosphorus concentrations was recorded as 0.214% (Wardle et al., 2009).

2.7. Coprosma robusta (Karamū)

Commonly known as Karamū, *Coprosma robusta* is an endemic species. While there are several cultivars and different species, *C. robusta* is one of the most common (Orwin, 2007). *C. robusta* has a quick and bushy growth pattern which makes it ideal for revegetation, forage, and shelter projects (Franklin, 2014; Heenan, Molloy, Bicknell, & Luo, 2003; Marden, Rowan, & Phillips, 2008). Although it will withstand some wind it will not tolerate sustained strong winds (Franklin, 2014; Marden et al., 2008). Dodd (2009), described height increases in a trial as 0.44m at planting, 1.00m after one year, and 2.25m five years after planting.

There is little known about the nutritional qualities of *C. robusta* other than it is highly palatable to stock and easily established in the right conditions such as adequate sunshine, rain, and no sustained strong winds. (Dodd, Power, & Douglas, 2007; Marden et al., 2008). Hahner (2012), showed that *C. robusta* had high concentrations of calcium, and magnesium, and that trace elements including boron, and cadmium were found to be at a higher concentration when compared to New Zealand pasture (Hahner, 2012). *C. robusta* had lower nitrogen and phosphorus concentrations than the pasture (Hahner, 2012) contrasting Franklin (2014), who found the concentrations of foliar nitrogen of *C. robusta* to be comparable to those of *L. perenne* (see Table 1). Sulphur and Zinc concentrations were found to be comparable in *C. robusta* to *L. perenne* (Hahner, 2012). Compared to other natives (*Phormium tenax, Cortaderia richardii*, *Pittosporum tenuifolium*, *Cordyline australis*, and *Kunzea ericoide*s), *C. robusta* had higher concentrations of sulphur (Hahner, 2012). Franklin (2014), found that the growth of *C. robusta* increased following the addition of nitrogen and noted a high tolerance to nitrogen loading above levels where pasture would decline in growth. Two flavonoids were identified in *C. robusta*, Quercetin, and quercetin glycoside as identified by (Wilson, 1979) and recorded in Cambie (1988). Oskoueian, Abdullah, and Oskoueian (2013), found that quercetin had a significant reduction on methane production in ruminants.

C. robusta is palatable to browsing stock, but much less so to possums (Marden et al., 2008). The average above ground biomass for a five-year-old *C. robusta* tree is roughly 4.8kg which is complemented by around 1.3kg of biomass below ground (Marden et al., 2008).

2.8. Pseudopanax arboreus (Whauwhaupaku or Five-finger)

Commonly known as Whauwhaupaku, *Pseudopanax arboreus* is an endemic species found in native forests where it has been found to have foliar traits that provide high palatability for ungulates and has shown to be highly preferred in deer diets (Bulloch, 1995; Forsyth et al., 2003; Forsyth et al., 2002; Nugent et al., 1997). A large proportion of the diet of red deer came from *P. arboreus* of which a large proportion was litterfall (Nugent et al., 1997). High palatability of *P. arboreus* is due to low contents of cellulose, fibre, lignin, and higher levels of phosphorus (Forsyth et al., 2002). Fitzgerald (1976), measured the fibre and crude protein in *P. arboreus* which were 27% and 8%, respectively. The fibre and crude protein found in *P. arboreus* are lower than in *Melicytus ramiflorus* by half (Fitzgerald, 1976). Forsyth et al. (2002), showed that where lignin percentages are high the palatability suffers as this increases the indigestibility of the leaves.

The total energy is around 21 MJ/kg in *P. arboreus*, higher than in *M. ramiflorus* (Fitzgerald, 1976). Nitrogen contents of preferred species vary making it a poor measure of palatability for *P. arboreus* (Forsyth et al., 2002). Enright and Ogden (1987), reported that *P. arboreus* had high levels of foliar magnesium, calcium, and potassium, with average levels of nitrogen and phosphorus. It has also been found to have significantly higher concentrations of foliar sulphur than many other native species (Dickinson et al., 2015).

Survival in other studies showed poor survival rates due to wind damage, frost damage, and soil types although there was no herbivorous damage to leaves (Pratt, 1999). There is relatively little information surrounding the survival of *P. arboreus* and what can be found shows low survival rates in open pasture plantings, although the trial sites were based in the Canterbury region of the south island which has a different climate from Palmerston North and Mahia (Pratt, 1999). Dodd (2009) showed that five finger increased from a planted height of 0.35m to 0.65m after one year of growth and 2.69m after five years of growth which suggests that *P. arboreus* has a reasonably quick growth rate.

2.9. Melicytus ramiflorus (Māhoe or whiteywood)

M. ramiflorus is a native species found throughout New Zealand. *Melicytus ramiflorus* is highly selected for by browsing ungulates and is always preferred where it is found (Forsyth et al., 2002). Bulloch (1995) and Greenwood and Atkinson (1977), found *M. ramiflorus* to produce a toxic or unpalatable secondary compound which may have evolved as a response to browsing pressures and perform poorly across a range of factors. This is in direct contrast to Nugent et al. (1997), Husheer (2007), and Pollock (1986) who found that *M. ramiflorus* was always palatable, particularly to deer and stock, and slightly palatable to possums. In regards to the foliar nutritional traits found in *M. ramiflorus* and shown in Table 1, the crude protein was 14%, fibre was just over 50% and the total energy was approximately 18% dependent on the time of year (Fitzgerald, 1976). The nutrient concentrations of sodium, magnesium, potassium, and calcium were found to be high sitting at 0.14, 0.47, 1.54, and 1.99%, respectively (Enright & Ogden, 1987).

Similar to the diet preference of deer and possums, chamois diets are comprised largely of *M. ramiflorus* alongside other preferred species such as *G. littoralis*, and *Coprosma spp.*(Yockney & Hickling, 2000). Dickinson et al. (2015), found *M. ramiflorus* had similar concentration levels of phosphorus to that of the pasture grass tested, similar levels can be seen in Table 1.

In respect to growth and survivability in *M. ramiflorus*, is found to have quick early growth, making it ideal for revegetation or forest restoration projects (Pollock, 1986). Mean growth over 3 years in one study found increases in 11.0cm ± 4.55cm for the first two years followed by 6.6cm ± 7.77cm in the final year of the trial (Pratt, 1999). Dodd (2009) found that *M. ramiflorus* increased from 0.53m planting height to 0.57m after one year, and 2.08m after 5 years, showing a slow increase initially followed by a significant increase in the following four years. Pollock (1986) noted that *M. ramiflorus* had a tolerance to exposed sites but preferred moist climates. *M. ramiflorus* also showed a high drought avoidance with a high internal water potential maintained over dry periods (Innes & Kelly, 1992).

2.10. Coprosma repens (Taupata)

Coprosma repens or Taupata, is somewhat an unknown in terms of its nutritional value and productivity. Its name technically means creeping, though it is not strictly a creeping plant in its growth form (T.E.R.R.A.I.N., 2019). Instead, *C. repens* has numerous growth forms, which includes the capacity to grow amongst rocks, and in coastal environments it is extremely tolerant of salt spray (Dawson, 1961). As a member of the *Coprosma* genus in New Zealand, *C. repens* bears the distinctive drupes with orange to orange-red colours. These berries are very attractive to birds and once constituted a part of Maori diets, they also make a suitable coffee substitute as they are from the same Rubiaceae family (T.E.R.R.A.I.N., 2019). While there is limited nutritional information known currently there is data for phosphorus, total phenolics, fibre, and cellulose (Wardle et al., 2009). As there is little known regarding the palatability of this species, the information discovered in this study will be highly informative. Comparing what is currently known in the literature regarding the aforementioned nutritional traits, *C. repens* has similar percentages of cellulose, fibre, and phosphorus with apparently lower phenolic concentrations. Cambie (1988), found there were four flavonoids (Quercetin, kaempferol, quercetin and kaempferol glycosides) as identified by Wilson (1979) present in the leaves of *C. repens.*

Table 1. Nutritional values as found in the literature.

Species [1]	Reference(s)	Crude Protein	Nitrogen	Phosphorus	ME	Ash	Condensed Tannins	Total Phenolics	Fibre / NDF/ ADF/ Lignin	Cellulose
Native species										
H. populnea[2]	(Sims et al., 2018)	2.6%	0.416%			12.1%				
G. littoralis[3]	(Coomes et al., 2009)[a], (Kurokawa et al., 2010)[b]		.94% ± 0.081[a], 1.48%[b]	1715 ± 211[a], 0.201%[b]			0.20%[b]	2.12%[b]	26.4%(ADF), 16.14% (Lignin)[b]	10.25%[b]
P. arboreus	(Kurokawa et al., 2010)[c], (Fitzgerald, 1976)[d]	8.6%[d]	1.38%[c]	0.119%[c]	21.606 MJ/kg[d]	5.7%[d]	0.20%[c]	3.29%[c]	23.0%(ADF), 11.15% (Lignin)[c], 27.7%(Fibre)[d]	11.70%[c]
P. crassifolium	(Wardle et al., 2009)			0.214%				2.14%	28.9%(ADF)	14.9%
C. repens	(Wardle et al., 2009)[3]			0.289%				0.16%	28.5%(ADF)	15.8%
C. robusta	(Kurokawa et al., 2010)		1.54%	0.148%			0.20%	1.80%	29.7% (ADF), 9.66% (Lignin)	19.91%
M. ramiflorus	(Kurokawa et al., 2010)[e], (Fitzgerald, 1976)[f], (Wardle et al., 2009)[g],	14.5%[f]	2.76%[e]	0.243%[1], 0.398%[g]	17.836-18.870 MJ/kg[f]	9.7%[f]	0.20%[e]	1.51%[e], 0.48%[g]	30.0%(ADF), 10.16%(Lignin)[e], 34.2%[g](ADF), 50.6%(Fibre)[f]	19.55%[e], 24.7%[g]
Introduced species for comparison										
S. kinuyanagi	(Oppong, 1998)[h], (Kemp, Barry, & Douglas, 2003)[i], (Douglas, Bulloch, & Foote, 1996)[j],(Oppong, Kemp, Douglas, & Foote, 2001)[u]	7.1%[i]	2.1%[h]	0.27%[h]	9.7 MJ/kg[i]	1.6% [i], 5.9-6.5%[h]	25.5-27.5%[h], 27.4-30.3%[u]		35.7-38.7% (NDF), 6.7-9.5% (Lignin)[h],	20.8%[j]

[1] Data from Wardle et al. (2009) given as concentration percentage for fresh litter.
[2] Data given in w/w percentage of leaf extract from Sims et al. (2018)
[3] Data for Phosphorus given in µg g^{-1}, Nitrogen given in mg g^{-1} from Coomes et al. (2009), Kurokawa et al. (2010) data given in percentages.

									9.5% (Lignin)[j]	
L. perenne	(Hahner, 2012)[k], (Barry, Mcneill, & McNabb, 2001)[m], (Gordon, Lomax, Dalgarno, & Chesson, 1985)[n], (Margan, Graham, Minson, & Searle, 1988)[o] (Hannaway et al., 1999)[r4], (McWilliam, Barry, López-Villalobos, Cameron, & Kemp, 2005)[s], (Diaz Lira, 2005)[t]	1.74-2.14%[n], 15%[o], 16-19%[r]	2.5%[k], 0.8%[o], 1.59%±1.26[s]	~0.49%[k]	8.3-8.5 MJ/kg[o], 10.794 - 12.008 MJ/kg[r], 7.2 MJ/kg ±0.08[s]	2.18%[n]	0.18% [m]	5.01-5.31%[n]	32%[o], 60.3%[ts] (NDF), 30.6% (ADF)[s]	~40%[n]
C. palmensis	(Bonsi, Osuji, & Tuah, 1995)[p]		35.4 g/kg^{-1}[p]	0.12%[p]			5.6%[p]		20.2% NDF 8.3% ADF[p]	
M. oleifera	(Gopalakrishnan, Doriya, & Kumar, 2016)[q]	6.7g/100g in dry leaves 29.4g/100g in fresh leaves		70mg/100g in fresh leaves 252mg/100g in dry leaves					0.9g/100g in fresh leaves 12.5g /100g in dry leaves	

2.11. Conclusions

In conclusion, the species reviewed throughout are largely preferred in many species' diets such as deer species, possums, and goats. This suggests there may be cross over, however, it is clear that much of the literature available is outdated and could benefit from modern technology analysis. Nutritional analysis has come a long way and all of the foliar nutritional traits of interest can be easily acquired through lab testing. In recognising that there is a large knowledge gap which can be easily filled, the literature available could benefit greatly from being updated. Table 1 has been compiled to show the nutritional information available on the chosen species from the literature. This area is where the scientific community will benefit from the research performed throughout this project. The need for ease of access to forage's nutritional traits is a high priority for the advancement of agricultural science. This can be achieved through the creation of a

[4] Traits are taken from Fresh, early vegetative and Fresh, late vegetative from Table 2 in Hannaway et al. (1999)

database where any species that is sent in for analysis can be added to the database. Through additions to a database over time, an average concentration for each nutritional trait can be formed, thus providing key information for interested parties. This would enable those wanting to plant native tree species as fodder to be able to make accurate decisions based on up to date data.

In respect to the relative ages of the published literature, there is a significant gap in recent years which will start to be filled by the data produced in this thesis. With the considerable amount of technology available currently there can be significantly more information provided in terms of the nutritional content of the foliage of native species.

Considering the movement towards more sustainable agricultural models, the introduction of native species into agricultural systems could provide multiple benefits such as carbon credits, increased water quality, soil stabilisation, erosion control and many other benefits not yet identified. This area of research has the potential to increase dramatically in quality with the advancement of technology, any opportunity to do so should be fully embraced.

3. Research objective

The literature review has revealed there is sparse information available on forage growth, forage quality, and performance for various native shrub species. Therefore, the aim of this thesis is to address some of these gaps for *Hoheria populnea, Griselinia littoralis, Pittosporum crassifolium, Coprosma robusta, Pseudopanax arboreus, Coprosma repens* and *Melicytus ramiflorus* on two North Island sites at Massey No.4 in Palmerston North and Pongaroa station at Mahia. Specific research questions that will be addressed include: "Which native species could be suitable as a supplementary feed for ungulates in farming systems?", and "Is the use of native species as a fodder species feasible, considering growth needs of plants, available land, and nutritional content benefits." Each of these questions will provide crucial information for both farmers, and government bodies, be it local, regional, or national level.

The hypothesis for this thesis is that the native species studied throughout this thesis could make a viable alternative or supplementary feed to the current forages used in drier months.

4. Methodology and Materials

This section describes the methodology used throughout this trial. The first sections discusses each locations characteristics including weather and soil. The next section describes methods used in assessing the establishment at each site, followed by the methods used to assess vigour at each site. Nutritional sampling methods are described next followed by a section containing the methods used to assess productivity and post-summer survival. The final section in this section is that of statistical methods, this section will discuss the statistical methods used to analyse each score, nutritional result, and measurement.

4.1. Location

4.1.1. Massey No.4 Site

The Palmerston North site on Massey University farm Dairy No. 4 is at -40.401447, 175.617912 in longitude and latitude coordinates respectively, and sits at an altitude of approximately 50 metres. The trial site measures 28.5m across and 34.5m vertically. The site itself is on a steep south-facing slope which eases off towards the base of the slope around plots 7 and 8 in blocks 3 and 4 (Figure 1 & 2). The site is part of an active dairy cattle farm and was used for grazing up until the start of this trial. The land use capability (LUC) for this site is 3s4, indicating the land has moderate physical limitations for arable uses such as agriculture and cropping.

Figure 1. Photograph showing Massey University Dairy No. 4 Trial site. Taken from bottom left corner of block 3.

Block 1		Block 2	
Plot 1	Plot 2	Plot 1	Plot 2
Salix	Pittosporum	Coprosma	Griselinia
Plot 3	Plot 4	Plot 3	Plot 4
Hoheria	Pseudopanax	Pittosporum	Pseudopanax
Plot 5	Plot 6	Plot 5	Plot 6
Coprosma	Napier Griselinia	Napier Griselinia	Napier Pseudopanax
Plot 7	Plot 8	Plot 7	Plot 8
Griselinia	Napier Pseudopanax	Salix	Hoheria
Block 3 Plot 1	Plot 2	Block 4 Plot 1	Plot 2
Pittosporum	Pseudopanax	Hoheria	Pittosporum
Plot 3	Plot 4	Plot 3	Plot 4
Napier Griselinia	Napier Pseudopanax	Napier Griselinia	Salix
Plot 5	Plot 6	Plot 5	Plot 6
Salix	Hoheria	Griselinia	Coprosma
Plot 7	Plot 8	Plot 7	Plot 8
Coprosma	Griselinia	Napier Pseudopanax	Pseudopanax

Figure 2. Palmerston North trial design for Massey No.4.

Soil type (Tokomaru Silt Loam, and Ohakea Silt) is the main limiting factor at this site for long term use due to poor soil texture (Fletcher, 1987). The site also has a lower rating in terms of versatility, meaning there is an increased degree of limitations for the management of the land (Lynn et al., 2009).

Weather and climate data for Palmerston North is displayed in Figures 4 and 6. The warmest period is from November through till March each year. The driest period over the past year was from January to March in 2019.

The soil type for the Dairy No. 4 trial is considered a mix of two soil types. The first is found at the top of the slope, considered to be Tokomaru Silt Loam with the soil becoming Ohakea silt at the bottom of the slope (Cowie, 1978). These soils are easily distinguishable due to the presence of gravels in the Ohakea silt loam (Cowie, 1978). They are described by Harmsworth, Tahi, Weeks, and Landcare Research (2013) as, GOT or Typic Orthic Gley Soils. These soils in respect to the LUC unit, are described by Page (1995) as poorly drained in winter and subject to soil moisture deficiencies in summer. The trial site is on the side of a terrace which has somewhat better drainage than the undulating tops of the terrace.

4.1.2. Mahia Site

The trial site at Mahia on Pongaroa station is situated at -39.112942, 177.932014 in longitude and latitude coordinates, respectively. It has a LUC of 6e4. This indicates this land is unsuitable for arable use and has slight or moderate physical limitations or hazards but is generally suitable for pastoral or forestry uses. This LUC unit has a potential for a moderate soil slip as well as sheet, and gully erosion types. The major limiting factor on this land is the erodibility of the soil, and has a decreasing versatility in the landscape (Fletcher, 1987). This site is situated at an elevation range between 50-100m. The site itself is on a steep north-facing slope measuring 36x16.5m. The land at Pongaroa station in Mahia has been used for sheep and beef farming but was fenced off and designated as QEII land requiring that only native species be planted in the plot in 2019. This provided a limitation to this trial site as it meant only native species could be planted on the exact site, thereby excluding the *S. kinuyanagi* control species.

Due to the nature of the slope the layout of the block design means the plot 1 in each block is higher on the slope in altitude and decreases towards plot 5 in each block. This is shown in Figure 3 where the picture is taken from below plot 5 areas.

Figure 3. Mahia trial site. Photo taken from below plot 5 for each block

Figures 5 & 7 provide weather data for Mahia site. The warmest period is from November through till march which is also the driest period although over the trial period rainfall was erratic.

The soil at the Mahia trial site is described as Central yellow-brown loams and brown granular clays (NZ Soil Bureau, 1968). The New Zealand Soil Class for the polygon the trial site is contained within is BOP which stands for Pallic Orthic Brown Soils (Harmsworth et al., 2013). As this site is prone to erosion, the planting is potentially beneficial for soil conservation.

4.2. Planting

The trial designs utilised a complete randomised block design to ensure bias in the positioning of the species within the blocks. The sites differ in design due to specific site conditions, and the number of species at each location. On both sites the number of plants per treatment plot (n=15), as well as the number of the blocks (n=4) was consistent. Each site was planted in 1.5 metre grids based on guidelines from Saunders (2017) as based on space available on the slope. The measuring at both sites was done prior to planting so as to ensure equidistant spaces.

4.2.1. Dairy No.4 – Palmerston North

The Massey No.4 site contains eight species *Hoheria populnea* (Houhere or lacebark), *Griselinia littoralis* (Pāpāuma), *Pittosporum crassifolium* (Karo), *Coprosma robusta* (Karamū), *Pseudopanax arboreus* (Whauwhaupaku), *Salix kinuyanagi* (Kinuyanagi willow), as well as Hawkes Bay ecotypes of the *Pseudopanax* and *Griselinia* species. The first five species were all been Eco sourced from the Manawatu region and the Salix species were clones. The plants were kept offsite prior to the planting and were trimmed to a height of approximately 40 centimetres in height (prior to transportation) to ensure the windy conditions in Palmerston North would not affect the establishment of the species. The height and stem basal diameter (SBD) measurements (measured from the very base of the stem) were taken on the 3rd of July and the subsequent trimming was done a week later on the 10th of July. Measurements for SBD and height were taken from 20 plants in each treatment. Prior to trimming the tallest species were the *H. populnea* which were 109.2cm on average. The *P. arboreus* shrubs were next tallest with an average of 64.8cm.

Site marking for the Massey No.4 trial was performed on the 6th of August 2019 with a distance on 1.5m between plants vertically and 1.5m horizontally on the slope. Planting was completed by the 15th of August in the design as seen in Figure 2 with spraying performed using a mixture of Copyralid (Versatil) and Haloxyfop (Gallant) completed on the 14th of October. Recommended application rates were used for both herbicides with no respraying necessary. Planting was done manually with holes dug for each individual plant with depths and widths of between 20-30cm. Because one species (Hawkes Bay *G. littoralis*) was still in root trainers the holes were smaller for this species. A replacement of dead shrubs was done on three plants on the 25th of October following the early establishment assessment on the 30th of September.

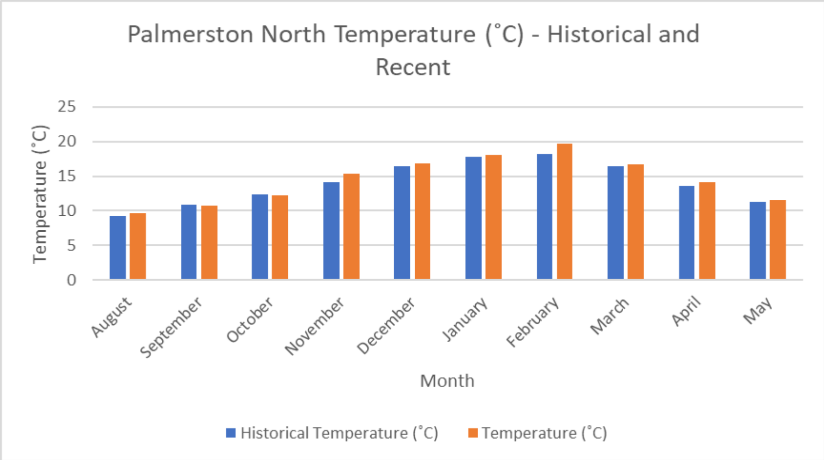

Figure 4. Temperatures at Palmerston North over the trial time period. Historical data reflects a 30-year average from 1981 to 2010. Recent data is from August 2019 to May 2020. Data retrieved from the National Climate Database

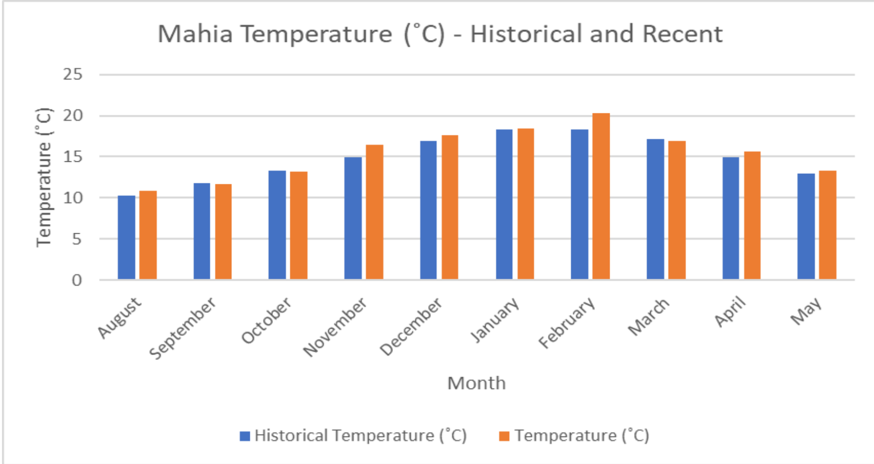

Figure 5. Temperature at Mahia over the trial period. Historical data taken from a 30-year average from 1981 to 2010. Recent data is from August 2019 to May 2020. Data retrieved from the National Climate Database.

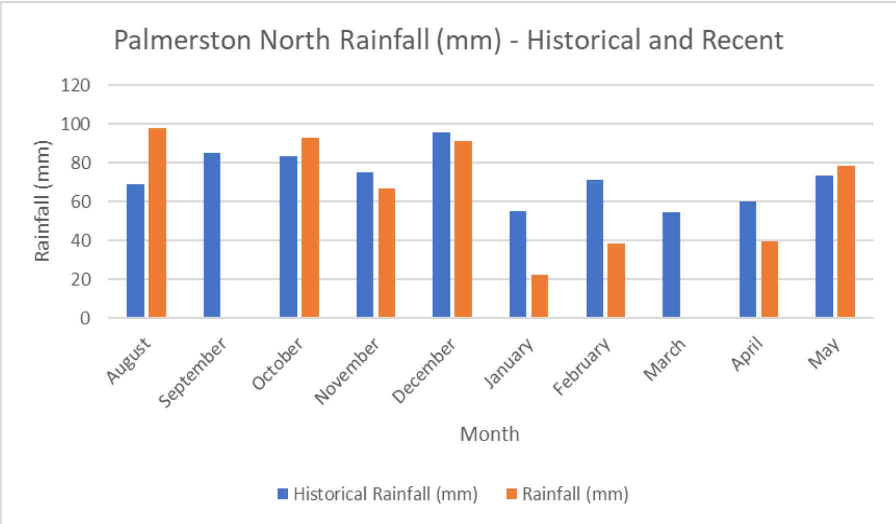

Figure 6. Historical and recent rainfall in Palmerston North over trial time period. Historical data reflects a 30-year average from 1981 to 2010. Recent data is from August 2019 to May 2020. Data retrieved from the National Climate Database.

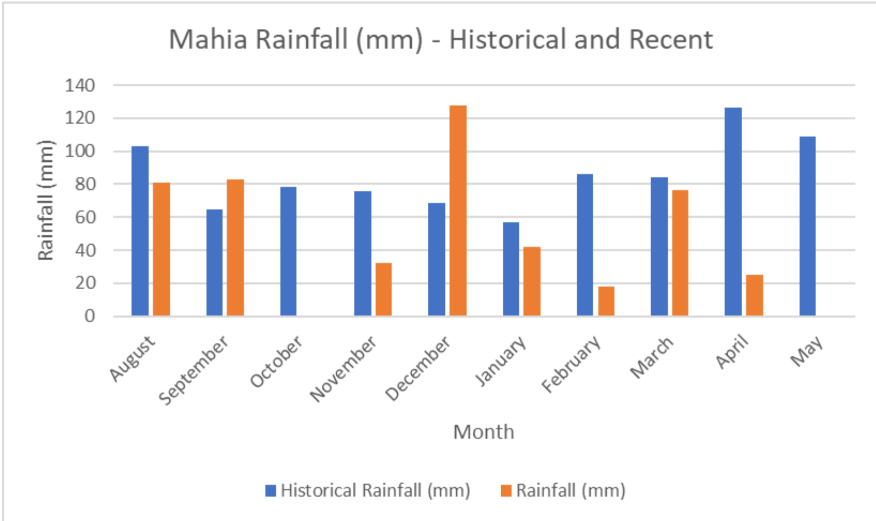

Figure 7. Rainfall at Mahia over the trial period. Historical data reflects a 30-year average taken from 1981 to 2010. Recent data is from August 2019 to May 2020. Data retrieved from the National Climate Database.

4.2.2. Pongaroa Station – Mahia

The Mahia site contains sixty individual plants of *Griselinia littoralis*, *Coprosma repens* (Taupata), *Pseudopanax arboreus*, *Melicytus ramiflorus* (Māhoe), as well as a Manawatu ecotype of *Griselinia littoralis* and *Salix kinuyanagi*. The *Salix* species, however, due to the covenant (QEII) conditions on the retired land that the trial is situated on, could not be planted on the site, and was instead planted outside the fence line in another area on Pongaroa station.

The planting for the Mahia site was completed on the 15th of August 2019 using a hole-borer to increase planting speed and was laid out in the design seen in Figure 8. The hole borer went down approximately 20 centimetres into the soil each time and the hole was roughly 15 centimetres wide. The aim was to have a spacing of 1.5m however due to variations in terrain, some plants were slightly closer. The trial had an area where blackberry is well established, and a large bush had to be avoided during planting. This patch was later removed over summer.

Spraying for the Mahia site was completed using Glufosinate (Agpro) at a 1.5% application rate before the six-week survival check; this was repeated due to the initial application leaving too much unsprayed vegetation immediately adjacent to the plants. The 2nd application controlled all weeds.

	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5
Block 1	Mahia Griselinia	Coprosma	Mahoe	Psuedopanax	Manawatu Griselinia
Block 2	Coprosma	Mahoe	Psuedopanax	Manawatu Griselinia	Mahia Griselinia
Block 3	Mahoe	Mahia Griselinia	Coprosma	Psuedopanax	Manawatu Griselinia
Block 4	Psuedopanax	Manawatu Griselinia	Mahia Griselinia	Coprosma	Mahoe

Figure 8. Mahia trial site design.

4.3. Establishment assessment methods

To assess early establishment and survival a visual assessment of each plant was undertaken. This occurred on the 30th of September at Massey No.4 and the 9th of October at Mahia. Any dead plants were replaced at this stage. From Massey No.4 the plants replaced were one each of Hawkes Bay *P. arboreus*, *P. crassifolium*, and Karamū.

At Mahia the plants replaced included one *M. ramiflorus*, four *P. arboreus*, and one Manawatu *G. littoralis* this number was much higher due to the damage described in the following section. Each plant was given an ID number following a lamb breaking into the Mahia trial site so as to track any future effects of the damage. This number contained the block, plot, row number and column letter. For example, a plant could have an ID of B3P52e, meaning this plant is in the third block, fifth plot, and second row in the column e.

4.3.1. Initial impacts

General overseeing of the site is done by Nicolas Caviale-Delzescaux who is a part of the Whangawehi Catchment Management Group. A lamb entered the site at Mahia and caused some damage. This was reported on the 4th October and a site visit was subsequently conducted. The lamb had eaten some plants. It was removed, but it is unknown how long the lamb was in the trial area. On the 9th of October, a site visit was made to determine the extent of the damage to the plants. Figure 9 contains the damage matrix from this visit of which each plant was given a score ranging from zero to ten, with ten being no damage at all and one indicating severe damage, but new growth can be seen, while zero indicated a dead plant. In total there were six plants which were replaced as indicated in red in Figure 9, each replacement was also given a score.

4.4. Vigour assessment methods

Plot vigour assessments were conducted on the 19th of November on Massey No.4 and 20th of November 2019 at Mahia. This visual assessment was conducted using a five-point scale from 0 to 4, (0 plant was dead, 1 near death or severe chlorosis, 2 no new growth but only some chlorosis, 3 some new growth, and 4 plant was full of new growth and was very vigorous). Plants were assessed individually, and scores were recorded directly onto an excel spreadsheet, if a plant was missing it was recorded as a 0. This method of assessing vigour was based on previous studies (Gadgil, Sandberg, & Lowe, 1999; Harrington & Schmitz, 2007). By assessing plot vigour using chlorosis level and amount of new growth the visual comparisons were simple and uncomplicated by other factors.

4.5. Nutritional analysis sampling

Sampling occurred on the 16th January at the Mahia site and 17th January at Massey No.4. To obtain between 30 and 40 grams of Dry Matter (DM) per plot, shoot sections containing a stem and leaf, or leaves were taken from vigorous plants within a plot and placed into pre-weighed and labelled bags. All samples included stems less than 5mm in diameter but were not individually measured as it was not feasible given species stem sizes varied greatly, some less than 2mm. The bags measured 230x305mm and were pre-weighed to three decimal places. Samples for each plot were separated into stem and leaf for each plot. A total of 72 samples were collected from Massey No.4. Once the samples were taken, they were placed into containers to keep the samples cool to prevent wilting and deterioration. At the trial site in Mahia due to the 5-hour distance from site to the lab, samples were packed in dry ice to preserve the sample quality. The samples from Massey No.4 did not require dry ice prior to being placed as the site was close to the lab.

After collection, the samples were weighed to obtain the fresh weight. Data including the sample name, bag weight, fresh weight in the bag and the fresh weight minus the bag weight, as well as the species names and sample type (stem or leaf), was entered into an excel spreadsheet. After weighing the bags, it was apparent that there would not be enough dry matter (DM) to complete the desired tests as there was only growth from one spring-summer season. Because of this, the desired tests were reduced down to only the most necessary which would then only require around five grams of DM (Association of Official Analytical Chemists (AOAC), 1990). Cost constraints meant that only the 72 samples from Massey No.4 were analysed and no samples from Mahia were analysed.

The tests run on the 72 Massey No.4 samples included Ash, NDF, ADF & Lignin, ME, CP, Nitrogen, and a range of in-vitro tests, the results of which can be seen in appendices A and B. Freeze drying and nutritional analysis was performed by the nutrition lab at Massey University. The samples were analysed for Nitrogen using the Dumas total combustion method (968.06, (Association of Official Analytical Chemists (AOAC), 1990)), and dry matter (DM) using methods 930.16 and 925.10 (Association of Official Analytical Chemists (AOAC), 1990). Ash was found using AOAC method 942.05 in a furnace at 550˚C. Neutral detergent fibre (NDF) and acid detergent fibre (ADF), and Lignin were determined using the Fibretec System, the methods 2002.04, and 973.18 respectively (Association of Official Analytical Chemists (AOAC), 1990). The in vitro digestible organic matter content (DOMD) and metabolisable energy (ME = 0.16× DOMD) were determined by the method of Roughan and Holland (1977).

4.6. Survival and Productivity Assessments

The final site assessments were conducted on the 18^{th}-23^{rd} of March where post-summer survival and productivity were assessed. This was assessed by measuring height and stem basal diameter (SBD), both of which were measured at the beginning of this trial. Height was recorded in centimetres and SBD was recorded in millimetres, there were no measurements taken in between the first and last measurements. A sample of five random plants from each plot were chosen at Massey No.4 and the same was done where possible at the Mahia site. Although some plots had very low survival rates which meant numbers had to be made up using other plots to create the average and median from 20 plants of each species. Digital callipers were used to record SBD and where there were multiple stems (as is the case with *M. ramiflorus* at the Mahia site) the largest one was used as the measurement. The measuring pole used to measure height was the same used at the first measurements. During site visits survival was also assessed which was done by checking each plant to see if it was alive or dead. Plants that had died were marked as such and a survival percentage for each plot was generated.

4.7. Statistical methods

4.7.1. Damage analysis

Damage scores were assessed using RStudio. When testing for normality, damage scores were observed to be distributed differently for each species. Therefore, a Welch's ANOVA was utilised. For post-hoc analysis a Games-Howell test was undertaken to determine statistical significance between species. Each of the five species was given an average damage score after statistical analysis.

Browsed proportions of each species were analysed using the Marascuilo procedure in RStudio to assess significance between species.

4.7.2. Vigour assessment

RStudio was used to analyse vigour data collected using, Kruskal Wallis tests and the subsequent Pairwise Wilcox test (Steel & Torrie, 1981) with the Benjamini & Hochberg (BH) adjustment method (Benjamini & Hochberg, 1995) to assess the differences between species and plots. Vigour at each site and differences between Mahia and Massey No.4 were assessed using a t-test. Vigour by site interactions were analysed via t-test to assess the null hypothesis that there is no difference in the means of vigour scores between the sites. Block, species, site, and plot columns were treated as factors so could be used to organise vigour scores by different categories. A linear regression model was run to assess if damage was a good predictor of vigour at Mahia (Steel & Torrie, 1981).

4.7.3. Survival

To assess survival at each site a two-sided proportions test was run to determine if the post-summer survival proportions at the sites were equal. This null (that the proportions of survival at each site were equal) was rejected so a one-sided test was run to see if the survival proportion at Massey No.4 was less than or equal to the survival proportion at Mahia. The Marascuilo procedure was used to assess statistical difference in survival proportions of each species at Mahia but was not used at Massey No.4 due to high survival. Survival after summer was assessed against species using a Chi-Square test (Steel & Torrie, 1981).

4.7.4. Productivity

Productivity was analysed using RStudio. Shapiro-Wilk normality tests (Steel & Torrie, 1981) were used to determine which species were normally distributed for height measurements (before and after summer), and stem basal diameter (SBD) measurements before and after summer. Some species were not normally distributed due to being topped before summer and had the same x value, which cannot be assessed in RStudio. As some species were considered normally distributed and others not, non-parametric assessments were used. Kruskal-Wallis tests were used to analyse the data collected and Pairwise Wilcox tests were used to discern which pairs were different ($P<0.05$) for each measurement(Steel & Torrie, 1981). Superscripts for the height before summer in Figure 12 used the significance levels produced in an ANOVA and Tukey HSD to due to incorrect superscripts generated when using Kruskal Wallis significance results.

When assessing change in SBD and height between before and after summer measurements. To discover if there was any effect on change in SBD and height from which block the species was in, an ANOVA was used (Steel & Torrie, 1981). A Tukey HSD test was run to determine where there was significant differences between pairs. Shapiro tests were run to determine normality for each variable. To assess changes in SBD and height between sites a T-test was used with the specification of “greater” to see if the mean change in height and SBD was greater at one site (Steel & Torrie, 1981).

Correlation tests using the spearman method were run to determine if there was a correlation between changes in height and SBD, and the changes for height and SBD against the average vigour for each species (Steel & Torrie, 1981).

4.7.5. Nutritional characteristics

RStudio was used to analyse the varying levels of each trait such as ash, nitrogen, and protein. An ANOVA was run on each trait to see if there were any significant differences in each trait between species. When testing for normality each trait was found to have no normal distributions ($p<0.05$) and no equal variances. Therefore, a Welch’s ANOVA was run which assumes no equal variances, alongside a Games’ Howell post-hoc test to determine which species pairs were significantly different from one another.

Each nutritional trait was run through a Welch’s ANOVA against sample names to determine if there were significant differences between species and samples (stem vs leaf). Post-hoc Games Howell tests revealed which treatment and sample pairs were significantly different. Stem was only compared with other stem samples, and leaf with leaf samples with the exception of within species comparisons. Superscripts were added to means to indicate differences between species for each trait.

Crude protein was calculated using N x 6.25 as described in Mariotti et al. (2008) in Microsoft Excel.

5. Results

This section will address the key results of several sections beginning with weather data obtained and the damage assessments at Mahia, followed by the vigour assessments undertaken at both sites, survival results for before and after summer, productivity results from initial planting measurements to those taken in March 2020, and ending with nutritional value results. Each section addresses both sites except for 5.1 which concerns only Mahia as damage only occurred there. Significant results are presented in terms of P-values ($P<0.05$)

5.1. Meteorological data and results

Data for the temperatures and rainfall during the trial period were obtained through the National Climate Database using the station numbers 3142 for Mahia and 3243 for Palmerston North, which was the closest site for Massey No.4 (NIWA, 2020). Both Mahia and Massey No.4 recorded similar temperatures over the duration of the trial period (Figures 4 & 5). February rainfall at Mahia was well below the long term mean but was higher than normal in December (Figures 6 & 7). Massey No.4 received around half of the usual rainfall in January and February, but no data was available for March 2020. Month by month differences between sites in rainfall can be seen in Figures 6 & 7.

5.2. Initial Results at Mahia

5.2.1. Survival post-damage at Mahia

Six plants were replaced on the 9th of October, four of these were *P. arboreus* and one each of *M. ramiflorus* and *G. littoralis* (Manawatu ecotype) due to the plants being dead. One had been pulled out of the ground and the root system exposed, others were dead due to failure to establish and were dead prior to potential animal damage. An unintentional incursion by lambs into the trial area at Mahia in October 2019 resulted in browsing damage. Damage was scored for later analysis (Table 2).

Some plants in the site were eaten to ground level or stripped bare. The overall survival rate, including those regrowth post-damage assessment, was 99.98% at Mahia meaning that survival was not influenced at the time of assessment.

Table 2. Mean scores, standard errors, median scores of damage and proportion of browsed plants for each species.

Species	**Mean scores**[5]	**Standard Error +/-**	**Median score**	**Browsed (%)**
Mahia – *G. littoralis*	8.0[c]	0.20	8	91.7%[b]
C. repens	9.1[d]	0.18	9	53.3%[a]
M. ramiflorus	1.1[a]	0.04	1	100.0%[b]
Manawatu - *G. littoralis*	5.8[b]	0.31	6	98.3%[b]
P. arboreus	7.6[c]	0.45	5	45.0%[a]

5.2.2. Damage scores

The mean damage score for *M. ramiflorus* was lower (P<0.01), than all other species (Table 2). The Manawatu ecotype of *G. littoralis* had a lower (P<0.05) damage score than *P. arboreus*, *C. repens*, and the Mahia ecotype of *G. littoralis*. *P. arboreus* and Mahia ecotype of *G. littoralis* did not differ (P>0.5) but had more (P<0.05) damage than *C. repens*. The percentage of Mahia *G. littoralis*, Manawatu *G. littoralis*, and *M. ramiflorus* plants browsed did not differ (P>0.05) but were greater (P<0.05) than *P. arboreus* and *C. repens*.

[5] The damage scoring system ran from 0 to 10 as described in section 4.3.1, with 10 indicating no damage and 0 indicating death. A score of 1 indicates new growth on severely damaged trees with new growth.

	Plot 1 Mahia griselinia					Plot 2 Taupata					Plot 3 Mahoe					Plot 4 Pseudopanax					Plot 5 Manawatu griselinia				
	9	9	9	9	9	9	9	9	9	9	1	1	1	1	2	8	1	5	2	2	9	4	9	4	3
Block 1	9	9	9	9	9	5	9	5	9	9	1	1	1	1	1	3	2	9	1	1	5	4	5	3	4
	9	9	9	9	9	9	9	9	9	9	1	1	1	**1**	1	9	1	9	1	2	5	4	4	3	2
	Treatment 1					Treatment 2					Treatment 3					Treatment 4					Treatment 5				

	Plot 1 Taupata					Plot 2 Mahoe					Plot 3 Pseudopanax					Plot 4 Manawatu griselinia					Plot 5 Mahia griselinia				
	5	10	10	10	10	1	1	1	1	1	9	10	10	5	**10**	9	8	6	8	6	7	8	5	4	5
Block 2	10	10	10	4	10	1	1	1	1	1	10	10	10	2	7	1	9	7	10	9	8	8	6	4	7
	10	10	10	10	10	1	1	1	1	1	10	10	10	9	9	9	8	9	9	9	9	6	6	4.5	7
	Treatment 1					Treatment 2					Treatment 3					Treatment 4					Treatment 5				

	Plot 1 Mahoe					Plot 2 Mahia griselinia					Plot 3 Taupata					Plot 4 Pseudopanax					Plot 5 Manawatu griselinia				
	1	1	1	1	1	8	8	8	8	8	10	10	10	10	9	10	7	10	4	**10**	4	1	**7**	5	5
Block 3	1	1	1	1	1	8	8	8	8	8	10	10	10	10	10	10	10	10	10	9	5	3	1	5	2
	1	1	1	1	1	8	8	8	8	8	10	9	9	10	10	9	1	9	**10**	10	5	3	2	4	3
	Treatment 1					Treatment 2					Treatment 3					Treatment 4					Treatment 5				

	Plot 1 Pseudopanax					Plot 2 Manawatu griselinia					Plot 3 Mahia griselinia					Plot 4 Taupata					Plot 5 Mahoe				
	10	10	10	10	10	7	7	7	7	7	8	10	10	9	10	9	10	9	10	9	2	2	1	1	1.5
Block 4	10	**10**	10	**1**	10	7	7	7	7	7	7	9	10	9	9	9	10	9	9	9	1	2	2	2	1.5
	10	10	10	10	10	7	7	7	7	7	8	9	10	8	3	9	5	9	9	9	1	2	1	1	1

Plant replaced

Weak or near dead (not sheep damage)

Figure 9. Mahia block matrix showing damage scores on the 9th of October 2019. A score of 10 indicates the plant was not touched, a score of 1 indicates intense damage but signs of new growth.

5.3. Vigour Testing

To assess the differences in vigour at each site a t-test was run which indicated the vigour scores from the trial site at Mahia (Figure 10) are lower than those at Massey No.4 (Figure 11) ($P<0.05$). A linear regression model run showed that damage score was a good predictor of vigour at Mahia ($P<0.05$) as there was no damage at Massey No.4. All assumptions for the linear model to be valid were met.

Because the data points for vigour are not normally distributed Kruskal-Wallis rank sum tests were run and post-hoc pairwise Wilcox tests to assess vigour differences between plots. On both sites' vigour differed between plots ($P<0.05$). Assessing these results in the pairwise Wilcox test showed 89 plot pairs were significantly different ($P<0.05$) at Massey No.4. At Mahia there were 77 plot pairs which were significantly different ($P<0.05$).

Differences between species in vigour scores were significant at both sites ($P<0.05$) as seen in Tables 3 and 4. At Mahia the mean vigour scores were highest in the Mahia ecotype of *G. littoralis* and *C. repens* which did not differ from each other ($P>0.05$). The Manawatu ecotype of *G. littoralis* did not differ from *P. arboreus* ($P>0.05$) but differed from all other species. *M. ramiflorus* differed from all species ($P<0.05$) except *P. arboreus* ($P>0.05$).

Table 3. Median, mean, and standard errors in vigour scores at Mahia.

Species	Mean Score	Standard error (±)	Median Score
G. littoralis (Mahia)	3.0^{c}	0.12	3
C. repens	3.0^{c}	0.09	3
M. ramiflorus	1.7^{b}	0.16	2
P. arboreus	2.0^{ba}	0.12	2
G. littoralis (Manawatu)	2.3^{a}	0.12	2

Testing the correlation of damage scores with vigour scores (using the Spearman method) revealed a weak positive correlation ($r = 0.287$) for the Mahia site.

The mean vigour scores at Massey No.4 showed that the Hawkes Bay ecotype of *P. arboreus* differed from all species ($P<0.05$) except *H. populnea* ($P>0.05$). *H. populnea* did not differ from *P. crassifolium* ($P>0.05$), and *P. crassifolium* did not differ from the Manawatu ecotypes of *P. arboreus* and *G. littoralis*, as well as the Hawkes Bay ecotype of *G. littoralis* (P>0.05). All of which did not differ from each other (P>0.05). Kinuyanagi willow did not differ from Manawatu *P. arboreus* and Karamū (P>0.05)

Table 4. Median, mean, and standard errors in vigour scores for Massey No.4.

Species	Mean score	Standard error (±)	Median score
Kinuyanagi willow	3.8[de]	0.06	4
P. crassifolium	3.3[bc]	0.11	3
H. populnea	3.1[ab]	0.10	3
P. arboreus	3.4[ce]	0.11	4
Karamū	3.8[d]	0.06	4
G. littoralis (Hawkes Bay)	3.4[c]	0.08	3
G. littoralis	3.4[c]	0.08	3
P. arboreus (Hawkes Bay)	3.0[a]	0.07	3

	Treatment 1 Plot 1 Mahia Griselinia					Treatment 2 Plot 2 Coprosma					Treatment 3 Plot 3 Mahoe					Treatment 4 Plot 4 Psuedopanax					Treatment 5 Plot 5 Manawatu Griselinia				
Block 1	2	2	3	3	2	3	2	4	4	4	3	2	3	3	3	4	0	2	3	3	4	4	4	3	0
	2	1	4	3	3	3	3	3	4	4	2	4	3	3	3	2	3	1	2	2	2	4	2	2	3
	3	4	4	3	4	4	3	4	4	3	2	3	4	0	3	2	3	2	2	2	4	3	2	2	2

	Treatment 1 Plot 1 Coprosma					Treatment 2 Plot 2 Mahoe					Treatment 3 Plot 3 Psuedopanax					Treatment 4 Plot 4 Manawatu Griselinia					Treatment 5 Plot 5 Mahia Griselinia				
Block 2	3	4	3	4	4	3	3	3	3	2	1	2	2	2	2	3	2	3	3	2	4	4	4	3	2
	3	3	2	3	3	0	0	1	1	0	2	2	2	2	1	2	2	2	3	2	4	4	4	2	2
	3	3	2	2	2	0	0	2	0	2	2	0	3	2	2	3	2	2	3	3	4	3	2	1	2

	Treatment 1 Plot 1 Mahoe					Treatment 2 Plot 2 Mahia Griselinia					Treatment 3 Plot 3 Coprosma					Treatment 4 Plot 4 Psuedopanax					Treatment 5 Plot 5 Manawatu Griselinia				
Block 3	1	2	2	3	0	3	2	4	4	4	3	3	3	3	3	3	2	2	3	1	2	2	2	2	2
	0	2	2	1	3	4	3	3	4	4	3	2	4	2	3	3	3	3	1	2	3	1	1	2	0
	1	2	0	2	0	4	3	3	3	3	2	2	2	3	3	3	0	2	2	2	2	2	2	1	1

	Treatment 1 Plot 1 Psuedopanax					Treatment 2 Plot 2 Manawatu Griselinia					Treatment 3 Plot 3 Mahia Griselinia					Treatment 4 Plot 4 Coprosma					Treatment 5 Plot 5 Mahoe				
Block 4	2	3	2	2	2	1	2	2	2	2	3	3	2	3	4	3	3	4	3	2	2	2	0	0	2
	2	2	3	0	0	3	2	3	4	3	0	2	2	4	4	3	3	4	2	3	1	2	2	2	2
	0	1	3	4	3	2	1	3	3	2	3	3	2	3	4	2	3	3	3	2	0	2	0	0	0

Figure 10. Vigour score matrix at Mahia. A vigour score of 4 indicates high vigour and a score of 0 indicates death.

Block 1	Salix P1					Pittosporum P2				Block 2	Coprosma P1					Griselinia P2			
3	3	3	3	3	4	4	4	2	3	3	3	4	4	3	3	3	3	3	2
3	3	3	3	3	4	4	4	4	3	4	4	4	4	4	4	3	4	3	4
3	3	3	3	3	3	3	3	4	4	4	3	3	4	3	3	2	3	3	3
	Hoheria P3					Pseudopanax P4					Pittosporum P3					Pseudopanax P4			
3	3	3	2	2	3	4	4	3	4	1	3	4	2	1	4	3	2	2	3
3	3	4	3	4	4	4	4	4	4	2	2	2	2	3	4	4	3	4	4
4	2	3	2	3	4	2	3	4	4	3	4	3	4	3	4	3	3	4	1
	Coprosma P5					Napier Griselinia P6					Napier Griselinia P5					Napier Pseudopanax P6			
4	3	4	3	4	3	4	4	3	4	4	3	3	4	3	3	3	4	2	2
4	4	4	4	4	4	4	4	3	3	4	4	3	4	4	4	3	3	3	3
4	4	4	4	4	3	3	3	3	3	2	3	4	4	3	3	3	3	3	3
	Griselinia P7					Napier Pseudopanax P8					Salix P7					Hoheria P8			
4	4	3	3	3	3	3	4	4	3	4	4	4	4	4	3	3	2	2	3
4	4	4	2	3	3	3	3	4	3	4	4	4	4	4	4	3	4	3	4
4	4	3	3	3	3	3	3	3	3	4	4	4	4	4	3	1	2	3	4
Block 3	Pittosporum P1					Pseudopanax P2				Block 4	Hoheria P1					Pittosporum P2			
3	3	4	3	4	4	4	4	4	4	2	4	4	4	4	3	2	4	4	3
4	4	2	4	3	4	4	4	3	4	4	3	4	2	4	4	3	4	4	4
4	4	2	2	3	4	3	3	4	4	3	3	3	4	4	3	4	4	4	4
	Napier Griselinia P3					Napier Pseudopanax P4					Napier Griselinia P3					Salix P4			
4	3	4	2	3	3	3	2	3	3	4	4	4	3	3	4	4	4	4	4
3	4	4	4	3	3	3	3	3	4	4	4	4	3	3	4	4	4	4	4
3	4	3	3	3	4	3	4	3	4	4	2	3	3	3	4	4	4	4	4
	Salix P5					Hoheria P6					Griselinia P5					Coprosma P6			
4	4	4	4	4	2	3	3	4	3	3	4	3	4	4	3	4	4	4	4
4	4	4	4	4	4	2	4	2	4	4	3	4	3	4	4	3	4	4	4
4	4	4	4	4	2	2	3	3	4	3	4	3	4	4	4	4	4	4	4
	Coprosma P7					Griselinia P8					Napier Pseudopanax P7					Pseudopanax P8			
3	4	4	4	4	4	4	4	4	4	2	2	2	3	3	4	4	3	4	4
4	4	3	2	4	4	2	3	4	4	3	2	3	3	3	4	3	3	3	0
3	4	4	4	4	3	3	4	3	3	2	3	2	3	3	2	3	4	3	2

Figure 11. Vigour score matrix at Massey No.4. A score of 4 indicates high vigour, whereas a score of 0 indicates death.

5.4. Survival

Overall, survival at Massey No.4 was greater than at Mahia ($P<0.05$). Survival at Massey No.4 ($P>0.05$) was not different between pre and post summer assessment, 99% vs 98% respectively. The only species which showed reduced survival at Massey No. 4 was *P. arboreus* (90% survival); all other species had 100% survival over summer. However, overall survival at Mahia differed over the summer with pre summer survival being 91% but 63% ($P<0.05$) after summer. Post-summer survival at Massey No.4 and Mahia were significantly different ($P<0.05$); survival was greater at Massey No.4. The survival rates after summer at Mahia for each species were 78.3% for Mahia ecotype of *G. littoralis*, 100% for *C. repens*, 38.3% for *M. ramiflorus*, 48.3% for *P. arboreus*, and 51.6% for Manawatu ecotype of *G. littoralis*.

Survival after summer was assessed against species using a Chi-Square test which showed that at both Massey No.4, and Mahia the survival after summer was not independent of species ($P<0.05$). To assess the proportion of species that survived summer at Mahia the Marascuilo procedure (Table 5) was used which found differences in survival ($P<0.05$) between Mahia *G. littoralis* against *C. repens*, and Manawatu *G. littoralis*. *C. repens* differed from *M. ramiflorus*, and *P. arboreus* ($P<0.05$). Manawatu *G. littoralis* was found to differ from *M. ramiflorus*, and Pseudopanax ($P<0.05$).

Table 5. Marascuilo procedure results showing significance in proportion differences for survival after summer at Mahia.

Species comparison	Value[6]	Critical Range	Significant (P<0.05)
Mahia *G. littoralis* - *C. repens*	0.383	0.227	yes
Mahia *G. littoralis* - *M. ramiflorus*	0.083	0.110	no
Mahia *G. littoralis* – *P. arboreus*	0.067	0.121	no
Mahia *G. littoralis* - Manawatu *G. littoralis*	0.467	0.226	yes
C. repens* - *M. ramiflorus	0.467	0.198	yes
C. repens* – *P. arboreus	0.450	0.205	yes
C. repens* - Manawatu *G. littoralis	0.083	0.280	no
M. ramiflorus* – *P. arboreus	0.017	0.051	no
M. ramiflorus* - Manawatu *G. littoralis	0.550	0.198	yes
P. arboreus* - Manawatu *G. littoralis	0.533	0.204	yes

[6]In the Marascuilo procedure the value or 'test statistic' are the absolute values of differences in proportions, and to be deemed significant they must exceed the critical range value.

5.5. Productivity

5.5.1. Height at Massey No.4

The means of height by species in July of 2019, and March 2020 differed (P <0.05) at Massey No.4 (Figure 12). The height before summer did not differ between species due to the topping of all species that were over 40cm back down to this height. There were also pairs that were not significantly different after summer (P>0.05). *H. populnea* and Karamū had greater (P<0.05) height than all other species after summer but did not differ from each other. *P. arboreus* and *P. crassifolium* were different from all other species (P<0.05) but were not different from each other. The Hawkes Bay ecotype of *P. arboreus* was different from all other species except *G. littoralis* from the Manawatu from which it did not differ (P>0.05). The Hawkes Bay ecotype of *G. littoralis* differed from all other species except the Manawatu *G. littoralis* ecotype.

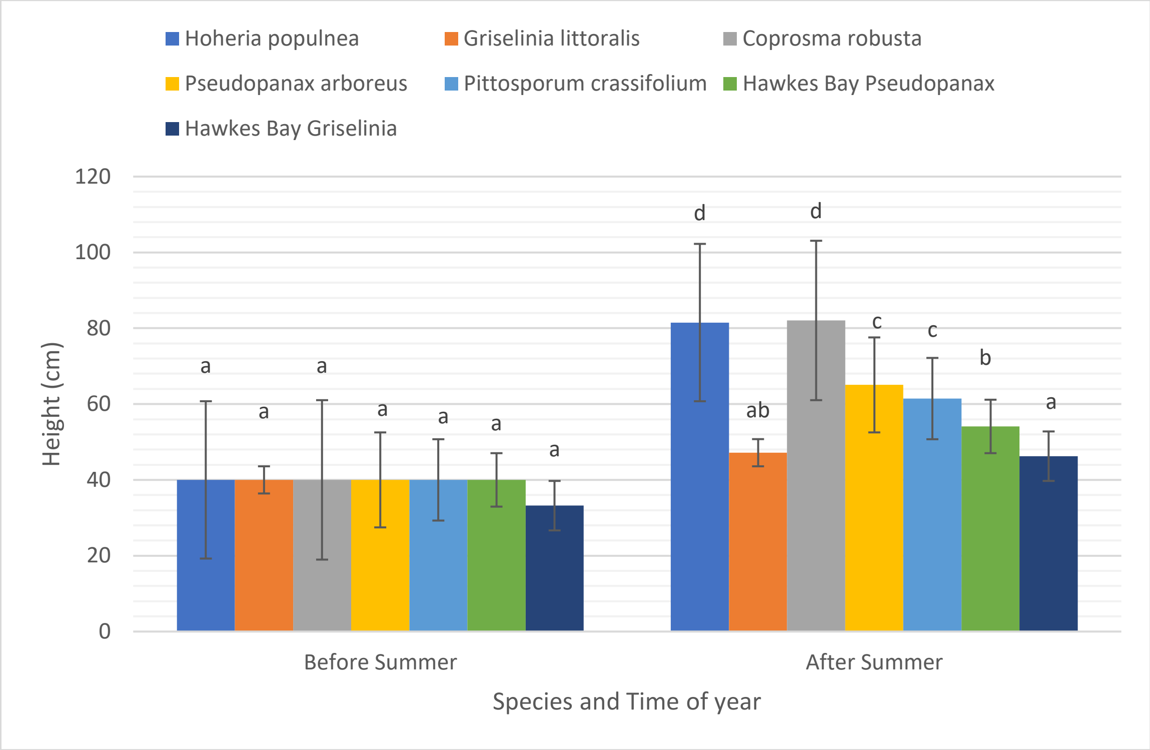

Figure 12.Changes in height (cm) at Massey University No.4 Dairy from 4/07/2019 (before summer) and 23/03/2020 (after summer) with standard error bars. Superscripts with the same letter show no difference at the 5% significance level.

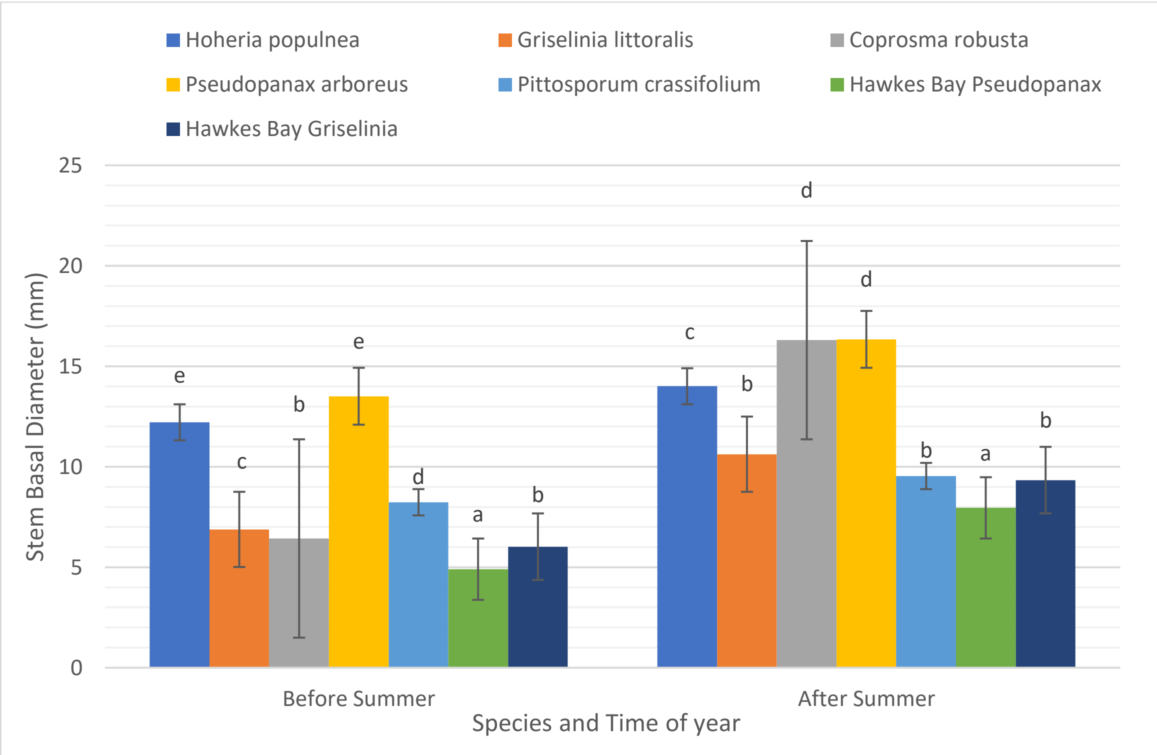

Figure 13. Changes in mean Stem Basal Diameter at Massey University No.4 Dairy from 4/07/2019 (before summer) and 23/03/2020 (after summer) with standard error bars. Superscripts with the same letter show no difference at the 5% significance level.

5.5.2. Stem basal diameter at Massey No.4

The stem basal diameter (SBD) before and after summer at Massey No.4 (Figure 13) differed between species (P<0.05). Before summer, *H. populnea* and *P. arboreus* did not differ (P>0.05). The Hawkes Bay ecotype of *P. arboreus* differed from all other species (P<0.05), and *P. crassifolium* was different from all species before summer (P<0.05), as was the Manawatu ecotype of *G. littoralis* (P<0.05).

After summer *H. populnea* was different from all species (P<0.05). Karamū did not differ from the Manawatu ecotype of *P. arboreus* (P>0.05). The Manawatu ecotype of *G. littoralis*, *P. crassifolium*, and Hawkes Bay *G. littoralis* ecotype did not differ from each other (P>0.05). The Hawkes Bay ecotype of *P. arboreus* differed from all other species (P<0.05).

5.5.3. Height at Mahia

At Mahia (Figure 14), the mean height of *M. ramiflorus* before summer differed from all other species (P<0.05). The Mahia ecotype of *G. littoralis* was different from all species (P<0.05), as was *P. arboreus*. The Manawatu ecotype of *G. littoralis* did not differ from *C. repens* before summer (P<0.05). After summer *P. arboreus*, and both ecotypes of *G. littoralis* were different from all species (P<0.05). Whereas *M. ramiflorus* and *C. repens* did not differ from each other (P>0.05).

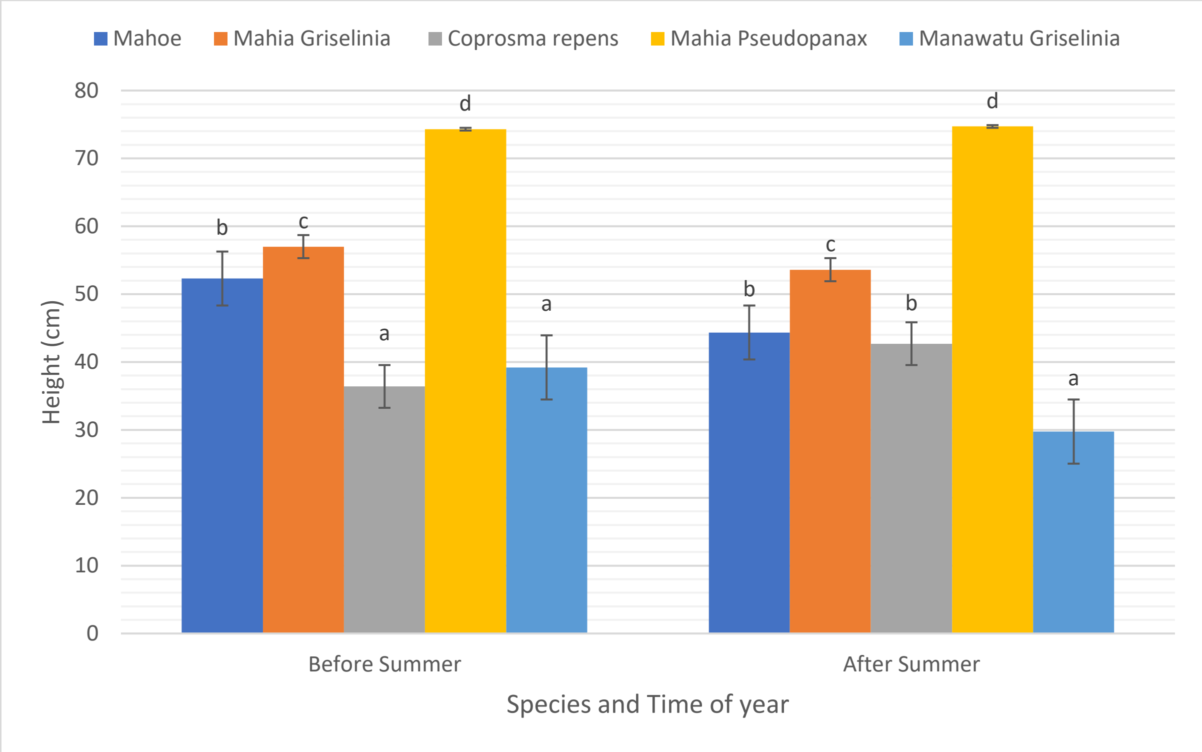

Figure 14. Changes in mean height (cm) at Mahia site from 15/08/2019 (before summer) and 18/03/2020 (after summer) with standard error bars. Superscripts with the same letter show no difference at the 5% significance level.

5.5.4. Stem basal diameter at Mahia

The stem basal diameter (SBD) at Mahia (Figure 15) differed between species. Before summer, the Mahia ecotype of *G. littoralis* differed from all other species (P<0.05). *M. ramiflorus* also differed from all other species (P<0.05), whereas *P. arboreus* and the Manawatu ecotype of *G. littoralis* did not differ from each other (P>0.05) before summer but did differ from all other species (P<0.05). *C. repens* was different from all species before summer (P<0.05).

After summer *C. repens* did not differ from the Mahia ecotype of *G. littoralis* (P>0.05) but they differed from all other species (P<0.05). *M. ramiflorus* was different from all species (P<0.05), and *P. arboreus* and the Manawatu ecotype of *G. littoralis* did not differ from each other (P<0.05) but did differ from all other species (P<0.05).

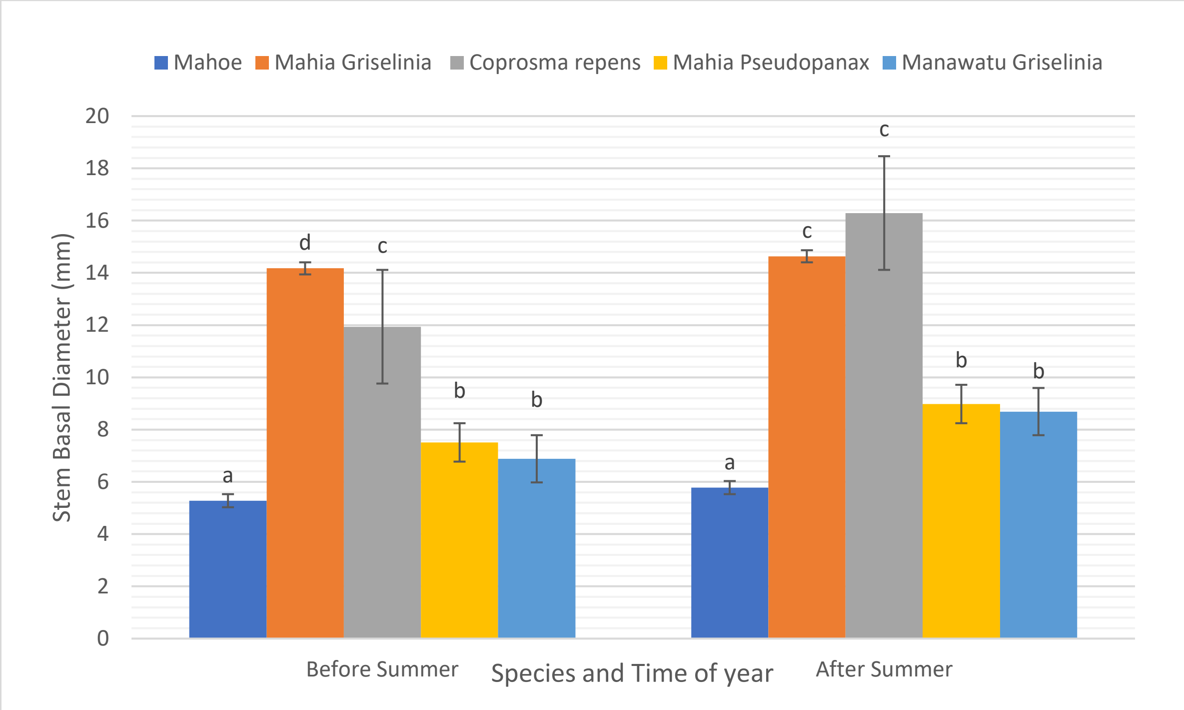

Figure 15. Changes in mean Stem Basal Diameter (mm) at Mahia site from 15/08/2019 (before summer) and 18/03/2020 (after summer) with standard error bars. Superscripts with the same letter show no difference at the 5% significance level.

5.5.5. Change in height and stem basal diameter

Assessing the changes in height from July/August and after summer in March by species and block showed differences between species ($P<0.05$). Block and species changes in stem basal diameter (SBD) and height can be seen in Figures 16 and 17 for Massey No.4 and Mahia respectively. The changes in height and SBD were found to differ between Mahia and Massey No.4 ($P<0.05$). With Massey No.4 showing a higher mean in both SBD and height ($P<0.05$).

5.5.5.1. Correlations between vigour and changes in height and stem basal diameter

The Spearman correlation between change in height and mean vigour was $r = 0.63$ with a significance of $P<0.05$, the correlation between mean vigour and change in SBD was $r = 0.56$ with a significance of $P<0.05$, while the correlation between change in height and change in SBD was $r = 0.42$ ($P<0.05$).

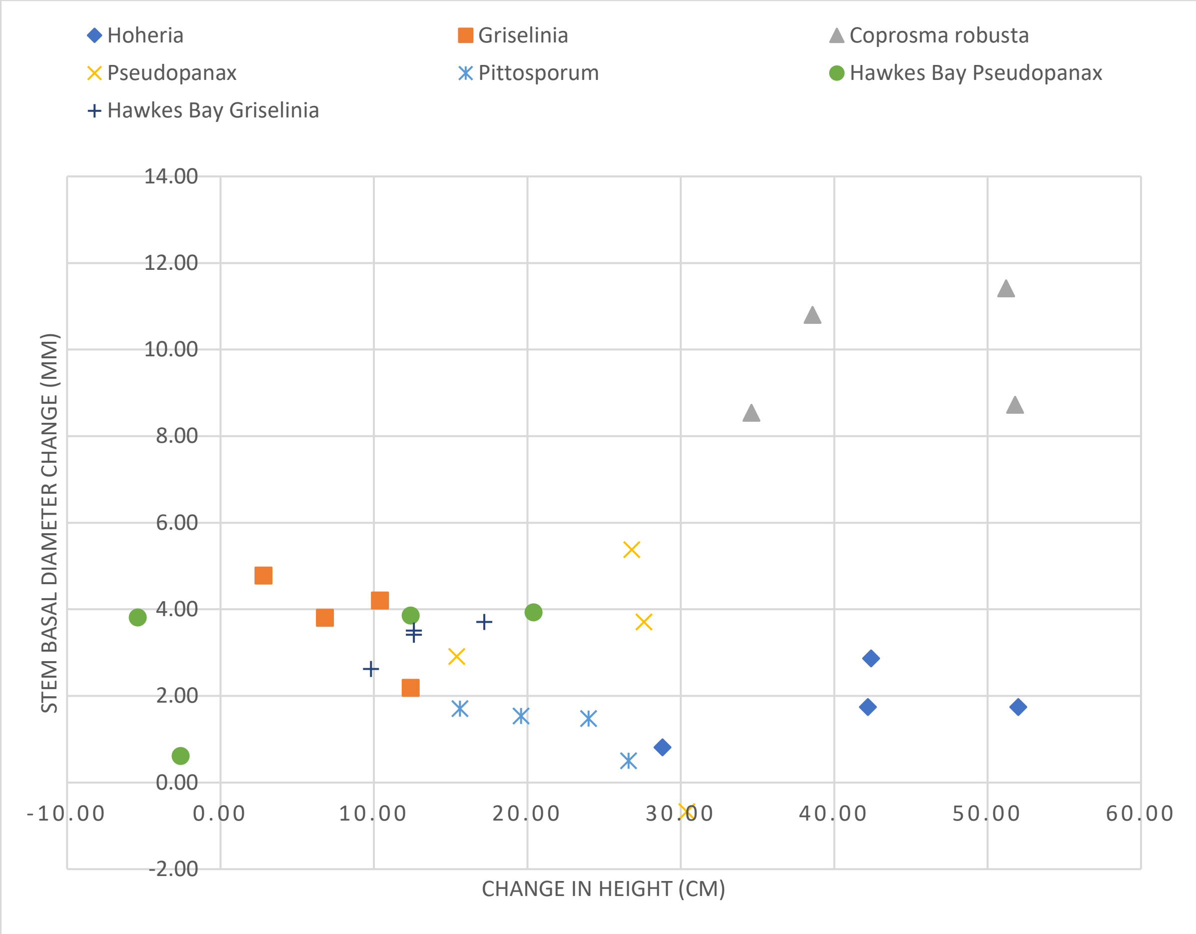

Figure 16. Scatterplot of mean height increment (cm) (horizontal axis), and mean stem basal diameter increment (mm) (vertical axis) by species at Massey No.4.

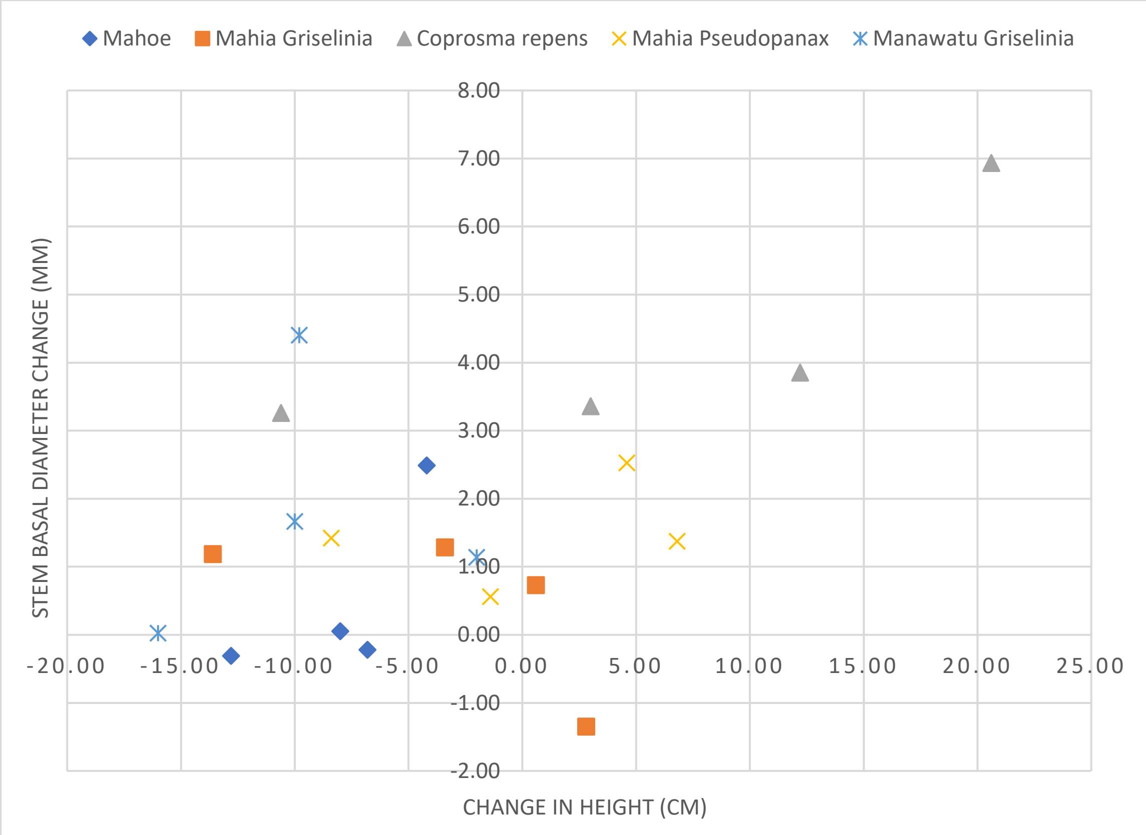

Figure 17. Scatterplot of mean height increment (cm) (horizontal axis), and mean stem basal diameter increment (mm) (vertical axis) by species at Mahia.

5.6. Nutritional values of species at Massey No.4

Nutritional traits grouped by sample names were not normally distributed (P<0.05). Variances were not equal between samples. *H. populnea* leaf differed from all species in ash percentage in leaf samples (P<0.05) (Table 6) but did not differ from *P. crassifolium* and *P. arboreus* in ash stem samples (P>0.05) (Table 7). *P. crassifolium* did not differ from Karamū and *G. littoralis* in leaf samples (P>0.05) and was not different from *H. populnea* and Karamū in stem samples (P>0.05). Kinuyanagi willow had the lowest ash percentage and did not differ from *P. arboreus* or *G. littoralis* in leaf samples but did differ from all species except *G. littoralis* (P>0.05) in stem samples (P<0.05).

P. arboreus leaf and stem samples contained the highest concentration of Metabolisable Energy (ME) and differed from all species (P<0.05) except *P. crassifolium* (P>0.05). *P. crassifolium* did not differ from any species (P>0.05) in both stem and leaf samples. Kinuyanagi willow, and *H. populnea* leaf samples differed from all other species

(P<0.05). *G. littoralis* and Karamū did not differ from each other (P>0.05) in leaf and stem samples.

H. populnea contained the highest concentrations of crude protein (CP) in both leaf and stem samples and did not differ from Kinuyanagi willow in leaf samples, and *P. crassifolium* in stem samples (P>0.05) but did differ from all other species (P<0.05). Kinuyanagi willow did not differ from Karamū and *P. crassifolium* in leaf samples (P>0.05), and *G. littoralis*, Karamū, and *P. crassifolium* in stem samples (P>0.05). *P. arboreus* did not differ from *G. littoralis* and *P. crassifolium* (P>0.05) in leaf samples but did not differ from only *G. littoralis* in stem samples (P>0.05).

Species	**Ash %**	**SE +/-**	**ME MJ/kg**	**SE +/-**	**CP %**	**SE +/-**	**NDF %**	**SE +/-**	**ADF %**	**SE +/-**	**Lignin %**	**SE +/-**
Kinuyanagi willow	5.72^{b}	0.18	10.49^{a}	0.03	8.80^{bc}	0.52	48.69^{c}	0.99	34.07^{d}	0.67	13.05^{b}	0.24
P. arboreus	6.25^{b}	0.12	12.18^{d}	0.03	5.42^{a}	0.11	21.01^{b}	1.23	15.01^{c}	0.44	8.64^{a}	0.43
G. littoralis	6.92^{ab}	0.33	11.75^{c}	0.05	6.02^{a}	0.19	30.63^{a}	0.84	21.17^{ab}	0.81	12.32^{b}	0.46
Karamū	7.25^{a}	0.10	11.59^{c}	0.08	7.80^{c}	0.20	34.66^{a}	0.89	24.05^{a}	0.34	11.72^{ab}	0.64
H. populnea	12.20^{c}	0.31	10.79^{b}	0.05	11.64^{b}	0.58	35.52^{a}	1.45	19.38^{b}	0.32	5.91^{c}	0.19
P. crassifolium	8.21^{a}	0.28	10.94^{abcd}	0.29	6.55^{ac}	0.55	34.75^{abc}	3.14	23.29^{abcd}	3.21	9.25^{a}	0.23

Table 6. Mean leaf nutritional traits by species with standard errors and superscript similarities from Massey No.4

Neutral Detergent Fibre (NDF) was highest in Kinuyanagi willow for leaf samples and differed from all species (P<0.05) except *P. crassifolium* which did not differ from any species (P>0.05). *H. populnea* only differed from *P. arboreus* and Kinuyanagi willow in leaf samples (P<0.05) and *P. arboreus* and Karamū in stem samples (P<0.05). *G. littoralis* and Karamū did not differ from each other in stem samples (P>0.05) but differed from Kinuyanagi willow and *P. arboreus* in leaf samples (P<0.05).

Acid Detergent Fibre (ADF) was highest in Kinuyanagi willow in leaf samples which differed from all (P<0.05) except *P. crassifolium* which did not differ from any species (P>0.05).

Species	Ash %	SE +/-	ME MJ/kg	SE +/-	CP %	SE +/-	NDF %	SE +/-	ADF %	SE +/-	Lignin %	SE +/-
Kinuyanagi willow	4.13^{d}	0.22	10.03^{c}	0.06	4.01^{cd}	0.21	52.78^{c}	0.60	39.99^{bc}	0.86	12.86^{b}	0.19
P. arboreus	7.61^{bc}	0.46	10.79^{b}	0.06	2.62^{b}	0.14	35.36^{b}	0.98	27.87^{a}	1.08	8.02^{a}	0.31
G. littoralis	5.00^{ad}	0.31	9.81^{c}	0.09	3.41^{bc}	0.19	49.50^{ac}	1.34	39.85^{bc}	1.40	12.29^{b}	0.30
Karamū	6.07^{ab}	0.28	10.05^{c}	0.13	4.45^{cd}	0.27	46.10^{a}	1.28	35.45^{b}	1.02	7.90^{a}	0.61
H. populnea	9.69^{c}	0.40	9.19^{a}	0.04	7.39^{a}	0.55	53.10^{c}	0.96	42.22^{c}	0.66	11.45^{b}	0.31
P. crassifolium	8.55^{c}	0.26	9.87^{abc}	0.31	4.90^{ad}	0.16	46.21^{abc}	3.06	35.60^{abc}	3.54	9.63^{a}	0.25

Table 7.Mean stem nutritional traits by species with standard errors and superscript similarities at Massey No.4.

This was also the case for *P. arboreus* leaf and stem samples which differed from all except *P. crassifolium* (P>0.05). *G. littoralis* and Karamū did not differ from each other (P>0.05) in leaf and stem samples. *G. littoralis* did not differ from *H. populnea* (P>0.05) in leaf and stem samples. In stem samples Kinuyanagi willow only differed from *P. arboreus* (P<0.05).

Lignin percentages were highest in Kinuyanagi willow leaf and stem samples but did not differ from *G. littoralis* and Karamū in leaf samples, and *G. littoralis* and *H. populnea* in stem samples (P>0.05). *H. populnea* differed from all species in leaf samples (P<0.05). *P. arboreus*, *P. crassifolium*, and Karamū did not differ from each other in leaf and stem samples (P>0.05). Karamū was only different from *H. populnea* in leaf samples (P<0.05).

Traits such as Nitrogen (N) are not listed in Tables 6 & 7 but can be seen in Appendix A, and B for individual samples.

6. Discussion

6.1. Survival

Survival before and after summer was an important variable in this study. How well different species would survive over the summer period was not understood. Davis et al. (2009), considered success as planted seedlings being alive after two years. For the purposes of this study however, establishment was limited to assessment in March 7 – 8 months post planting. Survival was greater at Massey No.4 after summer than at Mahia. This difference in survival cannot likely be explained by weather (specifically temperature) as this appeared to be similar, although there was less rainfall than in the past that fell at Mahia in February and more rainfall than in the past in December (Figure 7). Massey No.4 had less rainfall than what has been seen in the past for December, January, and February (Figure 6).

It is known that damage to the shrub reduces survival (Pollock, 1986; Porteous, 1993). Porteous (1993), stated that although sheep have the least impact due to their preference for grass species, sheep will eat palatable seedlings, affecting regeneration of native shrubs. At Mahia sheep damage occurred whereas there was no damage at Massey No.4. Consequently, the difference in survival between sites was very likely at least partially the result of browsing damage.

This demonstrates the importance of exclusion of grazing and browsing animals from planting sites as reported by Porteous (1993), Davis et al. (2009), and Bergin and Gea (2007). Pollock (1986), described *M. ramiflorus*, and *G. littoralis* as palatable to stock, and noted that species which are palatable to stock should be protected. Pollock (1986), stated that due to the palatability of some native species there is a need for browsing animals such as deer, hares, and rabbits to be excluded from the areas where highly palatable species have been planted.

Browsing damage at Mahia was different between species (Table 2). The mean damage scores of *C. repens* were lowest and differed from all other species showing the lamb preferred this species least. No nutritional composition tests were undertaken on *C. repens*, so it cannot be said if this dislike was due to any specific nutritional traits, including the presence of lignin or other chemical compounds. *M. ramiflorus* was the most preferred species as it had the highest damage score, with the Manawatu ecotype *G. littoralis* the next most preferred from damage score means. Pollock (1986), Nugent et al. (1997), Forsyth et al. (2005), and Nugent (1990) all suggested that *G. littoralis* was highly palatable, confirmed in this study. Similarly, Forsyth et al. (2002) found that *M. ramiflorus* was always preferred where it can be found by ungulates. *P. arboreus* had the third highest damage score and is also known to be highly palatable (Bulloch, 1995; Forsyth et al., 2003; Forsyth et al., 2002; Nugent et al., 1997). This suggests that stock exclusion is critical when establishing large areas of palatable species such as *M. ramiflorus*, *P. arboreus*, and *G. littoralis* on farmland.

With the likelihood of the browsing damage being the main cause of survival differences between sites, it would be remiss to ignore the differences in aspect of each site and the effect this has on factors such as evapotranspiration, and soil moisture tension. As the Mahia trial site has a northern aspect, evapotranspiration values are likely to be larger than those found at Massey No.4 which has a southern aspect (Lambert & Roberts, 1976). Soil moisture tension differences between the two sites during the time from spring to autumn could have potentially been higher at Mahia and lower at Massey No.4 due to their respective aspects (Lambert & Roberts, 1976).

6.2. Productivity

Productivity in the context of this thesis is the growth of the chosen species from their respective planting dates in July/August through to their final assessments in March. This measurement is key to answering the research questions concerning the feasibility of these species for use as forage on sheep and beef hill country farms. Due to the nature of the proposed use of these species as a forage, species that are fast growing and resilient to browse have a greater desirability for practical uses. Each site will be discussed individually in this section. There is potential for the browsing damage to have affected the results observed.

6.2.1. Massey No.4

Where Massey No.4 shows a clearer picture of productivity (Figure 16), Mahia can tell us about which species can handle challenging environments (Figure 17). Considering there were differences found between species for both stem basal diameter (SBD) and height, we can conclude that productivity was dependent on species.

Marden et al. (2018), reported that little is known in regards to growth rates of indigenous shrub species. Height growth increments were greatest in *H. populnea* and Karamū. Karamū also showed a marked increase in SBD. The performance of Karamū is consistent with published advice that it has a quick growth pattern ideal for revegetation, and tolerates most site conditions (Porteous, 1993; Standish, 2001). McGaw (2018), also found that Karamū showed good growth and was one of the tallest species after over a year of growth. Karamū's root collar diameter (RCD) of 72.4mm was recorded by Marden et al. (2018) after 5 years of growth while in the present study, the mean SBD of Karamū was 16.3mm after only 8 months. Karamū was the most productive species at Massey No.4.

H. populnea may be useful as a soil conservation plant as *H. populnea* has previously demonstrated exponential growth in SBD/RCD in a study examining below ground biomass (Marden et al., 2018). Marden et al. (2018), reported that the crown width of *H. populnea* was exceeded by the mean maximum spread of the root systems, and by the fifth year of study, root spread was almost double the crown width. This indicates that *H. populnea* root systems potentially have the capacity to help mitigate erosion on hill slopes. Although mean SBD change was minimal at Massey No. 4, previous studies have shown that *H. populnea* can be quite productive.

Although the Manawatu ecotype of *G. littoralis* did not exhibit rapid height growth, it did have rapid SBD growth suggesting good establishment as SBD is a reliable indication of the root system (Haase, 2008). Although there is some literature indicating the potential for *G. littoralis* to be used as a plant for revegetation projects (Pollock, 1986), most of the literature surrounding *G. littoralis* is actually based in its nutritional characteristics and preferences in ungulate diets (Bee et al., 2011; Coomes et al., 2009; Forsyth et al., 2002; Forsyth et al., 2005; Nugent, 1990; Nugent et al., 1997).

Growth at Massey No.4 was highest in Karamū, and *H. populnea* while *P. arboreus* and *G. littoralis* produced average growth.

6.2.2. Mahia

Results from Mahia need to be viewed cautiously due to the browsing damage experienced at the site. Species that showed good growth were constrained to *C. repens* and *P. arboreus*. All other species decreased in height and some species showed very minimal (*M. ramiflorus*, *P. arboreus*), or no (Mahia *G. littoralis*) increases in SBD. *C. repens* was almost completely untouched by browsing. *C. repens* did establish well at Mahia therefore, suggesting it has good potential to be used as a soil stabiliser on erodible land. Although the mean height growth increment was moderate at Mahia, *C. repens* did show a significant increase in SBD indicating good root growth (Haase, 2008).

P. arboreus was among those plants that were browsed and showed no change in mean height. There was, however, still an increase in the mean SBD which shows good root growth and a potential for this species to be useful in the Mahia area. The results from this trial site are not consistent with what is seen in previous literature such as that from Dodd (2009), which recorded the height of *P. arboreus* almost double the planting height after only one year after planting. It can be assumed that the reason for this disparity is the damage sustained to the plants in this trial.

Plants that show clear decreases in height such as *M. ramiflorus* and the Manawatu ecotype of *G. littoralis* were those that were the most damaged and therefore the measures for productivity for these species will not be accurate to the same degree that has been seen at Massey No.4. In Dodd (2009), *M. ramiflorus* was reported to be 0.53m at planting, 0.57m after one year, and 2.08m five years after planting. This gives an indication of how *M. ramiflorus* might have grown had there been no browse damage.

6.3. Nutritional Values

The literature on nutritional values of native species is sparse and often is lacking in specific traits or species. This section will discuss the results found in this study (Table 6 & 7, Appendix A& B) and compare results with those in the literature. The control species in the present study is Kinuyanagi willow (*S. kinuyanagi*) but nutritional values will also be compared to perennial ryegrass (*L. perenne*). Percentages referenced to in the following section are always on a percentage of dry matter (DM) basis unless stated otherwise.

6.3.1. Ash

Ash is the total mineral portion of the forage. The study from Sims et al. (2018), reported the ash content of *H. populnea* leaves as 12.1% DM which is very similar to the 12.20% found in the leaf samples of this present study at Massey No.4, but higher than the stem (9.69%).

P. arboreus leaf ash percentage samples in the present study (6.25%) were slightly greater than those found in the study by Fitzgerald (1976) (5.7% in leaves). Further this was not too different from the stem value observed in the present study (7.61%). Kinuyanagi willow ash contents of stem and leaf were 1.6% in Kemp et al. (2003) and 5.9-6.5% in Oppong (1998). In the present study ash was 4.13% in stem and 5.72% in leaf which is similar to in Oppong (1998) but slightly greater than Kemp et al. (2003). This present study appears to be the only study to report ash data for *G. littoralis*, *C. repens*, *P. crassifolium*, and Karamū.

6.3.2. Nitrogen

Nitrogen is a crucial measure to note in forage analysis as it is directly related to crude protein content, and can vary with different soil types, growing conditions, and species. N content was found for all species that were tested in this study with the exception of *P. crassifolium*. Kinuyanagi willow was found to have a concentration of 1.41% in leaf samples, and 0.64% in stem samples which is similar to the 2.1% concentration found in Oppong (1998). Compared to the other species tested in this study, Kinuyanagi willow had the second largest N concentration in leaf samples, but only fourth highest in stem samples.

Sims et al. (2018) reported N concentration of 0.416% for *H. populnea*. The concentration on nitrogen found in this study ranged from 1.18% in stem and 1.86% in leaf samples which was the highest concentration of all species tested in this study. Sims et al. (2018) was the only piece of literature found that discussed the nutritional content of *H. populnea*, so the results from this study are important in increasing what is known about the nutritional content of *H. populnea*. The results from this present study are similar to what was seen in Sims et al. (2018).

G. littoralis nitrogen concentrations were reported by Kurokawa et al. (2010) to be 1.48% which is similar to the 0.96% in leaf samples and 0.55% in stem samples found in this study. Coomes et al. (2009) recorded N concentration as 0.94% which very similar to the concentration of N found in the leaf samples in this study. The concentrations of nitrogen in *G. littoralis* were the second lowest in both stem and leaf samples tested in the present study of all species.

The lowest concentration of N in this study came from *P. arboreus* in both stem and leaf samples with concentrations of 0.42% and 0.87% respectively. Kurokawa et al. (2010), found the foliar N concentration to be 1.38%, similar to the concentration from the present study. There is no other information found in the available literature to compare either the data from the present study or the data found in Kurokawa et al. (2010)

Karamū was third highest in N content of the species tested in this study for both stem and leaf samples with concentrations of 0.71% and 1.25% respectively. This is very similar to the 1.54% found in Kurokawa et al. (2010). There are no other values in the literature that show the N content of Karamū, making the results from the present study a valuable addition to the information on Karamū.

These results appear to be the first in New Zealand literature for *P. crassifolium* and further research is needed to confirm these results, as well as determine if they are affected by changes in seasons and age of the plant.

6.3.3. Crude protein

Crude Protein (CP) is another trait which is presented sometimes in lieu of Nitrogen (N) as CP is calculated by N*6.25=CP as described in Mariotti et al. (2008). In this study the *H. populnea* leaf samples contained the highest CP concentration at 11.64%. Similarly, *H. populnea* stem samples contained the highest concentration of CP of all species at 7.39%. These figures do not align with what has been published previously by Sims et al. (2018) and there is no other published information available concerning the nutritional value of *H. populnea* which makes the results from this study highly valuable. *P. arboreus* had the lowest CP concentration of all species tested in this study with 5.42% and 2.62% for leaf and stem samples, respectively. Fitzgerald (1976) reported CP at 8.6% in *P. arboreus* which differs from what was found in this study.

Kinuyanagi willow has the second highest CP concentration in this study at 8.8% in leaf samples, which is not too dissimilar from the 7.1% found in Kemp et al. (2003).However, the concentration in Kemp et al. (2003) is measured using combined stem and leaf to <5mm which would equate to around 6.4% in this study if stem and leaf samples were combined as stem concentrations were 4.01%.

Crude protein concentrations were only found in published literature for one other species, *M. ramiflorus* which was not tested in this study.

6.3.4. Metabolisable energy

Metabolisable Energy (ME) is an estimate of the energy content potentially available in a forage. This value is derived from Digestibility of Organic Matter in the percentage of DM (DOMD). It is the proportion of the forage which is absorbed from the digestive tract and retained for metabolic purposes. Therefore, ME is predicted from the digestibility of the feed (Hill Laboratories, n.d.).

Metabolisable energy was highest in *P. arboreus* in both stem and leaf samples, with concentrations of 10.79 MJ/kg dry matter (DM) and 12.18MJ/kg DM, respectively. This is much less than what has been recorded by Fitzgerald (1976) which was 21.606 MJ/kg DM. However, due to the age of this literature there are likely differing methods used to estimate ME as the method used in this study was from Roughan and Holland (1977). Fitzgerald (1976) analysed samples in 1969 and 1974.

Kinuyanagi willow was found to have a concentration of 9.7MJ/kg DM in Kemp et al. (2003) which is very similar to the 10.03 MJ/kg DM in stem samples and 10.49MJ/kg DM in leaf samples from this study. Relative to all other samples of species analysed in this study, Kinuyanagi willow was third highest in stem samples, and had the lowest ME of all leaf samples.

Karamū and *G. littoralis* had high concentrations of ME in leaf samples (11.59MJ/kg and 11.75MJ/kg respectively) and were not statistically different from each other in both leaf and stem samples. Because there was no existing data in the published literature surrounding the ME in Karamū and *G. littoralis* the results from this study provide valuable information concerning the value of these species as forage.

All species tested in this study ranged from 9.19 to 12.18MJ/kg DM (stem and leaf samples included) meaning that all species had high ME values, comparable with those of Kinuyanagi willow (9.7MJ/kg DM(Kemp et al., 2003)) and Perennial ryegrass (*L. perenne*) which ranged from 7.2MJ/kg DM in McWilliam et al. (2005) right up to 12.008MJ/kg DM in Hannaway et al. (1999).

Out of all species tested in terms of ME, *P. arboreus* was the highest performer, exceeding Perennial ryegrass and Kinuyanagi willow. There is, however, no known ME values for almost all species tested in the present study apart from *P. arboreus*. This means that the results from this study are possibly the first in New Zealand literature. This does mean that while the values found in this present study are valuable, more research is needed to confirm these results and understand how they change over time.

6.3.5. Lignin, NDF, ADF, Fibre

Lignin, NDF (Neutral Detergent Fibre), and ADF (Acid Detergent Fibre) are all related measures which can identify how digestible a plant is in a sense. ADF is made up of cellulose and lignin with a small amount of ash, NDF includes all of the above plus hemicellulose. Lignin is related to digestibility in the sense that as lignin increases, digestibility decreases (Hill Laboratories, n.d.). Though there are very few studies which have reported on the nutritional content of native shrub species, those that do, do not always use the same trait to describe the fibre aspect of nutritional concentrations. Some studies state lignin percentages, others state Acid Detergent Fibre (ADF), some report Neutral Detergent Fibre (NDF), and some only use “fibre” as a classifier. Kurokawa et al. (2010), reported both lignin and ADF percentages for *G. littoralis*, *P. arboreus*, Karamū, and *M. ramiflorus*.

Lignin and ADF concentrations in *G. littoralis* leaf samples were 16.4% and 26.4% respectively in Kurokawa et al. (2010). In *G. littoralis* leaf samples from the present study, lignin was 12.32% and 21.7% ADF. These values are not drastically different from what can be seen in Kurokawa et al. (2010). NDF in *G. littoralis* leaf was 30.63% in the present study but there is no published literature to compare the NDF values with for native shrubs, thus making the results from the present study new and requiring further research to corroborate these values.

P. arboreus had lower lignin, ADF, and NDF than *G. littoralis* in the present study (8.64%, 15.01%, and 21.01% respectively). Fitzgerald (1976) reported a fibre percentage of 27.7% in leaf samples, whereas Kurokawa et al. (2010) who specified ADF noted a concentration of 23% and 11.25% concentration of lignin in leaf samples.

Khazaal, Markantonatos, Nastis, and Ørskov (1993) remarked that in Van Soest (1994) the decline in digestibility of forages in temperate areas as they mature was due to an increase in lignin concentrations over time. Dietz (1972) also noted that lignin concentrations in shrubs do increase as plants age which could explain why lignin concentrations are lower in the shrubs tested in this study than in the published literature.

Wardle et al. (2009) recorded ADF concentration of 28.9% in *P. crassifolium* leaves which is not too dissimilar from the 23.29% in the leaf samples in the present study. Lignin in *P. crassifolium* leaves was found to be 9.25% in this study which is lower than all species except *P. arboreus* and *H. populnea*. However, there were no recorded percentages of lignin for *P. crassifolium* in the published literature to compare this result to.

Karamū was recorded as the second highest ADF concentration in leaf samples (24.05%) in this study but the second lowest ADF concentration in stem samples (35.45%). In Kurokawa et al. (2010) the ADF concentration was 29.7% which is fairly average compared to the concentration in the control species (Kinuyanagi willow) for this study.

Kinuyanagi willow contained the highest concentration percentage of Lignin of all species tested. At 13.05% in leaf samples and 12.86% in stem samples, the lignin concentrations were higher than the 6.7-9.5% reported in Oppong (1998). NDF was also reported by Oppong (1998) to be between 35.7 and 38.7% which is lower than the 48.69% found in this study's leaf samples and 52.78% in stem samples. Moura, Bonine, De Oliveira Fernandes Viana, Dornelas, and Mazzafera (2010), explained that water stress can cause an increase in Lignin deposition. Because there was less rainfall than normal over the warmer months this has the potential to explain why NDF and lignin was higher in the Kinuyanagi willow in this trial as opposed to the Kinuyanagi willow in Oppong (1998).

The ages of the Kinuyanagi willows in Oppong (1998) was between 3-4 years old which would have significantly better established root systems than the 8 month root systems in this study, with the added water deficit stresses there are multiple potential explanations for the high lignin and NDF values in this study. Douglas et al. (1996) also measured lignin (9.5% DM) in Kinuyanagi willows of similar ages to those found in this study on a moist site, but they did not measure the concentrations on the dry site in their study. This could indicate that the dry summer months had more of an effect on lignin concentration percentages than first thought. Both Douglas et al. (1996); Oppong (1998) analysed edible forage material down to <5mm and did not separate the leaf and stem for chemical analysis as was done in the present study.

6.3.6. In-Vitro tests

The results of the in-vitro tests undertaken in this study are seen in appendices A and B. The range of in-vitro DOMD (Digestibility of organic matter in the DM) concentration over stem and leaf samples ranges from 57.45% in *H. populnea* stem to 76.13% in *P. arboreus* leaf. Because DOMD% is used to calculate metabolisable energy (ME), means of all the in-vitro tests were included in Tables 6 & 7. It is less common to include in-vitro test results as descriptors for plant matter as other traits can much better explain the characteristics of species such as ME which is calculated as DOMD*0.16=ME.

6.4. Overall performance

In assessing which species from the present study, it became apparent that while the current nutritional concentrations, and growth measurements were valuable and important for the understanding of which species were feasible as forage species, there was not yet enough information to make accurate recommendations. Therefore, this section will address species overall performance and suggest other reasons for planting the chosen species until more information has been collected over time.

The nutritional traits deemed to be most important for a forage were lignin, ADF, ME, and CP. Each of these nutritional traits were examined as they are the traits which primarily affect the palatability and nutritional value of plant species. Since the selected native species are being compared to Kinuyanagi willow, which is already used as fodder for stock, the results of the nutritional analysis provided essential knowledge for the interested parties.

Species with the quickest early growth and good vigour were most valued as they could provide the most environmental benefits early on. The most productive species were

Karamū, and *H. populnea*, followed closely by *P. arboreus*. Karamū was the most productive species in terms of growth with a mean vigour score of 3.8 and a 100% post-summer survival rate. Karamū also had high metabolisable energy in leaf samples with relatively high concentrations in stem samples as well. However, it is the intense growth difference from all other species combined with its relatively good vigour score which makes it valuable.

H. populnea was next in terms of growth productivity with a mean vigour score of 3.1 and a 100% survival rate. *H. populnea* had the highest level of crude protein of all tested species in leaf and stem samples. Although *H. populnea* had average metabolisable energy concentrations, *H. populnea* had the lowest lignin of all species in leaf samples as well as low ADF which has a positive impact on its ability to be used as a forage successfully. This has the potential to change over time however so in regards to revegetation and speedy growth *H. populnea* performed well in the literature and in the present study.

P. arboreus did not have extreme growth such as seen in Karamū or *H. populnea* but did not stagnant. It had a mean vigour score of 3.4 and samples contained the highest ME in both leaf and stem sections. There was also low lignin and ADF which made *P. arboreus* a good option as a forage. Although there was only a 90% survival rate for *P. arboreus* the vigour score and bushy growth make this species attractive for revegetation projects as well as potential forages in the future should future research prove to be encouraging.

Overall, based on the productivity growth and the nutritional values discussed, Karamū was the best all-round performing species, followed by *H. populnea* which had high concentrations of useful traits such as ME and CP yet low concentrations of ADF and lignin which affect digestibility. *P. arboreus* came in third with reasonable growth but good nutritional traits. The vigour scores showed promise for most species to be useful as revegetation plants with survival rates at 100% for all except *P. arboreus* of which there was only 6 plants lost at Massey No.4. At Mahia there was one species which had a 100% survival rate, good vigour and growth in SBD and height. That species was *C. repens* which has been recommended for controlling erosion in coastal areas by Hawkes Bay Regional Council (2004). Since this species appeared to not be preferred by the lamb which damaged the site, I would suggest future research to gather information surrounding palatability and secondary compounds. If this species could be planted without the need for exclusion of stock it could be widely used by farmers, especially those on hill country farms.

6.5. Uses of hill country

The species in this study were not chosen because of previous uses on hill slopes. However, some species have shown particularly vigorous growth on the hill slopes at the trial sites which agree with what has been written in previous reports. Marden et al. (2018), found that Karamū provided earlier root reinforcement benefits than other species studied. Also found by Marden et al. (2018) was the interception and transpiration benefits provided by Karamū due to the wide crown and the dense foliage. Interception and transpiration are known to have a significant role in reducing the occurrence of shallow slope failures (Marden et al., 2018).

H. populnea has performed well as a mitigating species for shallow forms of erosion in Marden et al. (2018). It was shown to develop a heart shaped root system and was among the species that adapted to the conditions at the site the earliest. Marden et al. (2018) also wrote that *H. populnea* was one of the species that had the largest root systems, thereby providing a high level of soil reinforcement. Cairns, Handyside, Harris, Lambreschtsen, and Ngapo (2001), highly recommended *H. populnea*, *M. ramiflorus*, *P. crassifolium*, and *P. arboreus* for use on slopes and classed them as providing good value for slope stabilisation. Karamū and *C. repens* were noted as providing some value for slope stabilisation but not as much as the four previously mentioned species. *G. littoralis* was mentioned to have medium to high tolerances for a range of conditions including droughts, frosts, wind, damp, and salt. However, *G. littoralis* was classed as of lower value for slope stabilisation due to either slower growth or root spread (Cairns et al., 2001).

The Hawkes Bay Regional Council (2004) has identified which types of erosion are best mitigated by which species. *H. populnea*, *C. repens*, *P. arboreus*, Karamū, and *M. ramiflorus* all showed they were good at mitigating sheet and rill erosion. The first four species also proved to be useful for dealing with wind erosion, whereas *C. repens* had the added specialty of helping mitigate coastal erosion. *M. ramiflorus* was the only species in the report that was included in the present study that was reported as useful for gully erosion (Hawkes Bay Regional Council, 2004). Based on the above mentioned recommendations from Hawkes Bay Regional Council (2004) and Cairns et al. (2001) all except *G. littoralis* have substantial benefits for controlling erosion on hill slopes.

6.6. Limitations

There were a few limitations to this study, the main limitations however, were primarily time based. Because of the 8-month time period the productivity measurements are restricted, the nutritional sampling took place using plants which had only been on site for 8 months. Furthermore, there was only one summer period that the trial sites have had to survive. Had this study been able to be undertaken over another year or two there is potential for the nutritional contents have changed with age, species would have also had more time to establish and grow larger root systems. Survival over multiple seasons would provide more accurate data as to how certain species respond to environmental pressures. These limitations are applicable to both Mahia and Massey No.4 sites.

However, the damage at Mahia was not a factor at Massey No.4 and as such the productivity analysis on the trial was not as accurate as it might have been had there been no damage. There is the potential for this site to provide details in future surrounding which species recover best over the long term but unfortunately that is outside the scope of this study.

The final limitation that impacted this study is a mix of financial and time-based limitations. Not all species in this study were analysed for nutritional content. This is partly time-based in the sense that some species had not matured enough to produce enough plant matter to freeze dry and grind into the required weight of dry matter. To obtain enough plant matter from each treatment would mean completely defoliating certain species, thereby impacting the future research that could be undertaken using these sites. Species that were heavily damaged at Mahia such as *M. ramiflorus* did not have enough plant material to perform any tests on at all.

Cost constraints were one of the primary reasons that more species were not analysed, as there was enough plant matter to undertake chemical analysis. These species include *C. repens*, and both *G. littoralis* ecotypes from the Mahia trial site.

7. Conclusions and recommendations

When considering the research question surrounding which species could be potentially used as forage there can be no real conclusions made. Because the trial sites have only been in place for a year there is not sufficient data to make effective and accurate recommendations for their use as forages. While some species show positive traits at this point in time there is not knowing exactly what might happen to nutritional values as they age. In respect to any further research I would recommend that these plants be re-sampled each year in March to provide a picture of how the nutritional traits of these species change over time.

Concerning the feasibility of planting native species as a potential fodder, while considering the growth needs of plants, and available land there are several conclusions that have become apparent. Firstly, the environmental benefits at this stage of the present study are going to more apparent and beneficial than any potential forage traits. While species have shown positive growth traits at this stage in the present study, further research is needed to assess if these traits will continue. So, although the suitability and feasibility cannot be accurately recommended at this stage, what can be concluded is how each species is performing at this stage of the present study. Species have shown good establishment-phase growth, particularly in Karamū and *H. populnea*. Early nutritional traits have also shown promise for some species such as high metabolisable energy in *P. arboreus*, and high crude protein and low lignin in *H. populnea*.

Overall, although there was a good indication for future potential for certain species to be used as forage but this early in the study the primary benefits are more likely to be environmentally based. Increased habitats for birdlife, potential erosion control on hill slopes, and even possibly cleaner water are all potential benefits to planting native species on hill slopes. Future research avenues could include how the nutritional traits change over time, how growth rates change and even monitoring soil over time to see if there is a reduction in soil losses.

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Appendices

Appendix A.

		DRY MATTER BASIS									
NutLab ID	**Sample Name**	**Ash %**	**N %**	**NDF %**	**ADF %**	**Lignin %**	**In vitro DMD %**	**In vitro DOMD %**	**In vitro OMD %**	**ME MJ/kg**	**Crude protein (%)**
TN20-102-01	**Massey No.4 B1 P1 SALIX LEAF**	5.9	1.4	44.8	31.2	12.1	69.2	66.3	72.1	10.6	8.91
TN20-102-02	**Massey No.4 B1 P1 SALIX STEM**	4.3	0.7	50.3	37.3	12.4	65.0	62.2	67.3	9.9	4.40
TN20-102-03	**Massey No.4 B1 P2 PITTOSPORUM LEAF**	7.1	1.0	38.9	20.2	9.0	74.4	70.8	77.6	11.3	6.39
TN20-102-04	**Massey No.4 B1 P2 PITTOSPORUM STEM**	7.5	0.7	52.0	38.6	10.2	65.7	61.5	67.5	9.8	4.55
TN20-102-05	**Massey No.4 B1 P3 HOHERIA LEAF**	11.7	1.8	39.9	19.1	6.0	74.1	68.6	76.8	11.0	11.13
TN20-102-06	**Massey No.4 B1 P3 HOHERIA STEM**	9.5	1.1	56.1	44.0	11.4	63.2	57.9	64.1	9.3	7.03
TN20-102-07	**Massey No.4 B1 P4 PSEUDOPANAX LEAF**	6.6	0.8	20.9	14.7	8.2	78.3	75.8	82.5	12.1	5.24
TN20-102-08	**Massey No.4 B1 P4 PSEUDOPANAX STEM**	8.3	0.5	35.5	30.1	8.4	72.1	68.1	74.9	10.9	2.92
TN20-102-09	**Massey No.4 B1 P5 COPROSMA LEAF**	7.0	1.3	37.7	23.5	9.6	77.2	74.7	81.5	12.0	8.25

TN20-102-10	Massey No.4 B1 P5 COPROSMA STEM	7.3	0.9	44.3	33.7	9.6	69.7	65.9	72.1	10.5	5.53
TN20-102-11	Massey No.4 B1 P6 NAPIER GRISELINIA LEAF	5.4	0.8	31.9	20.0	10.9	76.9	75.0	81.0	12.0	5.28
TN20-102-12	Massey No.4 B1 P6 NAPIER GRISELINIA STEM	3.8	0.5	55.3	45.8	13.3	61.4	58.7	63.5	9.4	2.83
TN20-102-13	Massey No.4 B1 P7 GRISELINIA LEAF	7.6	1.0	27.8	17.7	11.0	76.6	73.4	80.3	11.7	6.07
TN20-102-14	Massey No.4 B1 P7 GRISELINIA STEM	6.2	0.6	47.2	36.5	11.3	66.0	62.4	68.0	10.0	4.00
TN20-102-15	Massey No.4 B1 P8 NAPIER PSEUDOPANAX LEAF	6.0	0.9	18.8	13.7	7.0	78.7	76.6	83.1	12.3	5.46
TN20-102-16	Massey No.4 B1 P8 NAPIER PSEUDOPANAX STEM	6.1	0.4	39.3	31.4	7.3	69.2	65.8	71.7	10.5	2.58

Dry matter : (Feed, forages), AOAC 925.10, 930.16

Ash : Furnace 550°C AOAC 942.05 (Feed, meat)

Total Nitrogen : AOAC 968.06 (Dumas method)

NDF/ADF/Lignin : Fibertec, AOAC 2002.04, 973.18

Organic Matter Digestibility (ME estimation) : Roughan & Holland 1977

Appendix B.

DRY MATTER BASIS

NutLab ID	Sample Name	Ash %	N %	NDF %	ADF %	Lignin %	In vitro DMD %	In vitro DOMD %	In vitro OMD %	ME MJ/kg	Crude Protein (%)
TN20-208-01	Massey No.4 Salix leaf B1	5.3	1.5	49.2	35.7	13.9	67.6	64.8	70.4	10.4	9.64
TN20-208-02	Massey No.4 Salix leaf B2	5.9	1.1	51.9	34.6	13.3	68.0	65.3	71.1	10.5	7.13
TN20-208-03	Massey No.4 Salix leaf B3	5.4	1.2	49.6	34.7	13.1	68.1	65.5	71.0	10.5	7.75
TN20-208-04	Massey No.4 Salix leaf B4	5.3	1.4	49.3	35.1	13.1	68.6	65.9	71.4	10.5	8.67
TN20-208-05	Massey No.4 Salix leaf MIX	6.4	1.7	47.2	33.1	12.9	68.7	65.7	71.7	10.5	10.69
TN20-208-06	Massey No.4 Salix stem B1	4.5	0.7	52.7	40.2	12.8	65.6	62.7	67.8	10.0	4.34
TN20-208-07	Massey No.4 Salix stemB2	3.7	0.6	52.7	37.9	12.3	64.5	61.7	66.8	9.9	3.44
TN20-208-08	Massey No.4 Salix stemB3	3.9	0.6	53.0	40.1	13.3	66.9	64.6	69.6	10.3	3.54
TN20-208-09	Massey No.4 Salix stemB4	3.5	0.6	54.9	42.6	13.0	64.8	62.2	67.1	10.0	3.72
TN20-208-10	Massey No.4 Salix stem MIX	4.9	0.7	53.1	41.9	13.4	66.0	62.9	68.2	10.1	4.65
TN20-208-11	Massey No.4 Pseudopanax leaf B1	6.5	0.9	26.8	16.8	10.2	78.3	75.9	82.5	12.1	5.93
TN20-208-12	Massey No.4 Pseudopanax leaf B2	6.0	0.9	20.4	15.2	8.8	77.9	75.7	82.0	12.1	5.43
TN20-208-13	Massey No.4 Pseudopanax leaf B3	6.3	0.8	18.7	14.3	8.7	78.3	76.1	82.7	12.2	5.28

TN20-208-14	**Massey No.4 Pseudopanax leaf B4**	**6.1**	0.8	20.4	15.3	9.0	78.5	76.6	83.1	12.3	5.15
TN20-208-15	**Massey No.4 Pseudopanax stem B1**	**9.4**	0.5	32.0	24.0	9.3	72.5	68.0	75.2	10.9	3.02
TN20-208-16	**Massey No.4 Pseudopanax stemB2**	**7.2**	0.4	34.4	27.0	7.7	70.9	67.7	74.0	10.8	2.70
TN20-208-17	**Massey No.4 Pseudopanax stemB3**	**7.3**	0.3	35.0	26.7	7.3	71.0	67.8	74.2	10.8	2.11
TN20-208-18	**Massey No.4 Pseudopanax stemB4**	**7.3**	0.4	35.8	28.1	8.1	70.6	67.3	73.6	10.8	2.37
TN20-208-19	**Massey No.4 Griselinia leaf B1**	**7.1**	0.9	32.0	22.0	13.4	75.9	73.3	80.0	11.7	5.68
TN20-208-20	**Massey No.4 Griselinia leaf B2**	**6.9**	1.0	28.3	21.9	13.3	75.5	72.9	79.5	11.7	6.50
TN20-208-21	**Massey No.4 Griselinia leaf B3**	**7.5**	1.0	32.5	23.3	12.5	75.7	72.8	79.6	11.6	6.32
TN20-208-22	**Massey No.4 Griselinia leaf B4**	**7.2**	1.0	31.3	22.1	12.8	76.0	73.3	80.0	11.7	6.25
TN20-208-23	**Massey No.4 Griselinia stem B1**	**5.2**	0.5	45.8	36.7	12.3	65.6	62.5	67.9	10.0	2.93
TN20-208-24	**Massey No.4 Griselinia stemB2**	**4.8**	0.6	48.6	39.2	11.8	64.3	61.5	66.7	9.8	3.44
TN20-208-25	**Massey No.4 Griselinia stemB3**	**5.0**	0.6	50.0	39.9	12.2	64.5	61.2	66.4	9.8	3.53
TN20-208-26	**Massey No.4 Griselinia stemB4**	**5.0**	0.6	50.1	41.0	12.9	65.0	61.9	67.1	9.9	3.74
TN20-208-27	**Massey No.4 Coprosma leaf B1**	**7.5**	1.2	32.7	23.7	12.5	75.1	72.2	79.0	11.6	7.44
TN20-208-28	**Massey No.4 Coprosma leaf B2**	**7.5**	1.4	36.0	24.8	10.0	74.3	71.2	77.9	11.4	8.49
TN20-208-29	**Massey No.4 Coprosma leaf B3**	**7.0**	1.2	33.9	24.6	13.2	75.0	72.3	78.8	11.6	7.64
TN20-208-30	**Massey No.4 Coprosma leaf B4**	**7.3**	1.2	35.7	24.9	12.2	75.5	71.8	78.8	11.5	7.22

TN20-208-31	**Massey No.4 Coprosma leaf MIX**	**7.3**	1.2	31.9	22.8	12.9	76.2	72.5	79.6	11.6	7.74
TN20-208-32	**Massey No.4 Coprosma stem B1**	**5.8**	0.7	48.6	37.5	9.5	66.8	63.2	68.9	10.1	4.26
TN20-208-33	**Massey No.4 Coprosma stemB2**	**5.9**	0.7	47.5	36.8	7.7	65.1	61.4	67.0	9.8	4.64
TN20-208-34	**Massey No.4 Coprosma stemB3**	**5.7**	0.7	46.1	35.1	7.7	64.9	61.2	66.7	9.8	4.20
TN20-208-35	**Massey No.4 Coprosma stemB4**	**5.3**	0.6	49.3	38.0	7.1	64.4	60.9	66.3	9.7	3.49
TN20-208-36	**Massey No.4 Coprosma stem MIX**	**6.4**	0.7	40.9	31.5	5.8	68.0	64.2	70.2	10.3	4.58
TN20-208-37	**Massey No.4 Hoheria stem B2**	**9.9**	1.2	52.0	42.0	12.1	62.6	57.2	63.3	9.2	7.78
TN20-208-38	**Massey No.4 Hoheria leaf B2**	**12.8**	1.9	36.0	18.9	5.2	74.2	68.1	76.8	10.9	11.91
TN20-208-39	**Massey No.4 Hoheria leaf B3**	**12.5**	2.0	34.0	19.4	6.2	72.8	66.8	75.1	10.7	12.63
TN20-208-40	**Massey No.4 Hoheria leaf B4**	**11.6**	2.0	34.2	19.4	5.8	73.0	67.4	75.4	10.8	12.46
TN20-208-41	**Massey No.4 Hoheria leaf MIX**	**11.3**	1.4	38.7	20.8	6.6	72.6	67.1	75.1	10.7	9.02
TN20-208-42	**Massey No.4 Hoheria stem B1**	**11.3**	1.4	49.9	39.9	11.1	62.9	57.0	63.4	9.1	8.83
TN20-208-43	**Massey No.4 Hoheria leaf B1**	**13.3**	2.0	30.1	18.6	5.6	73.1	66.8	75.5	10.7	12.69
TN20-208-44	**Massey No.4 Hoheria stemB3**	**9.4**	1.1	51.9	41.6	10.9	62.2	57.1	63.0	9.1	7.07
TN20-208-45	**Massey No.4 Hoheria stemB4**	**9.7**	1.4	53.2	41.6	10.6	63.7	58.5	64.8	9.4	8.55
TN20-208-46	**Massey No.4 Hoheria stem MIX**	**8.3**	0.8	55.5	44.2	12.6	61.6	56.9	62.6	9.1	5.06
TN20-208-47	**Massey No.4 Pittosporum leaf B1**	**8.4**	1.2	30.6	20.4	9.4	73.6	69.5	76.6	11.1	7.54
TN20-208-48	**Massey No.4 Pittosporum leaf B2**	**8.2**	1.1	30.0	19.8	8.7	74.3	70.2	77.4	11.2	7.18

TN20-208-49	Massey No.4 Pittosporum leaf B3	8.0	1.1	29.0	19.6	9.0	74.4	70.5	77.6	11.3	7.03
TN20-208-50	Massey No.4 Pittosporum leaf B4	8.4	1.2	31.4	20.3	9.1	74.4	70.2	77.5	11.2	7.26
TN20-208-51	Massey No.4 Pittosporum leaf MIX	9.2	0.6	48.7	39.3	10.3	64.2	59.3	65.5	9.5	3.94
TN20-208-52	Massey No.4 Pittosporum stem B1	9.3	0.8	46.3	37.2	9.0	64.0	59.0	65.2	9.4	4.91
TN20-208-53	Massey No.4 Pittosporum stemB2	8.5	0.8	49.2	40.9	10.5	64.1	59.5	65.5	9.5	4.80
TN20-208-54	Massey No.4 Pittosporum stemB3	8.6	0.8	52.0	41.3	9.8	64.2	59.5	65.6	9.5	4.75
TN20-208-55	Massey No.4 Pittosporum stemB4	9.2	0.8	45.8	37.5	9.3	64.2	59.2	65.4	9.5	4.71
TN20-208-56	Massey No.4 Pittosporum stem MIX	8.4	0.9	31.9	18.2	9.0	75.2	71.1	78.5	11.4	5.65

Dry matter : (Feed, forages), AOAC 925.10, 930.16

Ash : Furnace 550°C AOAC 942.05 (Feed, meat)

Metabolizable Energy (ME) : By calculation

NDF/ADF/Lignin : Fibertec, AOAC 2002.04, 973.18

Total Nitrogen : AOAC 968.06 (Dumas method)

Organic Matter Digestibility (ME estimation) : Roughan & Holland 1977

*MIX in sample names indicates a sample was taken from mixed plots and plants to the side of the trial site planted at the same time but not included in trial design.