Composition, structure and restoration potential of riparian forest remnants, Hawke's Bay, New Zealand

A thesis
submitted in partial fulfilment
of the requirements for the degree
of
Master of Science (Research) in Ecology and Biodiversity
[Faculty of Science & Engineering]
at
The University of Waikato
by

Moari Denise West

KO TE TANGATA

THE UNIVERSITY OF
WAIKATO
Te Whare Wānanga o Waikato

2021

Abstract

Extensive modification of riparian zones across the globe has seen a reduction in the important functions and services provided by the vegetation. Maintaining water quality, sediment control, nutrient cycling, habitat provision, climate change mitigation, and increased biodiversity value are a few of the services provided by riparian vegetation. Within New Zealand, approximately 16,000 ha of native forest has been cleared in recent times. This forest loss, compounded by historical forest loss over the previous seven centuries (14 million ha as of 2002), alongside the important services, gives native forests occurring within riparian zones increased value. This research assessed the species composition, community structure, restoration potential, and restoration needs of native riparian forest remnants in the Hawke's Bay Region of New Zealand.

Eleven riparian forest remnants that were predominately comprised of native species and were greater than 0.25 ha in size were selected to be surveyed. Empirical data was collected through vegetation surveys, including 10 x 10 m RECCE plots, forest health assessments, bird counts, and visual soils assessments. Bagged regression trees were utilized to determine which explanatory variables were the most important for the species composition and community structure of the sites surveyed. Variable importance plots and partial dependence plots were used to interpret the results from the bagged regression trees.

Of the 127 vascular plant species identified, 66 were native or endemic and 61 were exotic. Only one species, *Kunzea robusta*, was deemed threatened. Species found in the greatest number of plots included, *Melicytus ramiflorus*, *Coprosma robusta*, *K. robusta*, and *Salix fragilis*. Bagged regression tree models indicated that the six key explanatory variables for the community structure and species composition of the sites surveyed were annual rainfall, elevation, mesotopographic index, road density, slope, and distance from the river. Partial dependence plots indicated that sites with high native species richness and importance, low exotic species richness and importance, high understory density and canopy cover were those with an annual rainfall between 1050 mm and 1200 mm, an elevation above 150 m above sea level (a.s.l.), a mesotopographic index of 45 or above, a road density of 0.60 km² or below, a slope between 15° and 30°.

Desirable or good species composition and community structure was associated with high native species richness and importance, low exotic species richness and importance, a high understory density, and a high canopy cover. Moderate forest health, good soil quality, and a mixture of good and poor community structure and species composition was observed across the Ngaruroro, Tutaekuri, and Tukituki Rivers. Sites or portions of a site with an annual rainfall outside of the 1050 mm to 1200 mm desirable range, that are present further than 190 m from the river's edge, have an elevation less than 150 m a.s.l., have a mesotopographic index of greater than 45, a road density of 0.60 km^2 or below, and have a slope outside of the 15° to 30° range, may require more intensive restoration efforts and greater investments.

Overall, sites with good current community structure and species composition were deemed to have the highest restoration potential as such sites had fewer restoration needs and would require fewer interventions and lower investments. Two of the Tukituki River sites, named TT-4 and TT-5, had the highest restoration potential of all the sites surveyed. This was largely due to the presence of diagnostic species from the ecological reference used, and the close proximity to each other and to a managed forest remnant. Sites TT-4 and TT-5 could be made a priority for restoration projects utilising more passive methods. The remaining Tukituki River site named MK-3[1] and one of the Ngaruroro River sites NG-6 were deemed to have the lowest restoration potential, particularly due to the lack of seed sources and poor community structure and species composition. Sites MK-3 and NG-6 could be made a priority in restoration projects utilising more active methods.

Future restoration projects should aim to improve species composition and community structure. The improvements could be made by removing undesirable species such as exotic and weed species and introduce desirable native and site-appropriate species. Interventions could utilize canopy manipulation, nurse plants, and ecological references.

This research contributes to the national reporting of quantitative data describing the community structure and species composition of native riparian forests in New Zealand, provides a quantitative model of the most important explanatory variables for community structure and species composition in the riparian forests surveyed, and contributes to the understanding of the restoration potential of riparian forest remnants in the region. Future studies could further explore the suitability of the restoration methods and ecological references outlined in this research, the future risk of forest clearance.

Key words: community structure, species composition, bagged regression tree model, riparian forest restoration, Hawke's Bay, Ngaruroro, Tutaekuri, Tukituki.

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[1] MK stands for the Makaretu River which feeds into the Tukituki River.

Acknowledgements

Firstly, I would like to thank my supervisors Professor Bruce Clarkson and Dr Adam Forbes for their guidance, expertise, and for giving me the opportunity to undertake this research project. In particular, I would like to thank Dr Adam Forbes for his endless patience, encouragement, and assistance.

To the Barnes Ecolab and Painting Invert Lab, thank you for your kindness, advice, and for putting up with my inconsistent attendance at lab meetings.

I would like to acknowledge the landowners and Waipukurau Golf Club who gave permission to survey remnants on their land, or permission to cross their land to access sites. Fieldwork would not have run as smoothly otherwise.

I am thankful for the comedic relief and sanity breaks that my peers and friends have provided me throughout my time at University. Nothing can quite compare to the relief of realising that you are all in the same boat!

Thank you Sally, of Tidy Head Solutions, for your expert proofreading skills. This thesis may not have made much sense otherwise! I give Sally an 11/10 rating and highly recommend her services to everyone!

For giving up their own time and allowing me to drag them through fields of blackberry, I thank my parents Aaron and Denise West, who were the star field helpers for this research. I also give them an 11/10 rating! Thank you, Mum and Dad, for your consistent reassurance, rock-solid advice, support, financial assistance, and for always believing in me.

Finally, I would like to thank my partner, Angus Gray, for being the best support a girl could ask for. Your advice, moral support, and encouragement has been greatly appreciated.

This thesis has given me the opportunity to learn many things and develop many skills. From computer to fieldwork to research to interpersonal skills, this experience will stick with me for an exceptionally long time. If you are thinking of doing a master’s degree, do it, just do it.

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Chapter One

Introduction

This research addresses the current lack of demographic data for riparian forest remnants and explores the restoration potential and needs of 11 native forest remnants in the Hawke's Bay Region. Within the following chapter is background information on riparian vegetation, forest clearance, ecological restoration, and the study region. Research aims and objectives, and an overview of the thesis layout is also provided in this chapter. Species nomenclature follows The Plant List for this thesis (http://www.theplantlist.org/).

1.1 Riparian vegetation

Worldwide, extensive modification of riparian vegetation has occurred (Miller, 2002; DeClerck *et al*., 2010; & Kominoski *et al*., 2013). Through this modification, much of the world's riparian vegetation has been reduced to degraded and isolated patches, reducing the functions that these forests serve (Miller, 2002). Riparian vegetation acts as the interface between terrestrial and freshwater environments (Storey & Cowley, 1997). Operating at this interface, riparian vegetation serves several functions and provides a number of ecological, economic and aesthetic benefits (Pusey & Arthington, 2003). Riparian vegetation can provide diversity in habitat structure, food resources, bank stabilization, stream shading, pollution management, temperature control, and water quality protection (Pusey & Arthington, 2003; Broadmeadow & Nisbet, 2004). Intact riparian vegetation is usually associated with disproportionately high levels of biodiversity (Miller, 2002; Schmidt *et al*., 2019; Shekhar & Azim, 2010). The spectrum of riparian plant communities represents adaptations to a wide range of habitat types and environmental conditions (Schmidt *et al*., 2019), including the river's natural flow regime, where the flow timing, frequency, magnitude, duration, and predictability of flow directly impacts the traits of riparian plant species (Mahoney & Rood, 1998; Karrenberg, Edwards & Kollmann, 2002; Middleton, 2002). These adaptations are what enables such species to persist in the sharp transition between terrestrial and freshwater environments (Schmidt *et al*., 2019). Terrestrial plants, in turn, support high diversity of animal species (Miller, 2002). Among these are freshwater fish that benefit from habitat heterogeneity (Miller, 2002). Branches hanging over the water and the input of wood are what provide the habitat heterogeneity (Broadmeadow & Nisbet, 2004).

The creation of vegetation corridors is another function of riparian vegetation, which allows for the movement of plant and animal species (Miller, 2002; Bennett *et al*., 2014). It has been demonstrated that riparian vegetation is important for the processing of carbon and nutrients, the retention of water (Owen *et al*., 2015), the interception of pesticides, and the mitigation of waterway eutrophication (Burrell *et al*., 2014). Root uptake, plant chemical cycling, leaf litter, and the stabilizing of nutrients in the soil by plants all influence carbon and nitrogen cycling processes (Dosskey *et al*., 2010; Hazlett *et al*., 2008). Riparian vegetation may also act as sinks for greenhouse gases including carbon dioxide (CO_2), nitrous oxide (N_20) and methane (CH_4) (Dosskey *et al*., 2010). Aside from nutrient and sediment interception, riparian vegetation can mitigate waterway eutrophication by providing shade to the associated waterway (Burrell *et al*., 2014). Shading of the water's surface reduces gross primary production, which reduces the likelihood of algal blooms (Burrell *et al*., 2014). The interception of groundwater, surface water, and rainfall by the roots, shoots, and canopy of riparian vegetation slows down the rate at which water can enter the freshwater system, which reduces the risk of flooding (Broadmeadow & Nisbet, 2004). The interception of water also reduces the risk of landslides and the associated input of sediments to the freshwater system (Broadmeadow & Nisbet, 2004). Erosion protection is another important function served by the below-ground biomass of riparian plants (Marden, Rowan & Phillips, 2005). For the freshwater environment, erosion protection reduces sediment inputs and reduces the risk of changes in flow and habitat availability (Broadmeadow & Nisbet, 2004). For the terrestrial environment, erosion protection reduces the risk of habitat loss and increased flooding (Broadmeadow & Nisbet, 2004).

1.1.1 Modification of riparian vegetation

Remnants of riparian forests or other such riparian vegetation types are often retained to maintain the functions that they serve and the benefits that they provide to humans (Schmidt *et al*., 2019). Benefits for humans include water management, fertile soil, timber, wood, and useful plant species (Schmidt *et al*., 2019). In areas where benefits such as these are not required, modification of riparian vegetation is a risk (Schmidt *et al*., 2019).

High-fertility soils and accessible locations have resulted in large areas of riparian vegetation being cleared and converted to agricultural land (Miller, 2002), settlements (Schmidt *et al*., 2019), or infrastructure (Tockner and Stanford, 2002; Naiman *et al*., 2005). Clearance of riparian vegetation decreases habitat availability and biodiversity, and results in increased nutrient leaching, erosion risk, drought risk, species invasions, as well as increased frequency and/or severity of algal blooms (Burrell *et al*., 2014; Schmidt *et al*., 2019). Flood protection schemes and the taking of water from waterways often results in hydrological changes which can, in turn, affect the riparian vegetation (Tockner and Stanford, 2002; Naiman *et al*., 2005). Dams, diversion structures, canals and constructed waterways are further examples of human modifications to the flow of water and sediments in freshwater systems (Poff *et al*., 1997; Naiman, De´camps & McClain, 2005). These modifications have direct effects on the composition, structure, and abundance of riparian vegetation, which can result in inadvertent modification of riparian vegetation (Merritt *et al*., 2010). Plants retained on managed land are usually those with a specific purpose (Schmidt *et al*., 2019). For example, trees are often kept for shade, timber, or firewood (Schmidt *et al*., 2019). Many countries see an increase in the planting of exotic species as they are generally deemed to better serve the intended purpose (Schmidt *et al*., 2019). However, this can result in the loss of biodiversity (Schmidt *et al*., 2019). Increasing populations across the globe are putting increased pressure on the existing cleared land and in turn are putting remnants at risk of further degradation and clearance (Schmidt *et al*., 2019).

1.2 Forest clearance

Approximately 230 million ha of forest were lost globally between 2000 and 2012 (Hansen *et al*., 2013). The highest portion of this loss occurred in the tropics (Hansen *et al*., 2013) where approximately 195 million ha of tropical forests were cleared between 1990 and 2015 (Keenan *et al*., 2015). Forest loss has also been significant in non-tropical biomes (Bradshaw, Warkentin & Sodhi, 2009; Echeverría *et al*., 2006). Boreal forests account for approximately one third of the forests on earth (Ruckstuhl *et al*., 2008). Forest loss on boreal forests has previously been linked with natural events such as fires, due to limited human population size in boreal zones (Soja *et al*., 2007). Increasing human population has led to an increased demand for resources such as timber and minerals in boreal zones (Smith & Lee, 2000). These increases have led to an increased risk of clearance for boreal forests (Bradshaw *et al*., 2009). The increasing human population and changing climate has led to increases in the frequency of fires, which has also led to increased losses of boreal forests (Mollicone *et al*., 2006). Increased fires, rapid urban development, and logging are some examples of the threats to boreal forests that have resulted in increased forest fragmentation (Bradshaw *et al*., 2009). Approximately 44 % of the remaining boreal forest extent is intact or ecologically contiguous (Bradshaw et al., 2009). It has been suggested that boreal forests could wind up as threatened as tropical forests (Bradshaw *et al*., 2009). Forest clearance is also a threat for temperate forests (Echeverría *et al*., 2006). Approximately half of the temperate forests in the southern hemisphere occur in Chile (Donoso, 1993). Temperate forests cover approximately 13.4 million ha of the country (Conaf *et al*., 1999) and have been described as biodiversity hotspots (Myers *et al*., 2000). A major threat to temperate forests in Chile is the expansion of commercial plantations, which have been largely responsible for the loss of 67 % of temperate forests in Chile between 1975 and 2000 (Echeverría *et al*., 2006). Extensive forest clearance poses significant threats to biodiversity and ecosystem services, such as increased carbon emissions (Cushman *et al*., 2017).

Forest loss and clearance is usually associated with land use changes, particularly conversion of land for agriculture and urban development (Thorn *et al*., 2016). As the global population continues to increase, many regions are noticing an increase in the conversion of forest for urban development compared to agriculture (Thorn *et al*., 2016). Forest loss to urban development is deemed to be particularly problematic as the associated infrastructure is permanent (Thorn *et al*., 2016). Over time, the continual improvement of technology and the associated economic viability of farming more marginal land areas is leading to further loss of natural forests (Monks *et al*., 2019). Sites that previously would not have been selected for clearance, such as those on marginal or steep land and sites that are cold or dry, have shown an increased clearance probability over time (Monks *et al*., 2019).

In pre-human times the New Zealand land mass was dominated by forests (McGlone, 1989) with approximately 96 % of the North Island, and 72 % of the South Island likely being covered in native forest (Leathwick, McGlone & Walker, 2004). During the time of Polynesian settlement, human-induced fires as well as natural climatic and volcanic events reduced the forest cover from 82 % to 68 % of the total land area (McGlone, 1989; McWethy *et al*., 2014). During the time of European settlement, plant and animal introductions and conversion to pasture resulted in further forest loss down to 23 % of the total land area (Wardle, 1991; Fleet, 1986). Initially, clearance was limited to the flatter, fertile and warmer lowland (MacLeod & Moller, 2006). However, increasing population size and land clearance subsidies resulted in the majority of shallow-sloped and low-elevation hill country being cleared for agriculture and development (MacLeod & Moller, 2006). Over time, approximately seven million ha each of native forest has been lost from the North and South Islands of New Zealand (Ewers *et al*., 2006). The non-random process of forest clearance has led to large areas on the East Coast of the South Island, and the low-lying areas of the North Island being cleared of native forest (Ewers *et al*., 2006). The North Island has experienced a greater degree of fragmentation, with the average forest area being approximately five times smaller than that of the South Island (Ewers *et al*., 2006).

In recent times, clearance of native forest in New Zealand has not ceased (Monks *et al*., 2019), with approximately 16,000 ha of native forest being cleared between 1996 and 2012 (MfE & Stats NZ, 2018). Historicaly, some districts have experienced more than 90 % of the native forest being cleared (Ewers *et al*., 2006). Much of the native forest clearance has been due to the conversion of land for other uses such as plantation forestry, particularly in the North Island, urban development and the building of infrastructure, as well as horticulture and agriculture (Ewers *et al*., 2006). However, public, private and community-led efforts such as 32 % of the total land area being protected by the Department of Conservation (MfE & Stats NZ, 2018), the QEII National Trust and Nga Whenua Rāhui covenants have resulted in a number of remaining remnants being protected from further clearance (Monks *et al*., 2019). Unfortunately, significant gaps in protection do exist as the land managed by the Department of Conservation is mostly high elevation steeplands which are unsuited to farming (Cieraad *et al*., 2015) and not all private landowners are protecting remnants on their land (Monks *et al*., 2019). Due to the agriculturally productive nature of alluvial soils, native riparian forests have been particularly depleted (Miller, 2002).

1.2.1 Risk of future clearance

1.2.1.1 Site characteristics

One site characteristic that has been demonstrated to be associated with forest clearance is slope (Monks *et al*., 2019; Echeverría *et al*., 2007). By plotting the probability of clearance per year against slope, Monks *et al*. (2019) were able to identify the trends in forest loss associated with slope for recommended areas for protection (RAPs) in New Zealand. These plots gave a line gradient of -1.01, -0.60, and 0.03 for the time periods 1989 to 2001, 2001 to 2008, and 2008 to 2015, respectively, demonstrated that over time the probability of forests on steeper land to be cleared increased (Monks *et al*., 2019). Through the use of multiple logistic regression models, Echeverría *et al*. (2007) were able to demonstrate the effect that slope had on the probability of forest clearance at a number of sites including two temperate forest sites in Chile. Multiple logistic regression gave a coefficient of -0.03 with a *p* value of <0.01 at Rio Maule-Cobquecura, between 1900 and 2000, and at Los Muermos-Ancud, a coefficient of -0.05 with a *p* value of <0.01 between 1976 and 1985, and a coefficient of -5.72x10 $^{-2}$ with a p value <0.01 (Echeverría *et al*., 2007), indicating that clearance was more likely to occur on shallow slopes compared to steep slopes (Echeverría *et al*., 2007), at least initially.

1.2.1.2 Urban development

Past studies have demonstrated that road density is a significant explanatory variable for forest loss and fragmentation in New Zealand (Ewers *et al*., 2006). Of the 13 variables measured, road density was the most important for cumulative forest loss and forest fragmentation (Ewers *et al*., 2006). Multiple linear regression gave a *r* value of 312.58 and a *p* value of <0.01, and a randomisation test gave a *F* value of 34.87 and a *p* value of <0.01, indicating that historic forest loss was largely related to increases in road density (Ewers *et al*., 2006). Multiple linear regression gave a *r* value of 321.16 and a *p* value of <0.01, and a randomisation test gave a *F* value of 39.32 and a *p* value of <0.01, indicating that low road densities are associated with increased forest fragmentation (Ewers *et al*., 2006). In 2019 Monks *et al*. assessed predictors of forest loss in areas of high ecological value that had no legal protection (RAPs) at the time of the study. By plotting the probability of clearance per year against road density, Monks et al. (2019) were able to identify trends in the probability of clearance for different time periods. The trends identified were relatively weak (Monks *et al.,* 2019). Between 1989 and 2001, a line gradient of -0.15 indicated that the probability of forest clearance in areas with a low road density was higher than the probability of clearance in areas with a high road density (Monks *et al*., 2019). Between 2001 and 1008, a line gradient of 0.14 indicated that the opposite trend to the previous time period occurred (Monks *et al*., 2019). The same trend occurred between 2008 and 2015, with a line gradient of 0.27 (Monks *et al*., 2019). These relatively weak trends indicate that road density was not a significant predictor of forest clearance within RAPs (Monks *et al*., 2019). Ewers *et al*., (2006) recognised that road density does not exclusively predict forest clearance. A number of locations within the study showed low road density with high amounts of forest clearance, indicating that a number of variables must be assessed to predict the risk of forest clearance (Ewers *et al*., 2006).

Past studies have demonstrated a correlation between road density and population density (Ewers *et al*., 2006). In 2016, Thorn *et al*. used boosted regression tree models to assess which variables are the most important for forest loss to urban development in New England temperate forests. Of the 15 variables included in the boosted regression tree models, population density had the highest relative influence of 30 % (Thorn *et al*., 2016). This was considerably higher than the influence of slope and elevation which both had a relative influence of <5 % (Thorn *et al*., 2016). The probability of forest clearance and conversion for urban development increased rapidly from 0 % to 2 % between a population density of 0 per km² and 600 per km² before decreasing (Thorn *et al*., 2016). If population density and road density are correlates, then sites with a low road density and therefore low population density, would be at a lower risk of forest clearance compared to sites with a high road density and therefore high population density.

1.2.1.3 Surrounding land use

Past studies have demonstrated that the surrounding land use can be an important predictor of forest loss (Ewers *et al*., 2006, Monks *et al.,* 2019).

Monks *et al* (2019) assessed the probability of forest clearance in RAPs due to the surrounding land use. Land use was plotted against the annual probability of clearance and the slope was analysed to determine the likelihood of forest clearance. For dairy farming the plots gave a line gradient of -0.14, 0.05, and 0.24 for the time periods 1989 to 2002, 2002 to 2008, and 2008 to 2015, respectively (Monks *et al.,* 2019). The results indicated that over time the probability of forest clearance in areas surrounded by dairy farming increased (Monks *et al.,* 2019). By the 2008 to 2015 time period, clearance was more likely to occur in areas with dairy farming compared to those without (Monks *et al.,* 2019). Areas surrounded by cropping and horticulture were not associated with forest clearance (Monks *et al.,* 2019), as demonstrated by a line gradient of -0.30, -0.13, and -0.11 for the three time periods measured (Monks *et al.,* 2019). For plantation forestry the plots gave a line gradient of 0.38, -0.1, and -0.36 for the time periods, 1989 to 2001, 2001 to 2008, and 2008 to 2015, respectively (Monks *et al.,* 2019). The results indicated that for the time periods 1989 to 2001 and 2001 to 2008, RAPs surrounded by plantation forestry were more likely to be cleared than those not surrounded by plantation forestry (Monks *et al.,* 2019). These plantation forestry results are supported by the Ewers *et al*. (2006) study. Increases in exotic forest cover were largely due to conversion of land to plantation forestry in the Ewers *et al*. (2006) study. Changes in exotic forest cover was the most important predictor of forest clearance in New Zealand between 1997 to 2002 (Ewers *et al*., 2006). Multiple linear regression gave a r value of 28.05 and a p value of <0.01, and a randomization test gave a F value of 15.06 and a p value of <0.001, indicating that increases in exotic forest cover was the most important explanatory variable for forest loss between 1997 and 2002 (Ewers *et al*., 2006). As Monks *et al.,* (2019) demonstrated, the probability of forest clearance in areas surrounded by plantation forestry decreased in recent times.

1.3 Ecological restoration

Ecological restoration is ‘the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed’ (SER, 2004). Ecological restoration involves economical, ecological, social, political, and legislative aspects and aims to conserve ecosystems and biodiversity, as well as renewable and non-renewable resources (Andel & Aronson, 2012). Restoration ecology is the field that aims to develop concepts and theories that feed into successful ecological restoration projects. Modern restoration efforts are aimed at restoring whole ecosystems, as ecosystems are complex, and the results are usually long term. Restoration ecology is often inter- and transdisciplinary and can involve geomorphology, hydrology, physics, chemistry, organism physiology, genetics, and other fields of ecology such as landscape ecology and community ecology (Andel & Aronson, 2012). Personal, cultural, ecological, and socio-economic values are often incorporated into restoration projects (Clewell *et al*., 2013). The range of fields or disciplines, and values associated with restoration projects results in a range of people being involved (Clewell *et al*., 2013). Such people may include a range of scientists, policymakers, land managers, and the general public

(Clewell *et al*., 2013). Restoration projects usually follow a number of stages including planning and design, implementation, monitoring, and maintenance stages (Clewell *et al*., 2013). Successful restoration projects will achieve the protection of biodiversity, improvement of human health and wellbeing, and provide resilience to climate change (Clewell *et al*., 2013).

The society for ecological restoration has put forward eight principles of ecological restoration (Clewell *et al*., 2013). Stakeholder engagement, knowledge from a range of fields, the use of appropriate reference ecosystems, the enhancement of natural ecosystem recovery processes, clear goals, objectives, and measurable indicators, making the highest level of recovery the target, cumulative gains in ecological value, and a continuum of restoration activities are all part of successful restoration projects (Clewell *et al*., 2013). A restored site will contain species native to the area that represent all of the known functional groups, the ecological reference used, and are appropriate for the specific site (Clewell *et al*., 2013). Species within a restored ecosystem will be sufficiently abundant and distributed across the site and will be sufficiently supported by the abiotic environment (Clewell *et al*., 2013). Ideally, a restored site will be integrated into the surrounding ecological landscape or be in close proximity to other restoration projects (Clewell *et al*., 2013). Restored sites should also have ecological functionality, ecological complexity, be self-sustaining and be resilient to disturbance (Clewell *et al*., 2013).

Species composition is an important aspect of ecological restoration (Clewell *et al*., 2013). As mentioned above, representation of all known functional groups is important to ensure that a restored site will be able to function properly and be self-sustaining (Clewell *et al*., 2013; Lavorel *et al*., 1997; Gondard *et al*., 2003; Rosenfeld, 2002). Decomposition, carbon fixation, and nitrogen sequestration are examples of some of the functional roles required for a healthy, functioning ecosystem (Clewell *et al*., 2013; Lavorel et al. 1997; Gondard et al. 2003; Rosenfeld 2002). Plant species composition is important for ecological restoration as plants are the primary producers of the system, consequently governing the attributes of the ecosystem (Clewell *et al*., 2013). In a restoration project, the species composition should be based on what was present at the site prior to disturbance, with an intact example being used as a reference (Clewell *et al*., 2013). As environmental conditions change over time, flexibility must be taken into consideration, and some species may need to be substituted for those better adapted to the new conditions, to ensure optimal functionality (Clewell *et al*., 2013). Animal species composition and the representation of functional roles that animals play within an ecosystem are also important for ecological restoration (Clewell *et al*., 2013). However, natural, and spontaneous reintroductions may not occur (Clewell *et al*., 2013). In these instances, captive breeding programmes and translocations may be required as part of a restoration project (Clewell *et al*., 2013).

Community structure is another important aspect of ecological restoration as it describes the 3-dimensional components of a community (Clewell *et al*., 2013). Community structure is affected by the species composition, as well as the abundance and distribution of the species within a site (Clewell *et al*., 2013). Greater structure allows for more interactions between organisms and allows for more ecological processes to take place (Clewell *et al*., 2013). In restoration projects most of the structure is developed over time as growth continues and demographic and successional processes occur (Clewell *et al*., 2013; Forbes *et al*., 2020). To speed up the process of structural development and succession, certain species may be removed or introduced to the restoration site as the presence of particular species allows for the presence of other species and vice versa (Clewell *et al*., 2013; Forbes *et al*., 2020).

1.3.1 Barriers to restoration

A number of factors may limit or, in extreme cases, prevent restoration of riparian vegetation (Schmidt *et al*., 2019). One of the key limiting factors is society's competition for land (Meli *et al*., 2019). In particular, agriculture requires significant areas of land, reducing the space available for riparian vegetation and restoration projects (Meli *et al*., 2019). Human preferences may limit the location, patch size, and species planted for restoration projects (Schmidt *et al*., 2019). Low diversity of plants within remnants or planting efforts may lead to long-term resilience issues (Buchanan *et al*., 2020). It has been demonstrated that stands with low diversity have a higher risk of invasions due to decreased competition (Cramer *et al*., 2008). Stands with low diversity have also been shown to have low resilience to disturbances, potentially affecting the long-term viability of the stand (Buchanan *et al*., 2020). Low diversity and structure also inhibit the ability of riparian vegetation to sequester carbon, affecting the ecosystem as a whole (Meli *et al*., 2019). Other factors such as the soil type and quality as well as the level of the water table may also affect the species that can survive at the restoration site (Schmidt *et al*., 2019). Soil types, water tables, and human preferences are a few examples of some of the barriers that may prevent the protection and restoration of riparian forests (Schmidt *et al*., 2019). Social issues, such as landowner participation and engagement, a breakdown of communication between parties involved, legislation, or lack thereof, monitoring or lack thereof, and funding may also limit the success of restoration projects (Viani *et al*., 2019). Other limiting factors include the relatively limited set of theories and principles within the field of restoration ecology, a lack of historical data, a lack of reference sites, and the introduction or extinction of key species or the attainment of alternative stable states that cannot be reversed (Halle & Fattorini, 2004; SER, 2004; Beisner *et al*., 2003).

1.4 Study region

The Hawke's Bay region is located on the east coast of the North Island and covers approximately 1.42 million ha (Hawke's Bay Regional Council, n.d.). Hawke's Bay Regional Council is the regional authority. Within the region there are four local councils: the Wairoa District, Hastings District, Central Hawke's Bay District, and Napier City. Approximately 150, 000 people live in the region's two main cities, Napier, and Hastings, as well as several small towns such as Wairoa, Waipawa and Waipukurau, and many small settlements spread across the region (Hawke's Bay Regional Council, n.d.).

1.4.1 Climate

The Hawke's Bay region typically experiences warm, dry summers and cool, wet winters with the occasional frost and snow (Chappel, n.d.). While the region overall is one of the driest in the North Island, rainfall is highly variable (Chappel, n.d.). The variance in annual rainfall is governed by elevation and exposure the predominant wind direction (Chappel, n.d.). In general, higher elevations and areas further inland experience higher rainfall and colder temperatures compared to the plains (Reed & Ide, 2012). Coastal areas, particularly to the south, are typically warm to hot, dry, and windy. The region is flood and drought prone (Reed & Ide, 2012).

1.4.2 Physiography and geology

The Hawke’s Bay region is comprised of mountain ranges, hill country, lowland zones, plains, shorelines, and freshwater features such as lakes, swamps, and rivers (Grant, 1996). The 350 km of coastline is diverse (Hawke’s Bay Regional Council, n.d.). Coastal features in the area include estuaries, such as the Ahuriri Estuary, two peninsulas, including Cape Kidnappers to the south, and a small number of islands, including Bare Island, also to the south (Reed & Ide, 2012). Mountain ranges occur in the north and west, productive plains and hill country occur elsewhere (Hawke’s Bay Regional Council, n.d.). Seven major rivers flow across the region including the Wairoa, Mohaka, Esk, Ngaruroro, Tutaekuri, Tukituki and Waipawa Rivers (Hawke’s Bay Regional Council, n.d.).

The hill country is dominated by soft sediments and is erosion prone. Higher hill country and steep lands are also erosion prone but are dominated by hard greywacke or argillite and often underneath a volcanic, loess or ash overlay (Reed & Ide, 2012). The plains are typically dominated by alluvial sediments which are usually poor draining with high fertility, compared to the pumice flatlands in the north which are faster draining with low fertility (Reed & Ide, 2012).

1.4.3 Soils

Across the region, soil types generally differ according to topography (Reed & Ide, 2012). Hill country is usually dominated by soft sediments such as sandstone, siltstone, mudstone, or limestone. Higher hill country and steep lands are often dominated by greywacke or argillite, with some locations having a volcanic, loess, or ash overlay. Alluvial soils and sediments dominate valleys, plains, and terraces (Reed & Ide, 2012).

1.4.4 Land use

Land use across the Hawke’s Bay region is largely determined by slope and fertility (Reed & Ide, 2012). Marginal land is usually dominated by plantation forestry. Hill country is often dominated by extensive sheep and beef farming, and the fertile lowlands are often used for intensive horticulture and viticulture. Other farming uses include dairy farming which is common in discrete areas, and deer farming which is less common (Reed & Ide, 2012). The region’s economy is largely driven by farming, horticulture, wineries, and tourism (Hawke’s

Bay Regional Council, n.d.). The region contains a number of conservation areas, such as Te Urewera National Park as well as significant areas of native forest as seen in the Mohaka catchment where approximately 50 % of the land is covered in native forest (Reed & Ide, 2012). Areas for recreation are common, such as the sandy beaches to the south. The remaining land is used for infrastructure, with a number of villages, towns, and cities occupying the region (Reed & Ide, 2012).

1.4.5 Ecology

The ecological value of the terrestrial areas within the Hawke's Bay is variable (Reed & Ide, 2012). Some areas are dominated by commercial land uses with little to no native forest cover. There are some areas containing isolated patches of native forest, and other areas, usually those found further inland from the coast, have extensive native forest such as Boundary Stream and the Kaweka and Ruahine Ranges. In terms of pest animals, significant possum control occurs in some regions and deer hunting is a popular activity in the ranges (Reed & Ide, 2012).

The ecological values of the freshwater systems within the region are also variable (Reed & Ide, 2012) with the region supporting productive trout, whitebait, and eel fisheries. Many freshwater systems are home to threatened native fish such as the longfin eel and the koaro, while others are quite degraded and of low ecological value. Run-off from urban areas has led to the degradation of many urban streams, leaving them with a lower value compared to rural streams. The Waitangi wetland is one example of a significant freshwater system in the region (Reed & Ide, 2012).

On the coast, areas of ecological significance include the Porangahou estuary, the Cape Kidnappers Gannet Reserve, Te Angiangi Marine Reserve, and the sand dunes at Ocean Beach (Reed & Ide, 2012).

1.4.6 Forest extent and modification

In 1280 AD, it is likely that 94-98 % or 1.69 million ha (Ewers *et al.*, 2006) of the Hawke's Bay region was covered in native forest (Grant, 1996). By 1990, only 18 % of the land was covered in forest, 17 % of this in the mountain areas and 1 % in lowland areas. Of the remaining 82 % of non-native forest, 76 % had been converted to either pasture or exotic forest. By 2002 only 17 % of the land area in the region was covered in native forest with 16 % covered in plantation forestry, and 11 % protected by the Department of Conservation (Ewers *et al*., 2006). Evidence-based theories have been put forward to try and explain the key drivers of forest loss in the region (Grant, 1996).

Radiocarbon dating has indicated that the burning of Hawke's Bay forests occurred during Polynesian times (Molloy *et al*., 1963). Based on this evidence, the theory that the fires were intentionally started by Polynesians was put forward and widely accepted (Molloy *et al*., 1963; Grant, 1996). Since then, more research has led to another theory being put forward. In 1996, Grant put forward his theory that forest loss in the Hawke's Bay was in fact due to natural events, with human interference only playing a minor role.

Grant (1996) suggested that a continual cycle of extreme gales followed by severe fires and then sedimentation, all in quick succession and repeated over a long period of time, had been the key drivers of forest loss in the Hawke's Bay region. Evidence that led to this theory included charred wood found in older alluvium, indicating that burning had occurred prior to sedimentation, as well as cavities found in older felled trees. It is likely that human activities such as intentional fires, the introductions of exotic animals and plants, and the clearance of land for a range of land uses, by both Maori and Europeans, exacerbated the forest loss originally caused by catastrophic climatic events (Grant, 1996).

1.5 Study site descriptions

1.5.1 Ngaruroro River

The Hawke's Bay is home to the braided Ngaruroro River, pictured in Figure 1.1, whose headwaters are located in the Kaimanawa Range (Parrish, 1988). Greywacke gorges confine the upper portion of the Ngaruroro River, before the riverbed widens out to approximately 1 km at the widest span. The river flows across the Heretaunga Plains before flowing into the Waitangi Estuary alongside the Tutaekuri and Clive Rivers. In the late 1960s the lower portion of the Ngaruroro River was diverted and is now confined by stopbanks (Parrish, 1988). Commercial and recreational uses of the river include gravel extraction, fishing, and a range of motorsports (Forbes, 2011).

A range of habitats are supported by the Ngaruroro including wetlands, forests, an estuary, and a gravel beach (Forbes, 2011). These habitats in turn support a range of native species such as *Botaurus poiciloptilus, Charadrius bicintus* (Parrish 1988), *Galaxias brevipinnis,* and *Anguilla dieffenbachia* (Forbes, 2011). Also supported are a range of introduced pest species such as *Rattus rattus* and *Mustela erminea.* Alongside animal species, the Ngaruroro River supports a range of plant species, including *M. ramiflorus*, *Myoporum laetum*, *Sophora teptraptera,* and *Alectryon excelsus* (Forbes 2011). The upper portion of the river is dominated by native vegetation, while the lower portion is dominated by exotic species and has a higher level of stock access to the water's edge (Hashiba, 2014). Exotic species such as *Salix* spp. and *Populus* spp. can be found along the stopbanks (Parrish, 1988). In pre-human times, it is likely that the Ngaruroro River was dominated by *Dacrycarpus dacrydioides, Podocarpus totara, Prumnopitys taxifolia* forest on the floodplains, particularly in the middle and lower reaches, and to a lesser extent, *P. totara*, *Alectryon excelsus* forest, particularly in the upper regions (Singers, 2017).

Figure 1.1: Braided section of the Ngaruroro River near Whanawhana. Image taken in the December of 2019.

1.5.2 Tutaekuri River

The braided, torrent, gorge-confined and meandering portions of the Tutaekuri River (Figure 1.2) start in the Kaweka Range and cross the Heretaunga Plains before flowing into the Waitangi Estuary (Parrish, 1988). The upper portion of the river is confined by cliffs, the middle portion is confined by dense *Salix* spp., and the lower portion is confined by stopbanks. Much like the Ngaruroro River, the flow of the Tutaekuri was diverted from its original path. Prior to the 1931 Napier earthquake, the Tutaekuri flowed into the Ahuriri lagoon, further north from the Waitangi Estuary (Parrish, 1988). Commercial and recreational uses of the river include gravel extraction, whitebaiting, motorsports, and kayaking (Forbes & Whitesell, 2015).

Many habitat types are supported by the Tutaekuri River: grasslands, forests, gravel bed, and gravel beach (Forbes & Whitesell, 2015). These habitat types support a range of species such as *Porzana tabuensis*, *Himantopushimantopus, Rhombosolea retiarii*, and *Galaxias maculatus.* Plant species include *Kunzea robusta, Cordyline australis, Pseudopanax arboreus, C. robusta,* and exotic species such as *Populus* spp. and *Salix* spp. (Forbes & Whitesell, 2015). The upper portion of the river is predominately native vegetation with low stock access, while the lower portion is predominately exotic forest, with relatively low stock access (Hashiba, 2014). In pre-human times, it is likely that the Tutaekuri River was dominated by *D. dacrydioides*, *P. totara*, *Prumnopitys taxifolia* forest in the mid to lower reaches and *P. totara*, *A. excelsus* forest in the mid to upper reaches (Singers, 2017).

Figure 1.2: Tutaekuri River near Waiwhare. Image taken in February of 2020.

1.5.3 Tukituki River

Starting in the Ruahine Range and flowing across the Ruataniwha and Heretaunga Plains are the torrent, meandering, and braided portions of the Tukituki River (Figure 1.3) Parrish, 1988). The Tukituki and Waipawa Rivers join just below Waipukurau, where they form a single channel river. Located in Haumoana is the river mouth, which forms a smaller estuary zone compared to the Waitangi Estuary. River control works have converted a large portion of the river from braided to meandering, and stopbanks have been put in place across the Ruataniwha Plains (Parrish, 1988). Other human activities include gravel extraction, beach raking, whitebaiting, and swimming (Forbes *et al*., 2011).

Boulderfields, gravel beach, gravel bed and an estuary are a few of the habitat types supported by the river (Forbes et al. 2011). These habitat types in turn support a range of species such as *Thinornis novaeseelandiae, Bowdleria punctate, Geotria australis,* and *Galaxias fasciatus* (Walls 2005). Introduced species include *Cervus elaphus* and *Felis catus* (Forbes *et al*., 2011). Native trees include *A. excelsus, D. dacrydioides,* and *Beilschmiedia tawa.* Exotic trees such as *Salix* spp. and *Populus* spp. have been planted along the river (Forbes *et al*., 2011). The riparian vegetation along the Tukituki River is variable (Hashiba, 2014a) with the upper portion being dominated by native vegetation, largely due to the high altitude and areas of conservation land. Further downstream sees a shift to a dominance of exotic species, largely due to plantation forestry (Hashiba, 2014a). Before the arrival of humans, it is likely that the Tukituki River margins would have been dominated by *D. dacrydioides*, *P. totara*, *P. taxifolia* forest and *P. totara*, *A. excelsus subsp. excelsus* forest with patches of *D. dacrydioides* forest in the upper reaches (Singers, 2017).

Figure 1.3: Tukituki River near Ashley Clinton. Image taken in January of 2020.

1.6 Regression tree models

Regression trees are useful for the descriptive and predictive modelling of the relationship between a given continuous response variable and at least one explanatory variable (Breiman *et al.*, 1984; De'ath & Fabricius, 2000). Benefits of regression trees are their ability to deal with missing values, a range of variable types such as numeric or categorical variables, and non-linear relationships Each tree contains a root, which contains all of the observations or data. From the root, the data is split into two branches. Each subsequent split is called a node. The terminal node is called a leaf. The splitting process is designed to minimise the residual sums of squares and create more homogenous groups with each split. When a node is strongly homogenous, no further splits are made, and the node becomes a leaf (Breiman *et al*., 1984; De'ath & Fabricius, 2000). Figure 1.4 is an example of a regression tree where only one split was made. The root contained 100 % of the data, and the predicted mean of the response variable was 3.30 units. From here, the data was split where the explanatory variable (X), was >47 units or <47 units. Twenty-nine percent of the data had a X value <47 units, and the predicted mean for the response variable was 1.80 units. Seventy-one percent of the data had an X value >47 units, and the predicted mean of the response variable was 3.90 units.

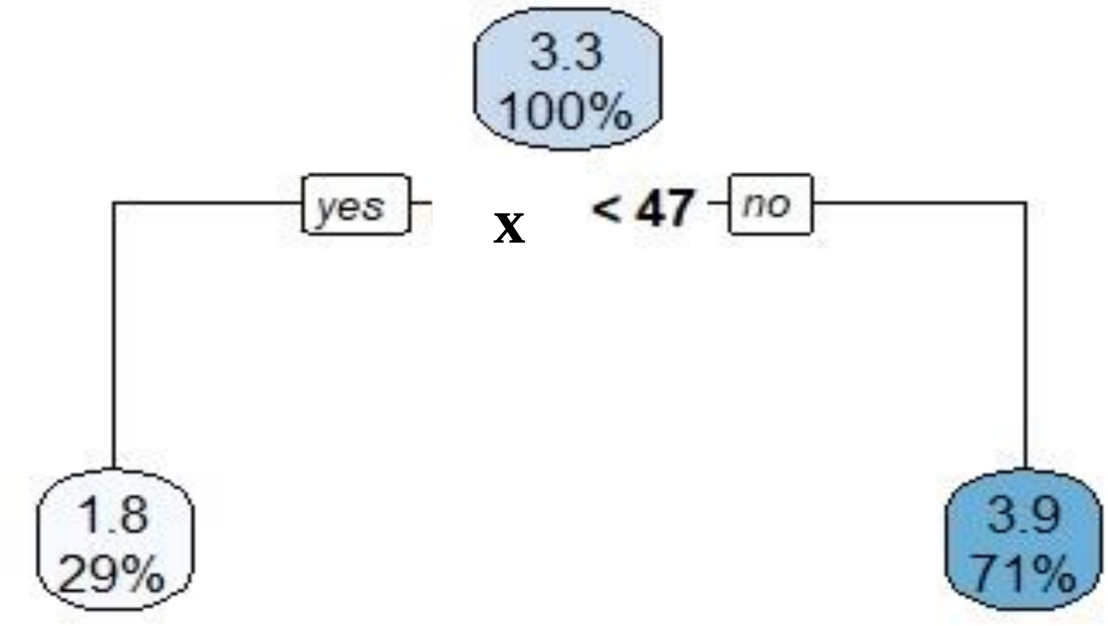


Figure 1.4: Example of a single regression tree model showing the percentage of the data and the predicted response variable value at the root and leaves. The explanatory variable is represented by X. Produced in RStudio (version 3.6.3) using the rpart (version 4. 1-15; Therneau, Atkinson & Ripley, 2019), and rpart.plot (version 3.0.8; Milborrow, 2019) packages.

Various methods of pruning and tuning can be used in order to reduce the size of the trees (Breiman *et al*., 1984; De'ath & Fabricius, 2000). This is usually a compromise between reducing the number of nodes and the explained variance of the response variable (Breiman *et al.*, 1984; De'ath & Fabricius, 2000). Regression tree models are often used in machine learning where methods such as bootstrap aggregation (bagging) can be used to further improve the predictive power and robustness of the models (Dietterich, 2000). An ensemble of trees is created in the bagging process in order to improve the model performance (Dietterich, 2000). In bagging, bootstrap copies of the training data set are created and then a base learner algorithm is applied to each (Breiman, 1996). The predictions from this process are then averaged to create the final model (Breiman, 1996). Many trees are bagged in the bagging process. The specific number is dependent on the variance and number of strong predictors within a data set (Breiman, 1996). Usually, 50-500 trees are sufficient for optimal model performance (Breiman, 1996). Bagging is particularly useful for improving the prediction accuracy of high variance models; however, the method does have limitations (Breiman, 1996). Tree correlation is a result of the trees produced in the bagging process not being independent of one another (Breiman, 1996). Such trees from different bootstrap samples usually have a similar structure as all of the features are considered at each split (Breiman, 1996). Unfortunately, the bagging process renders regression trees uninterpretable (Dietterich, 2000). Alternative was of interpreting the features of the models such as variable importance and response curves must be used in place of dendrograms (Dietterich, 2000).

1.7 Research objectives, aims and hypotheses

There are two main objectives for this research. The first objective is to quantify the current structure and composition of riparian forest remnants along the Ngaruroro, Tutaekuri, and Tukituki Rivers in the Hawke’s Bay region. This objective will be achieved through the collection of empirical data from vegetation surveys and forest health assessments with supporting data from bird counts and visual soils assessments. The second objective is to determine which explanatory variables are the most important for explaining the structure, composition, and ecological health of the remnants. This objective will be achieved through the use of bagged regression tree models. It is predicted that proximity to the river, road density, adjacent land use, annual rainfall, topsoil depth, slope direction and steepness will be the most important explanatory variables for the community structure, species composition and restoration potential of the sites surveyed.

With the knowledge of the relative strengths of explanatory variables, recommendations for management are made regarding where restoration potential lies and the types of restoration interventions necessary, in regard to improving the species composition and community structure.

1.8 Thesis structure

This thesis is structured according to the four chapters outlined below.

Chapter one: Introduction

This chapter provides background information on riparian vegetation, including the modification of riparian vegetation, and ecological restoration, including the barriers to restoration. Included in this chapter is also a broad description of the study region including the climate, physiology, geology, soils, land use and ecology. This chapter also identifies and describes the rivers used in the research. Research aims and objectives are also covered in Chapter One.

Chapter Two: Materials and methods

This chapter outlines the materials and methods used for data collection (fieldwork) and statistical analysis of these data. Included in this chapter are descriptions of the vegetation, site characteristics, forest health, soil, and presence-of-bird surveys. Also included is a description of the site selection process and statistical analyses used.

Chapter Three: Results

This Chapter presents the results obtained during the fieldwork and statistical components of this research. Included in chapter three are descriptions of the site characteristics, forest health, soils, presence of birds and plant species. Results from the statistical analyses are also included in chapter three.

Chapter Four: Discussion

This chapter discusses the results from the fieldwork and statistical analyses. In particular, chapter four explores the restoration potential and needs of the sites surveyed, and the implications of the results for restoration management. A summary of the research and key findings are also included in this chapter.

Chapter Two

Methods

The Hawke's Bay region was selected for this research due to the significant amount of vegetation clearance and land conversion, as well as the ecologically significant rivers present in the region. Vegetation, site characteristics, forest health, soils, and the presence of birds were assessed at 11 sites selected for the research. The site selection process, field methods and statistical analysis methods are outlined below.

2.1 Site selection

Forest remnants were selected based on nine selection criteria outlined in Table 2.1. The selection criteria represented variables likely to affect the composition, structure, and ecological health of the remnants. The remnants were selected to demonstrate the possible range of each criterion.

The present study was focused on native riparian forest remnants, meaning all sites were required to have a dominance of native species. All sites were required to have a minimum size of 0.25 ha, to ensure that there was enough space within the site for sampling. Sites were also required to be within 500 m of the water's edge, to ensure that each site was within the riparian zone.

The total length of all roads and highways within 10 km^2 of each remnant (road density) was included in the selection criteria to act as a surrogate for urban development. Remnants selected, had road densities ranging from low to high in order to demonstrate the effects of urban development on the remnants. Variables likely to have an effect on the distribution of plant species such as annual rainfall, depth of the topsoil, aspect, and slope were included to determine the effects of species preferences and requirements. Adjacent land use was included to demonstrate the effects of human preferences.

Table 2.1: Criteria used for site selection.

Criteria	Units	Description
Native forest		Forest patch comprised of predominately native species
Size	ha	>0.25 ha
Proximity to river	m	Part of remnant is within 500 m of wetted river edge
Road Density	km²	Low (<0.5 km²), Medium-Low (0.5-1.0 km²), High-Medium (1-1.5 km²), High (>1.5 km²)
Adjacent land use		Dairy Farming, Farming non-dairy, Plantation Forestry, Recreation
Annual rainfall	mm	Low (<650 mm), Medium-Low (650-850 mm), High-Medium (850-1050 mm), High (>1050 mm)
Topsoil Depth	cm	Very Shallow (<20 cm), Shallow (20-45 cm), Moderately Deep (45-100 cm), Deep (>100 cm)
Aspect	°	N (316-45°), S (136-225°), E (46-135°), W (226-315°)
Slope	°	Undulating (0-9°), Rolling (10-19°), Steep (20-29°), Very steep (>30°)

The desktop application QGIS (version 3.4.14) (QGIS.org, 2019) was used in the remnant selection process. Layers for the presence of native forest, New Zealand roads, land use, annual rainfall, and soil depth were obtained from the Koordinates website (https://koordinates.com/). To measure road density, a square of approximately 10 km² was drawn around each plot, with the centre of the remnant and the square lining up. Within the square, the total length of all roads and highways was measured in km. The total length of roads was then multiplied by the area of the square to give the road density. This process was repeated for each remnant. A list of the layers used are outlined in Table 2.2. below. Once obtained, layers were imported into QGIS (version 3.4.14) and laid on top of one another; remnants that fit the selection criteria were then assessed for aspect and slope on the OurEnvironment website (https://ourenvironment.scinfo.org.nz/). Each remnant was given a code for easy identification. Each code indicated which river the remnant was associated with, NG for Ngaruroro, TK for Tutaekuri, TT for Tukituki, and MK for Makaretu, as well as a unique number for easy identification. Two spare sites each for the Ngaruroro, Tutaekuri, and Tukituki Rivers were identified in case the site selection process yielded any inappropriate sites.

Table 2.2: GIS layers used in the site selection process.

Name	Date	Created by	Description
NZ native polygons (Topo, 1:50k)	21/10/2019	LINZ	Patches of indigenous forest patches as of October 2019
NZ roads: road section geometry	17/12/2019	LINZ	Map of New Zealand roads as of December 2019
LUCAS NZ Land Use Map 1990 2008 2012 2016 v006	21/10/2019	Ministry for the Environment	Land use as of October 2019
Average annual rainfall, 2016	18/10/2017	Ministry for the Environment	Average annual rainfall depth in mm for 2016
Smap Soil depth august 2018	23/08/2018	Smap	Soil depth in cm for august 2018

The site selection process identified 26 possible sites that were field checked to ensure that they met the selection criteria and that access to the sites was possible. A number of the sites either did not meet the selection criteria or were not accessible and had to be discarded from use in the study. A list of the discarded sites can be found in Appendix One, which includes all 26 sites and their associated site selection data. Field checking resulted in a final shortlist of 11 remnants. Four of the remnants were from the Ngaruroro River known as NG-3, NG-5, NG-6, and NG-7, four were from the Tutaekuri River known as TK-4, TK-5, TK-6, and TK-7, two were from the Tukituki River known as TT-4 and TT-5, and one was from the Makaretu River known as MK-3. As the Makaretu River flows into the Tukituki River, the Makaretu River site is referred to as one of the Tukituki River sites.

Forest surveys were carried out between January and February of 2020, with the exception of the three Ngaruroro River sites. The forest survey for site NG-5 was carried out between December and February of 2018/2019. The forest health assessment for sites NG-6 and NG-7 was also undertaken between December and February of 2018/2019.

2.2 RECCE plots

Three 10 x 10 m RECCE plots, that followed Hurst and Allen (2007), in part, were undertaken per remnant, with a total of 33 plots. RECCE plots were used to determine the current species composition, community structure, and site characteristic. Plot location was determined randomly by placing a grid over each remnant using QGIS (version 3.4.14). For remnants under 5.5 ha a 10 m grid size was used and for remnants over 5.5 ha a 100 m grid size was used. A random number generator was used to select six grid intersect points and those locations were translated to coordinates in the New

Zealand Transverse Mercator 2000 (NZTM2000) format and this provided the sampling locations. Three of the grid references were surveyed and three were kept spare in case of inaccessibility.

A Garmin GPS device (model GPSMAP 64x) was used to locate the predetermined sampling locations; the coordinate defined the centre of each plot. The GPS accuracy was recorded in metres. At each plot, the parameters outlined in table 2.3 below were measured and recorded.

Elevation was measured in metres above sea level (m a.s.l.) using a Garmin GPS device at the approximate centre of each plot. Slope aspect (aspect) was measured at the centre of each plot. The observer stood with their back to the slope, facing in the same direction and took the reading off a magnetic compass to determine which direction the slope was facing. Slope angle (slope) was measured using a clinometer; the observer looked down the slope, lined up the clinometer with the ground, and took the reading. The mesotopographic index was measured from the plot centre using a clinometer and compass. At six compass bearings, 45°, 90°, 135°, 225°, 315°, and 360°, the clinometer was used to measure the angle from eye height to the horizon. Where vegetation blocked the view of the horizon, the reading was taken at the lowest light-gap in the vegetation. The mesotopographic index was measured to give an indication of how protected or exposed from the elements each plot was (McNab, 1993). For sites with a closed canopy this angle was large, for sites with a more open or no canopy, the angle was small. The angle for each of the six compass bearings was averaged to give the mesotopographic index. The percentage of cover was recorded for five categories: vascular plants, nonvascular plants, leaf litter, bare ground, and rock. Vascular plants included all live material, including leaves, branches, trunks, and exposed roots. Rock included all rocks, stones, and pebbles visible on the surface of the ground. Canopy height for each plot was estimated in metres. Where the canopy height was not even, the observer estimated the average height. The total canopy cover for the entire plot was estimated in percent. This was achieved by the observer assessing the amount and size of all gaps, small and large, in the canopy.

Table 2.3: Parameters measured and recorded during the RECCE plot surveys.

Parameter	Description
Elevation	Measured in metres above sea level (a.s.l)
Slope aspect	Measured in degrees
Slope angle	Measured in degrees
Physiography	Either ridge, face, gully, or terrace
Shape of land surface	Either, convex, concave, or linear
Drainage	Categorized on a scale from good to poor
Mesotopographic index	The degree of protection or exposure
Cultural information	Was noted including cultural significance, fauna, browsing and browse species
Cover categories	The percentage of the plot covered in vascular plants, nonvascular plants, leaf litter, bare ground, and rock
Rock	The percentage of bedrock and broken rock
Canopy height	Estimated in metres
Canopy cover	Measured in percentages, the total canopy cover of the plot

2.2.1 Seedlings

The number of seedlings per species were recorded in five height classes: <15 cm, 16 - 45 cm, 46 - 75 cm, 76 - 105 cm, and 106 - 135 cm. Any seedlings less than 15 cm in height were recorded as ‘present’. Species were recorded using their National Vegetation Survey (NVS) code and the sum of seedlings per species was calculated for each plot.

2.2.2 Saplings and trees

For saplings and trees, each plot was split into quarters - named, north west quarter, north east quarter, south west quarter, and south east quarter. The number of saplings per species were noted per quarter and the sum calculated. This approach was taken instead of individual seedling plots due to the low stem-densities occurring in most plots. The diameter at breast height (DBH) of woody stems >2.5 cm was measured for each tree per plot.

2.2.3 Composition

Each plot was split into seven vertical tiers: >25 m, 12 – 25 m, 5 – 12 m, 2 – 5 m, 0.3 – 2 m, <0.3 m, and epiphytes. The percentage of each species was split into six cover classes: <1 %, 1 – 5 %, 6 – 25 %, 26 – 50 %, 51 – 75 %, and 79 – 100 %. All plant species present within the plot boundaries, including those rooted outside but hanging over the plot were allocated a cover class within the appropriate vertical tiers.

Only woody vascular plant species were identified and included in the RECCE data.

2.3 Forest health assessment

One forest health assessment was undertaken per remnant to determine the current state of health and highlight areas requiring interventions. Forest health assessments for NG-5, NG-6 and NG-7 were undertaken in the summer of 2018/2019 and updated as required in January-February of 2020. The method was adapted from the FORMAK site assessment (FORMAK, 2005). The assessment was split into the six categories:

- Management
- Overview of site
- On the forest edge
- Moving through the forest
- Canopy gaps
- Threats.

2.3.1 Management

Within the management section, history, animal pest control, and weed control were assessed. The history of the site was recorded as either primary (score = 4), modified primary (score = 3), secondary (score = 2), or revegetated (score = 1). Evidence of animal pest and weed control was given a score of 4. A lack of evidence of animal pest or weed control was given a score of 1. Where the observer was unsure about animal pest or weed control, it was assumed that no control had taken place.

2.3.2 Site overview

Size, shape, proximity to indigenous forest, and the presence of corridors were assessed in the site overview section. The size of the site was recorded as either 0-5 ha (score = 1), 5-25 ha (score = 2), 25-100 ha (score = 3) or >100 ha (score = 4). The shape of the site was noted on a scale ranging from a narrow long strip (Score = 1) to an extensive round or square area (Score = 4). The distance between the site and indigenous forest patches that were >10 ha in size was recorded on a scale ranging from no patches present (score = 1) to large continuous area of forests present within 50 m of the site (score = 4). Presence of corridors was recorded on a scale ranging from site completely isolated (score = 1) to extensive vegetation corridors (score = 4).

2.3.3 On the forest edge

At the edge of the forest, dieback, understory, weeds, fencing, and the adjacent land use were recorded in the 'on the forest edge' section. The degree of dieback was measured on a scale ranging from major dieback in canopy (score = 1) to canopy without dieback (score = 4). Forest edge understory was ranked from understory completely absent (score = 1) to vigorous, abundant understory present (score = 4). Forest edge weeds were measured on a scale ranging from many weeds present (score = 1) to no weeds present (score = 4). Fencing was ranked from no fencing (score = 1) to secure intact fencing (score = 4). Adjacent land use was noted as either livestock farming (score = 1), exotic forest (score = 2), residential or urban (score = 3) or reserve (score = 4).

2.3.4 Moving through the forest

Within the forest, the canopy condition, canopy browse, regeneration, understory browsing, ground cover, and bird song, were assessed in the 'moving through the forest' section. The condition of the canopy was measured on a scale ranging from very sparse foliage (score = 1) to abundant dense foliage (score = 4). Canopy browsing was measured by looking for any signs of browse on plant species known to be preferred by *Trichosurus vulpecula* (Department of Conservation, 2014). Canopy browse was recorded as either severe (75-100 % of leaves browsed; score = 1), moderate (25-75 % of leaves browsed; score = 2), light (1-25 % of leaves browsed; score = 3) or no canopy browse (score = 4). The presence of seedlings known to be preferred by ungulates (order *Artiodactyla*) was used to determine regeneration within the forest (Forsyth *et al*., 2002). Regeneration was recorded on a scale ranging from understory completely bare of all species (score = 1) to abundant regeneration of preferred species (score = 4). Understory browsing was measured by looking for any signs of browse on the stems of plant species known to be preferred by ungulates. Understory browsing was recorded as either severe (75-100 % of stems browsed; score = 1), moderate (25-75 % of stems browsed; score = 2), light (1-25 % of stems browsed; score = 3) or no understory browse (score = 4). Ground cover was measured on a scale ranging from bare soil covering >20 % of ground (score = 1) to no bare soil (score = 4). Bird song was measured on a scale ranging from bird song almost entirely absent (score = 1) to continuous bird song with no breaks (score = 4).

2.3.5 Canopy gaps

Regeneration and the presence of species preferred by ungulates, were measured within canopy gaps. The abundance of seedlings was used to measure regeneration. Regeneration was recorded on a scale ranging from no seedlings (score = 1) to abundant seedlings (score = 4). The presence of species preferred by ungulates, within canopy gaps was measured on a scale ranging from canopy gaps dominated by non-preferred species (score = 1), to canopy gaps dominated by preferred species (score = 4).

2.3.6 Threats

The threats section covered the effects of plant and animal pests as well as anthropogenic damage within the remnants. Plant pests were split into three categories: vine, shrub, and ground cover. The dominance of plant pests was recorded in percentages, on a scale ranging from >50 % (score = 1) to <1 % (score = 4). The abundance of fresh signs of *T. vulpecula* and ungulates were noted as either abundant fresh signs (score = 1), common fresh sign (score = 2), sign uncommon (score = 3) and no sign (score = 4). The degree of anthropogenic damage was ranked on a scale ranging from severe damage (score = 1) to no damage (score = 4).

2.3.7 Forest health scores

For each remnant, the forest health score was calculated by taking the average score per theme and then summing all the theme scores together. Where no score was given, the variable was not included in the calculation. Higher scores were associated with healthier remnants, with a perfect score being 24.

2.4 Visual soil assessment

Visual soil assessments were undertaken at each plot to determine the current health of soil. Method was adapted from Shepherd and Janssen (2000). A hole was dug at the approximate centre of each plot. The layers of the soil were laid out on a sack for a photo to be taken and for the soil parameters to be assessed. The texture was noted as sandy, loamy, or clayey. The moisture was categorized on a scale ranging from dry to wet. The seasonal weather conditions were noted on a scale ranging from dry to wet. The seasonal temperature was noted on a scale ranging from cold to warm. The degree of soil erosion was noted on a scale ranging from <1 % to >5 %. The surface relief was categorized on a scale ranging from surface smooth and unbroken (score = 2) to surface very broken (score = 0). The topsoil depth was noted on a scale from >20 cm to <12 cm. Humus type was noted as either mull, moder, or mor. The soil structure consistency was recorded on a scale ranging from a dominance of friable finer aggregates (score = 2) to a dominance of extremely coarse and firm clods (score = 0). Soil porosity was recorded on a scale ranging from many macropores (score = 2) to no macropores (score = 0). Soil colour was noted on a scale ranging from dark to pale. The number and colour of soil mottles was categorized on a scale ranging from generally absent (score = 2) to abundant (score = 0). The number of earthworms was noted on a scale ranging from >15 to <5.

A ranking score was calculated from the above parameters. Each parameter was given a weighting and added together to give the final score. A ranking score of <10 translates to a poor soil quality. A ranking score of 10 to 25 translates to a moderate soil quality. A ranking score of greater than 25 translates to a good soil quality.

2.5 Bird counts

A 5-minute bird count was undertaken at each plot using a method adapted from Dawson and Bull (1975) to determine the importance of each site for wildlife. Prior to each count, the observers, date and start time were noted. During each count, all birds seen or heard were identified and recorded. Individual birds were recorded only once, even if they were both seen and heard. Birds or calls that could not be identified were recorded as “UNID”. After each count, the temperature, wind, other noise, sun in minutes, precipitation type and the precipitation value were recorded. Each variable was categorized. Temperature ranged from <0° C (score = 1) to >22° C (score = 6). Wind level ranged from leaves still (score = 0), to branches and trees sway (score = 3). Other noise ranged from not important (score = 0) to loud (score = 2). The amount of time the sun was present during the count was noted in minutes. Precipitation type was recorded as either none, mist, rain, hail, or snow. The precipitation value ranged from none (score = 0) to heavy (score = 5). As many birds seen and heard remained unidentified, the bird count data was not included in the analysis.

2.6 Canopy and ground cover assessment

Canopy and ground cover assessments were undertaken at each plot to determine the current health of the canopy and ground cover. The method was adapted from the cylinder intercept assessment and the point intercept assessment outlined by Handford (2000). The assessment was repeated five times per plot, in each of the four corners and in the approximate centre. At each point, the canopy cover and height were assessed in a 2 m diameter circle directly above the point. The percentage of canopy cover, the percentage of indigenous species in the canopy, and the average canopy height in metres were recorded. Within a 20 cm diameter circle around each point, the ground cover was assessed. The percentage of indigenous woody plants, other indigenous plants, exotic woody plants, exotic grass, other exotic plants, roots, moss, leaf litter, wood, soil, and rock surrounding each point were recorded to the nearest five percent. The NG-5 canopy and ground cover assessment was undertaken in the summer of 2018-2019 with a slightly differing methodology. Four transects were run perpendicular to the fence line. Each transect started at the fence line and was run into the remnant towards the water's edge for 25-35 metres. The transect length was variable due to inaccessible steep sections. The start of each transect was located at a random fence baton. Each point was spaced five metres apart and the slope, aspect, and landform were recorded at each. Canopy and ground cover categories were also recorded at each point in the same fashion as the remaining sites. Due to the methodology between NG-5 and the remaining sites being different, the data from the canopy and ground cover assessment was not included in the analysis. This was to avoid any issues associated with incomparable data.

2.7 Ecological references

Ecological references in the form of predicted pre-human forest types were assessed for suitability at each site. The predicted pre-human vegetation types for each of the remnants was taken from the Hawke's Bay potential ecosystem map created by Singers (2018). The predicted vegetation type was then compared to the species present at the site. Diagnostic species were used to determine if the site fitted the predicted vegetation type or would be better classed as another vegetation type. The characteristics and preferences of the species present at each site was also taken into consideration during this process. Where no diagnostic species were present, the site characteristics were assessed against the preferences of the diagnostic species from the predicted vegetation type to determine if the predicted vegetation type could be used as a model for restoration.

2.8 Vegetation classification

A vegetation classification was generated for each plot based on the classification guide created by Atkinson (1962). Each plot was given a floristic and structural name. The floristic name was based on the canopy species that were present in 20 % or more of the plot. No more than five species were included in the floristic name. Scientific names were used in place of common names. The structural name was based on the composition of growth forms. Four key structural classes were used: forest, treeland, shrubland, and grassland. Where woody vegetation covered more than 80 % of the plot, the plot was called a forest; where woody vegetation covered 20 – 80 % of the plot, the pot was called a treeland; where shrubs occupied 20 – 80 % of the canopy, the plot was called a shrubland; and where grass occupied 20 – 100 % of the canopy, the plot was called a grassland.

2.9 Statistical analysis

One-way ANOVA analyses were conducted in RStudio (version 3.6.3) for the soil ranking scores and forest health scores to test the differences in the mean scores between the sites and rivers, respectively (Quinn & Keough, 2002). Levene's tests were conducted to test the homogeneity of variance, and Shapiro-Wilk tests were conducted to test the normality of that data (Quinn & Keough, 2002). As the soil ranking score data and forest health score data was normally distributed no data transformations were performed. Where the one-way ANOVAs showed statistically significant differences, a Tukey-HSD post hoc test was used to determine where the differences were (Quinn & Keough, 2002). Adjusted p values of less than one were recorded as <0.01.

The ggplot2 (version 3.3.2; Wickham et al., 2020) package in RStudio (version 3.6.3) was used to create violin plots for the forest health scores. These plots were used to display the median, interquartile range, upper and lower limits, and the distribution of the data.

2.9.1 Data transformations

Some of the data obtained from the fieldwork required transformations before being included in the analysis. Species richness was calculated as the number of species within a given plot. Species richness was calculated by summing the number of species in a given plot. This was repeated for total species richness, native species richness, and exotic species richness. Importance values were calculated using the RECCE composition data. For each species in a given plot, the cover classes from each tier that the species was present in were summed, to give that species importance value for that specific plot. For saplings the stem density, or stems per hectare, was calculated by summing the number of stems of each individual species in all of the four sectors. The total number of stems was then multiplied by 100 to give the stem density per hectare. Stem density for seedlings was calculated in a similar fashion; for each species, the total number of seedlings present in the plot were added together and then multiplied by 100 to give the stems per hectare. For each tree within a plot, the basal area per hectare was calculated. This was achieved by first squaring the tree's diameter at breast height (DBH), then by multiplying by 0.0000785. The tree's basal area was then multiplied by 100 to give that tree's basal area per hectare. The true aspect was calculated by adjusting the magnetic aspect in accordance with the magnetic declination of the region. This was achieved by adding 21 to the magnetic bearing. For the regression tree models outline in section 2.8.3 below, the true aspect was assigned to a cardinal direction; flat = <5˚, N = 337.5 - 22.5˚, NE = 22.5 - 67.5˚, E = 67.5 - 112.5˚, SE = 112.5 - 157.5˚, S = 157.5 - 202.5˚, SW = 202.5 - 247.5˚, W = 247.5 - 292.5˚, and NW = 292.5 - 337.5˚. The cardinal directions were then allocated a number; N = 1, NE = 2, E = 3, SE = 4, S = 5, SW = 6, W = 7, NW = 8 and flat = 9. Distance from the river was measured using QGIS (version 3.4.14), from the approximate centre of each plot to the nearest wetted edge.

2.9.2 Exploratory analysis

To test the strength of relationships between variables measured and to determine which variables would be included in the bagged regression tree models, a scatterplot matrix was created using RStudio (version 3.6.3). Site, plot, forest health, and soil data were included in the matrix, as outlined below.

A total of 20 numeric variables were included in the scatterplot matrix (Table 2.4). Total species richness, native species richness, and exotic species richness were adapted from the RECCE data, as outlined in section 2.8.1 above. The sum of importance values per plot for native and exotic species were included, as were the average importance value per plot for native and exotic species. The average sapling density per plot and average seedling density per plot were used in the analysis. The average basal area per hectare of all the trees within a plot was also included. Canopy height, canopy cover, slope, aspect, elevation, and mesotopographic index were taken directly from the RECCE data, as were the percentage of foliage, nonvascular plants, leaf litter, bare ground, and rock within each plot. The overall soil score was taken directly from the visual soil assessments. Road density (MfE, 2017), annual rainfall depth (LINZ, 2019), true aspect, and distance from the river were also included.

A total of four categorical variables were included in the scatterplot matrix (Table 2.4). Physiography was assigned to a number: 1 = terrace, 2 = gully, 3 = face, 4 = ridge. Land use was adapted from the original forest health categories to better suit the study: 0 = dairy farming, 1 = non-dairy farming, 2 = plantation forestry, 3 = recreation. Included in the non-dairy farming category was all farming types other than dairy, such as deer, beef, and sheep farming. No sites included in the study were surrounded by horticulture or viticulture. From the visual soil assessments, the A horizon or topsoil depth was taken. Fencing condition was also taken from the forest health assessments where the score ranged from 1 to 4, or poor fencing to solid secure fencing around the whole of the site.

Table 2.4: All of the variables included in the exploratory scatterplot matrix. Including the code and variable type.

Variable	Description	Variable type
STotal	Total species richness	Numeric
Snative	Native species richness	Numeric
SExo	Exotic species richness	Numeric
IVNativeSum	The sum of native species importance	Numeric
IVNativeavg	The average of native species importance	Numeric
IVExoSum	The sum of exotic species importance	Numeric
IVExoavg	The average of exotic species importance	Numeric
Sapling	Sapling stem density per hectare	Numeric
Seedling	Seedling stem density per hectare	Numeric
BA	Basal area per hectare	Numeric
CanHT	Canopy height (m)	Numeric
CanCv	Canopy cover (%)	Numeric
VSA	Soil score	Numeric
Rainfall	Annual rainfall (mm)	Numeric
Roadden	Road density (km^2)	Numeric
Slope	Slope (°)	Numeric
Aspect_mag	Magnetic aspect (°)	Numeric
Aspect_Tru	Adjusted aspect (°)	Numeric
Elevation	Elevation (m a.s.l)	Numeric
Dist_river	Distance from the river (m)	Numeric
Meso	Mesotopographic index	Numeric
Foliage	Percentage of vascular plant material (%)	Numeric
Nonvas	Percentage of nonvascular plants (%)	Numeric
Litter	Percentage of leaf litter (%)	Numeric
Bareground	Percentage of bare ground (%)	Numeric
Rock	Percentage of rock (%)	Numeric
Physiography	Physiography of plot	Categorical
LU	Land use	Categorical
Ahor	A horizon depth	Categorical
Fencing	Fencing score	Categorical

Results from the scatterplot matrix were used to determine which variables would be used in the tree models explained in section 3.8.3 below.

2.9.3 Bagged regression tree models

Regression tree models were used to determine which of the explanatory variables were the most important in explaining values of the response variables and current community structure and species composition of the sites surveyed (Breiman et al., 1984; De'ath & Fabricius, 2000). Bootstrap aggregation (bagging) was used to reduce the variance and create more robust models (Breiman, 1996). The models were created in RStudio (version 3.6.3) using the caret (version 6.0-86; Kuhn et al., 2020), rpart (version 4.1-15; Therneau, Atkinson & Ripley, 2019), and ggplot2 (version 3.3.2; Wickham et al., 2020) packages.

As mentioned in section 2.8.2 above, the scatterplot matrix was used to determine which variables would be used in the tree models. Several variables not included in the scatterplot matrix, but were of interest to the study, were included for use in the models.

A total of four response variables, outlined in Table 2.5, were selected for use in the models. Response variables included native and exotic species richness, the sum of importance values for native and exotic species, understory density, and canopy cover. Species richness and importance were used to demonstrate species diversity, with species importance acting as a surrogate for species abundance. The sum of importance values for native and exotic species are henceforth referred to as native species importance and exotic species importance, respectively. Understory density was the sum of the average seedling and sapling stem densities in each plot. These variables were selected to represent the structure and composition of the sites surveyed.

Table 2.5: Response variables used for the bagged regression trees.

Response Variable	Description
SNative	Native species richness
SExo	Exotic species richness
IVNativeSum	Sum of the importance values for native species
IVExoSum	Sum of the importance values for exotic species
UnderDen	Understory density (stems ha^{-1})
CanCv	Canopy cover (%)

A total of 18 explanatory variables, outlined in Table 2.6, were selected for use in the tree models. All 18 were used in the understory density and canopy cover models, while only 17 and 16 were used in the native and exotic species importance models, respectively.

Of the 18 variables, 12 were categorical. Site history, size of site, overall shape of site, distance to nearby native forest, presence of vegetation corridors, fencing, land use, stock disturbance, the presence of vine weeds, and the presence of ground weeds were taken from the forest health assessments. All, except for land use, followed the original categories that ranged from 1 - 4 or least healthy to healthiest, as outlined in section 2.2 above. Land use followed the categories outlined in section 2.9.2 above: (0 = dairy farming, 1 = non-dairy farming, 2 = plantation forestry, and 3 = recreation). Vine weeds were only included in the understory density and canopy cover models as many of the vine species were native and exotic and were therefore not independent of the species importance variables. Ground weeds were not included in the exotic species importance model, as the ground weed species were all exotic meaning that the variable was not independent of exotic species importance. Site physiography followed the categories outline in section 2.9.2 above (1 = terrace, 2 = gully, 3 = face, 4 = ridge). The true aspect categories ranged from 1 - 9, where 1 was north-facing, and 9 was flat, as outlined in section 2.9.1. above.

The remaining six variables were numeric and included slope, elevation, and mesotopographic index, which were taken from the RECCE plot data, as well as road density (MfE, 2017), annual rainfall depth (LINZ, 2019), and distance from the river.

Table 2.6: Explanatory variables included in the bagged regression tree models.

Variable	Description	Type
History	1-4: Primary, modified-primary, secondary, or revegetated	Categorical
Size	1-4: 0-5 ha, 5-25 ha, 25-100 ha or >100 ha	Categorical
Shape	1-4: narrow strip to round/square	Categorical
NearbyNat	Nearby native forest. 1-4: from none to extensive areas within 50 m	Categorical
Corridors	1-4: from none to extensive vegetation corridors	Categorical
Fencing	1-4: poor to good	Categorical
LU	Land use. 0-3: dairy farming, non-dairy farming, plantation forestry, recreation	Categorical
Stock	1-4: low to high disturbance	Categorical
Vine_weeds	1-4: from > 50 % dominance to < 1 %	Categorical
Ground_weeds	1-4: from > 50 % dominance to < 1 %	Categorical
Physiography	1-4: terrace, gully, face, ridge	Categorical
Rainfall	Annual rainfall (mm)	Numeric
Roadden	Road density (km²)	Numeric
Slope	Slope (°)	Numeric
Aspect_tru	Adjusted aspect (°)	Numeric
Elevation	Elevation (m a.s.l)	Numeric
Dist_River	Distance from the river (m)	Numeric
Meso	Mesotopographic index	Numeric

Before the bagged tree models were created, the response variable data was tested for normality and transformed as a requirement of regression tree models (Breiman *et al.*, 1984; De’ath & Fabricius, 2000). The response variables were tested for normality using histograms in RStudio (version 3.6.3). As the response variables were not normally distributed, and there were zeros in the data, an arcsinh transformation (Fowler, Cohen & Jarvis, 2013) was performed using the ASINH(x) function in Microsoft Excel.

After being imported into RStudio (version 3.6.3), the data was split into training (75 %) and testing (25 %) data sets. The training data was used to fit the models and the testing data was used to test the strength of the models. Two hundred trees were created using the ‘train’ function from the caret package. The trees were 10-fold cross validated. The models were then trained in parallel and the results aggregated for the final model by creating eight clusters, fitting 160 trees in parallel and computing predictions on the test dataset. An error curve was created by calculating the root mean square error of each individual tree and plotting it against the number of trees. The error curve was produced to assess the benefit of bagging for reducing the error. As the bagging process leaves trees uninterpretable, variable importance and partial dependence plots were produced. The ‘VIP’ function from the caret package was used to create the variable importance plot which ranked the explanatory variables from the most to least important in regard to the response variable. The ‘partial’ function was used to generate a partial dependence plot (PDP) for each of the explanatory variables. Each PDP demonstrated the relationship between the response and the explanatory variable. The process was repeated for each response variable.

Chapter Three

Results

Chapter Three covers the results obtained during the fieldwork and statistical analysis components of this research. Below are descriptions of the site characteristics for the 11 sites surveyed, including forest health, soils, presence of birds and plant species. Results from the exploratory scatterplot matrix and bagged regression trees are also presented below.

3.1 Site characteristics

Abiotic site characteristics such as elevation, slope, and physiography, as well as native forest composition and structure, soils, the presence and number of birds, and forest health were measured in the REECE plots, while the forest health assessments were assessed at the site scale. Supplementary information, including GPS locations and forest survey dates can be found in Appendix Two. The site characteristics mentioned in the section below are broken down in Tables 3.1 and 3.2.

3.1.1 Ngaruroro river

The Ngaruroro River had the lowest mean elevation of all the rivers at 89.33±40 m above sea level (M±SD; a.s.l). In general, the sites were comprised of face and terrace physiography, except for NG-6 which was entirely flat (<5° slope). The faces were either south or south-west facing, with a mean slope of 32.50±20.77°. Shape was variable across all of the sites and plots. Linear, concave, and convex shapes were seen at most of the Ngaruroro River sites. Good drainage was observed at all of the sites. The mesotopographic index was variable between plots, indicating differences in topographic exposure.

The mean mesotopographic index was 42.48±19.35. Like the mesotopographic index, canopy cover was also variable between plots. The mean canopy cover for the Ngaruroro River plots was 65.00±32.61 %. All of the sites, except for NG-3, had at least one plot that was partially or wholly made up of exotic grass with no canopy above. The canopy height also varied according to the canopy cover, giving a mean canopy height of 7.99±7.82 m. All of the sites followed the same general trend in regard to the cover composition. Vegetation, including live vascular foliage, trunks, and exposed roots, made up the majority of all plots, with a mean of 76.25±26.21 m. Vegetation was followed by leaf litter with a mean of 40.0±34.28 %, then bare ground with a mean of 5±6.03 %, and the exposed rock with a mean of 2.50±3.37 %.

Nonvascular plants made up a relatively small proportion of each plot and were usually seen growing on tree trunks. The mean for nonvascular cover was 1.25±2.26 %.

Rainfall depth appeared to vary according to the distance from the river mouth. NG-3, which was the furthest inland, had the highest rainfall depth at 1039.17 mm, and NG-5, which was the closest to the river mouth had the lowest at 670.48 mm. The mean rainfall depth for the Ngaruroro River sites was 770.65±179.64 mm. Road density was generally low for all the Ngaruroro River sites; the mean was 0.58±0.20 km².

3.1.2 Tutaekuri river

The mean elevation for the Tutaekuri River sites was 112.08±35.70 m. In terms of physiography, at least a portion of each of the Tutaekuri River sites was comprised of a sloping face. Some of the sites also had terrace segments. The slope direction of the faces was variable between sites. All of the sites, except for TK-4, were either south, south-west or west-facing. Tk-4 was north or north-east-facing, depending on the exact location within the site. The mean slope was 30.00±19.07°. A slope of 60° was observed at TK-5, which was the steepest of all the slopes recorded at the Tutaekuri River sites. Much like the Ngaruroro River sites, shape was variable. Most of the sites had linear, convex, and concave segments. All sites had good drainage. Tutaekuri River sites were made up of segments dominated by either native trees, exotic trees and shrubs, or exotic grass. The differing species composition in each segment likely affected the mesotopographic index, canopy cover and canopy height.

The mean mesotopographic index was 58.07±14.93. The mean canopy cover was 70.42±20.39 %. The mean canopy height was 5.25±2.09 m. Plots with a higher proportion of exotic grass generally had a lower canopy cover, canopy height and mesotopographic index. Plot cover composition followed the same trend as that of the Ngaruroro River plots. Vegetation generally made up the highest proportion of each plot with a mean of 69.58±33.88 %, followed by leaf litter with a mean of 23.33±27.58 %. Leaf litter was significant at some of the sites. For example, TK-5 plot 3 was made up of 60 % leaf litter, likely due to the grazing history of the site and the species present. Following leaf litter was bare ground with a mean of 2.92±3.96 %, followed by exposed rock with a mean of 2.50±3.37 %, and then nonvascular plants with a mean of 1.25±2.26 %. All of the nonvascular plants were seen growing on tree trunks.

Like the Ngaruroro River, rainfall depth appeared to be affected by the distance from the river mouth. Site TK-7, furthest inland, had the highest rainfall depth of 1070.73 mm, and site TK-

5, closest to the river mouth, had the lowest rainfall depth of 878.76 mm. The mean rainfall depth for the Tutaekuri River sites was 987.98±82.17 mm. Road density was relatively low for all of the sites, with a mean of 0.45±0.08 km².

3.1.3 Tukituki river

During the study, the highest elevations were seen for the Tukituki River sites with a mean of 244.67±68.40 m. TT-4 and TT-5 had both terrace and face components, while MK-3 was completely flat. The faces were all north or north-east-facing and had a mean slope of 7.78±28.95°. One of the plots from TT-5 was the steepest of all plots sampled at 80°. All of the sites were concave in shape, except for one of the TT-4 plots which was convex. Drainage was only an issue at MK-3, where the soil was saturated, and pools of water were often seen on the surface. All of the other sites had good drainage.

The mean mesotopographic index for the Tukituki River was 57.65±12.00 and appeared to be affected by the variability in canopy cover. Canopy cover was generally high for the Tukituki River plots with a mean of 78.89±12.44 %. However, each of the sites did not have a continuous or closed canopy across the whole of the site. Each site was made up of areas dominated by differing plant types. For example, TT-4 comprised different areas dominated by native trees, exotic trees and shrubs, vine weeds, or exotic grass. The Tukituki River sites had the highest mean canopy height at 9.33±7.27 m. This is likely due to the significant age of some of the trees present at TT-4 and TT-5, where there are old native podocarps such as *P. totara* and *D. dacrydioides*. Cover composition followed the same trend as the Ngaruroro and Tutaekuri Rivers. The majority of each plot was made up of vegetation with a mean of 52.78±32.7 %, followed by leaf litter with a mean of 40.0±34.28 %, then bare ground, exposed rock and nonvascular plants with means of 2.78±3.63 %, 2.22±3.63 %, and 2.22±2.64 %, respectively.

Much like the other two rivers, the rainfall depth appeared to be affected by the distance from the river mouth for the Tukituki River sites. TT-5, the furthest inland site, had the highest rainfall depth of 1312.57 mm, while MK-3, the closest to the river mouth, had a rainfall depth of 683.40 mm. The mean rainfall depth was 997.62±314.59 mm, the highest of all three rivers. Roads were denser for the Tukituki River sites compared to the Ngaruroro and Tutaekuri Rivers with a mean of 0.85±0.19 km². Higher road density is likely due to the proximity of MK-3 to the town of Waipukurau.

Table 3.1: Plot attributes taken from the RECCE plot data.

Plot	Elevation (m)	Physiography	Aspect	Slope (°)	Shape	Drainage	Mesotopographic index
MK-3_1	155	Terrace	N	5	Concave	Poor	50
MK-3_2	152	Terrace	N	5	Concave	Poor	51
MK-3_5	157	Terrace	N	5	Concave	Poor	68
NG-3_2	156	Face	S	35	Concave	Good	56
NG-3_3	155	Terrace	N	5	Concave	Good	61
NG-3_7	151	Face-terrace	S	55	Concave	Good	54
NG-5_1	69	face	SE	25	Linear	Good	16
NG-5_2	51	face	SE	32	Concave	Good	39
NG-5_4	67	ridge	S	0	Convex	Good	11
NG-6_1	64	Terrace	S	5	Linear	Good	52
NG-6_2	61	Terrace	S	5	Linear	Good	11
NG-6_3	56	Terrace	S	10	Linear	Good	39
NG-7_1	86	Face	SW	60	Concave	Good	61
NG-7_2	74	Terrace	SW	10	Convex	Good	56
NG-7_3	82	Face	SW	40	Convex	Good	56
TK-4_1	123	Face	NE	50	Convex	Good	52
TK-4_2	128	Face	NE	35	Convex	Good	54
TK-4_3	119	Face	N	20	Convex	Good	51
TK-5_1	65	Terrace	N	5	Convex	Good	66
TK-5_2	76	Face	S	60	Linear	Good	37
TK-5_3	76	Face	S	45	Concave	Good	74
TK-6_2	79	Face	W	30	Convex	Good	68
TK-6_5	102	Face	S	40	Concave	Good	73
TK-6_6	94	Face	S	30	Concave	Good	73
TK-7_1	163	Terrace	S	5	Linear	Good	57
TK-7_2	166	Face	SW	40	Convex	Good	68
TK-7_3	154	Terrace	Flat	0	Linear	Good	27
TT-4_2	288	Terrace	Flat	0	Concave	Good	44
TT-4_4	278	Terrace	Flat	0	Convex	Good	51
TT-4_5	270	Face	NE	55	Concave	Good	50
TT-5_1	294	Terrace	N	5	Concave	Good	76
TT-5_2	302	Terrace	N	5	Concave	Good	74
TT-5_5	306	Face	NE	80	Concave	Good	54

Table 3.2: Proportion of cover, canopy height and canopy cover, taken from the RECCE data.

Plot	Vegetation (%)	Non-Vascular (%)	Litter (%)	Bare ground (%)	Exposed Rock (%)	Canopy height (m)	Canopy cover (%)
MK-3_1	90	0	5	5	0	8	70
MK-3_2	90	0	5	5	0	7	65
MK-3_5	45	5	45	5	0	8	65
NG-3_2	55	0	35	5	5	6	80
NG-3_3	85	0	5	10	0	13	85
NG-3_7	70	0	10	10	10	5	85
NG-5_1	100	0	35	0	0	4	85
NG-5_2	20	0	95	5	10	30	100
NG-5_4	100	0	0	0	0	0	0
NG-6_1	100	0	0	0	0	10	70
NG-6_2	95	0	0	5	0	0	0
NG-6_3	100	0	0	0	0	4	60
NG-7_1	50	5	20	20	5	7	80
NG-7_2	85	5	10	0	0	8	80
NG-7_3	55	5	25	5	10	8	55
TK-4_1	95	0	0	0	5	4	70
TK-4_2	100	0	0	0	0	5	75
TK-4_3	100	0	0	0	0	5	70
TK-5_1	95	0	5	0	0	7	65
TK-5_2	95	0	0	0	5	5	65
TK-5_3	30	0	60	0	5	4	95
TK-6_2	90	0	5	5	0	5	60
TK-6_5	25	5	50	10	10	3	75
TK-6_6	20	0	65	10	5	6	90
TK-7_1	40	5	50	5	0	7	85
TK-7_2	45	5	45	5	0	10	80
TK-7_3	100	0	0	0	0	2	15
TT-4_2	80	5	5	10	0	3	85
TT-4_4	75	5	20	0	0	5	85
TT-4_5	35	5	55	0	5	15	90
TT-5_1	5	0	95	0	0	13	95
TT-5_2	10	0	85	0	5	10	90
TT-5_5	45	0	45	0	10	15	65

3.1.4 Forest health

The health of the sites was determined through the forest health assessments and differed between sites and rivers, as outlined below.

3.1.4.1 Ngaruroro river

All of the Ngaruroro sites were made up of secondary forest except for NG-7 which was primary forest. Within NG-7 is a stand of old native trees including *Corynocarpus laevigatus*, *Alectryon excelsus subsp. excelsus*, *Myoporum laetum*, and *Myrsine australis*. NG-6 comprised a stand of mature *Kunzea robusta*, as well as significant areas of exotic grass, and *S. fragilis* along the river's edge. NG-5 consisted of exotic grass on the ridge then a band of *Ulex europaeus* before a stand of native forest. The canopy was dominated by *A. excelsus subsp. excelsus* and *M. laetum*. Between the native forest and the water's edge was a band of *S. fragilis*. NG-3 also contained significant areas dominated by exotic tree species and exotic grass. One area of NG-3 was dominated by native forest species including species such as *Melicytus ramiflorus*, *Veronica stricta var. stricta*, and *Sophora tetraptera*. No evidence of current or past weed control was seen at any of the sites. Evidence of animal pest control was present at NG-5 and NG-7 in the form of traps and bait stations.

Size was variable among the Ngaruroro River sites. The largest was NG-3 at 71.53 ha, followed by NG-5 at 0.89 ha, then NG-6 at 0.42 ha, and finally the smallest at 0.26 ha was NG-7. Size appeared to have an effect on the general shape of the overall site. NG-3, the largest site, was mostly compact in shape. NG-5, the next largest, was long and narrow with some wider areas. The two smaller sites, NG-6 and NG-7 were also long and narrow with many areas where the observer could look through to the other side of the site. NG-5 and NG-6 were relatively isolated, as there was no forest over 10 ha in size within 5 km of the sites. NG-3 and NG-7 were slightly less isolated, as there was forest over 10 ha in size within 1 - 5 km of the sites. Vegetation corridors were extensive surrounding all but NG-5, where the corridors were less extensive and made up of mostly planted *S. fragilis*.

On the forest edge, the canopy was generally healthy at all of the sites. At NG-6 and NG-7 there were small areas of localised dieback in the canopy. The understory on the edge of the sites was variable. NG-3 had a dense and abundant understory, NG-5 and NG-6 had some understory, and NG-6 had no understory at all. Weeds were a significant issue on the edge of NG-5, NG-6, and NG-7, where they dominated. Weeds on the edge of NG-3 were much less significant and with only a few being present. Fencing was also variable between the Ngaruroro

River sites. NG-5 has secure fencing around the site, NG-3 had some fencing on one side, and NG-6 and NG-7 had no fencing. Despite a fence running through the middle of NG-7, stock had access to both portions of the site. Stock also had access to NG-6.

Within the sites, the canopy was generally healthy with no dieback, except for NG-6 where canopy holes and occasional dieback were present. No canopy browse was observed at any of the sites. Abundant plants preferred by deer species were observed at NG-3, while a moderate number was observed at NG-5, with very few observed at NG-7 and no preferred plants were observed at NG-6. The lack of preferred species at NG-6 was unlikely to be due to browse and instead due to the limited number of species present at the site. No signs of understory browse were observed at NG-3 or NG-5. Severe understory browse was observed at NG-7 where stock had access and were likely limiting the regeneration of native species. Ongoing bird song with only occasional breaks was heard at all of the Ngaruroro River sites except for NG-7, where bird song was only heard some of the time.

Within canopy gaps, seedlings were common at NG-3 and NG-5 but were not present at NG-6 or NG-7. This is likely reflective of the differences in stock access between the sites. Plants preferred by deer were common in the canopy gaps at NG-3 and NG-5, were occasionally present at NG-7 and none were present in the canopy gaps at NG-6.

Weeds were an issue at all of the sites to varying extents. Vine, shrub, and ground cover weeds were occasionally present at NG-3. Vine weeds, *Clematis vitalba* in particular, were occasionally present at NG-5 where shrub weeds, particularly *U. europaeus*, were common. At NG-6 and NG-7, vine and ground cover weeds were very common and shrub weeds were occasional. *C. vitalba* was an issue at NG-6 and *Vinca major* was an issue at NG-7. No sign of recent *Trichosurus vulpecula*, deer, stock or human damage was observed at any of the sites. However, a *Mustela erminea* was seen on the river by NG-3, a *Cervus elaphus* and small group of *Ovis aries* were seen near NG-6, and a small group of *Ovis aries* were seen near NG-7.

3.1.4.2 Tutaekuri river

All of the Tutaekuri River sites were comprised of *K. robusta* stands, where many of the trees, particularly at TK-6, were of a significant age and size. TK-4 predominately comprised a *K. robusta* stand, with areas of exotic species including *S. fragilis* and exotic grass on and close to the water’s edge. TK-5 contained one *K. robusta* stand, one area of native forest, and a large area dominated by exotic species. Within TK-6 was a significant area dominated by *Cortaderia selloana*, with the majority of the site dominated by *K. robusta*. TK-7 contained two distinct parts; one was a *K. robusta* dominated stand, and the other was dominated by exotic species such as *Salix eleagnos*. There was no evidence of animal pest or weed control at TK-4, TK-6, or TK-7. Evidence of animal pest control was observed at TK-5 in the form of bait stations. No evidence of weed control was seen at TK-5.

Site size was variable across the Tutaekuri River sites. The largest was TK-6 at 14.42 ha, followed by TK-5 at 8.84 ha, then TK-4 at 0.86 ha, and finally the smallest was TK-7 at 0.78 ha. All of the sites were long and narrow with some wider areas where the observer could not see through to the other side. Isolation was variable between sites. TK-4, TK-5, and TK-6 were relatively isolated, with the nearest forest over 10 ha being 1 - 5 km away. TK-7 was less isolated, with an area of native forest over 10 ha in size being present across the river from the site. The presence of vegetation corridors was also variable. Extensive corridors were present for TK-5 and TK-6, while corridors were only present within 500 m for TK-7 and within 500 m – 1 km for TK-4.

On the forest edge, small areas of localized dieback were present the edge of the Tutaekuri River sites, except for TK-6 where no dieback was present on the edge. Some understory was present on the edge of TK-4, TK-6, and TK-7. The edge understory at TK-5 contained more seedlings and sapling compared to the other Tutaekuri River sites. The edge understory of all sites was dominated by weeds, most noticeably, the *C. selloana* at TK-6 and *Rubus fruticosus* at TK-4. Non-dairy farming was the adjacent land use for all of the Tutaekuri River sites.

Within the sites, the occasional canopy holes and dieback were seen at TK-4, TK-5, and TK-7. No canopy holes or dieback was seen at TK-6. No canopy or understory browse was observed at any of the sites. In general, the Tutaekuri River sites contained moderate numbers of plant species known to be preferred by deer. Bird song was heard continuously at TK-6 and TK-7 and was heard almost continuously with only occasional breaks at TK-4 and TK-5. Notably, a *Ninox novaeseelandiae* was seen resting in a tree within one of the plots at TK-6.

Within canopy gaps, occasional, scattered seedlings were present across all sites. Commonly seen among these seedlings were species known to be preferred by deer such as *M. ramiflorus* at all of the sites and *Geniostoma ligustrifolium var. ligustrifolium* at TK-7.

Vine weeds such as *Calystegia silvatica subsp. disjuncta* were occasionally seen at TK-5. Shrub and ground cover weeds were commonly seen. Examples of shrub and ground cover weeds include *Phytolacca octandra* seen at TK-6, *Ranunculus repens* was present at TK-5 and TK-6, and *R. fruticosus* was observed at all of the sites. No recent signs of *T. vulpecula*, deer, stock or human damage was observed at any of the sites. However, old *Bos taurus* dung and animal tracks were seen at TK-6. Signs of *Capra hircus* and *B. taurus* movement in the form of recent dung and hoof prints, was seen along the Tutaekuri riverbed, as seen in Figure 3.1 below.

Figure 3.1: Hoof prints and recent dung seen on the Tutaekuri riverbed at the beginning of February 2020.

3.1.4.3 Tukituki river

TT-4 and TT-5 were part of the original Ashcott Station and have a clear history of grazing. Despite the grazing history, a relatively small number of large, old, native podocarps including *D. dacrydioides* and *P. totara* still remain at the sites. *S. fragilis* and *S. elaeagnos* dominate the water's edge at TT-4 and TT-5. After the band of *Salix* species, was a band dominated by exotic grass, then a band of native forest. MK-3 was different from the other sites in that no native podocarps were present. The site formed a distinctive boomerang shape and comprised a mixture of exotic species such as *Prunus serrulata* and *S. cinerea* as well as native species such as *S. tetraptera* and *C. australis*. No evidence of pest animal or weed control was found at MK-3. Evidence of current animal pest control in the form of bait stations was found at TT-5, however, no evidence of weed control was seen. Evidence of animal pest and weed control was found at TT-4, including bait stations and the spraying of *R. fruticosus* by the landowner.

MK-3 was the smallest of the three Tukituki River sites at 1.09 ha, followed by TT-5 at 5.03 ha and TT-4 at 12.69 ha. In general, the Tukituki River sites formed long and narrow strips, with at least one segment where the observer could see through the forest to the other side of the site. MK-3 was the most isolated of the three sites as there were no forest areas over 10 ha within 5 km of the site. This could be due to the proximity of the site to an urban area. TT-4 and TT-5 were less isolated and had forested areas over 10 ha in size within 1 - 5 km from the sites. Just upstream of TT-4 is the Department of Conservation-managed Inglis Bush. Extensive vegetation corridors were present for TT-4 and TT-5. Within 500 m of MK-3 were vegetation corridors mostly made up of *S. fragilis* and other exotic species.

Small areas of dieback were seen within the canopy on the edge of sites TT-5 and MK-3. No canopy dieback was seen on the edge of TT-4. Occasional seedlings and saplings were present on the edge of TT-4 and TT-5. MK-3 had a higher number of seedlings and saplings present on the edge of the site compared to the other two. Weeds were an issue on the edge of all three sites and were either common or dominant. *R. fruticosus* was commonly seen on the edge of all three Tukituki River sites. Secure fencing was present at MK-3 and TT-4, while some fencing was present at TT-5. A single wire fence had been recently constructed to surround a stand of native podocarps including *Prumnopitys taxifolia* and *D. dacrydioides*. Non-dairy farming was the adjacent land use for TT-4 and TT-5 and the sites had a clear history of grazing but appeared to have been fenced off with little to no stock access within the past several years. MK-3 was located within the Waipukurau Golf Course and was actually classed as a water hazard for the course. Personal communication with the greenskeeper revealed that in the past, plans had been made to convert MK-3 into a wetland.

Within the sites, only occasional canopy holes and dieback were observed. At TT-4 no canopy holes or dieback were seen. No evidence of canopy or understory browse was observed at any of the Tukituki River sites. Few to moderate numbers of species preferred by deer were observed at all of the sites including *Coprosma grandifolia* at TT-4 and *M. australis* at TT-4 and TT-5. Bird song was heard for the majority of time spent at the sites; only occasional breaks occurred. Notably, a *Hemiphaga novaeseelandiae* was observed eating *M. ramiflorus* berries at one of the TT-4 plots.

Within canopy gaps, occasional scattered seedlings were present at TT-5 and MK-3, while abundant seedlings were present within canopy gaps at TT-4. Plants preferred by deer were common at TT-4 and TT-5 and seen occasionally at MK-3. The limited presence of species preferred by deer at MK-3 is more likely due to dispersal limitations rather than browsing by deer.

Vine weeds such as *C. vitalba* were common at TT-4 and TT-5 and occasionally seen at MK-3. Ground cover weeds were common at TT-4 and MK-3 and quite common at TT-5. For example, at TT-4, significant areas of the site were dominated by *Convulvulus arvensis*. Shrub weeds were also common at TT-5 and MK-3 and quite common at TT-4. In particular, *R. fruticosus* was an issue at all of the Tukituki River plots. No recent signs of *T. vulpecula*, deer, stock or human damage was observed at any of the sites. However, fresh, and old signs of *Oryctolagus cuniculus* and *Lepus europaeus* in the form of digging, holes, and pellets, were observed within TT-4.

3.1.4.4 Forest health scores

The median forest health score for all three rivers was between 15 and 17, indicating moderate health. The Ngaruroro River sites demonstrated a wider range of forest health scores, ranging from poor health to high health (Figure 3.2). Tukituki River sites demonstrated a smaller forest health score range and were more concentrated around the moderate health scores (Figure 3.2). Highly concentrated around the moderate health scores were the Tutaekuri River sites, demonstrating a smaller range and overall moderate forest health (Figure 3.2).

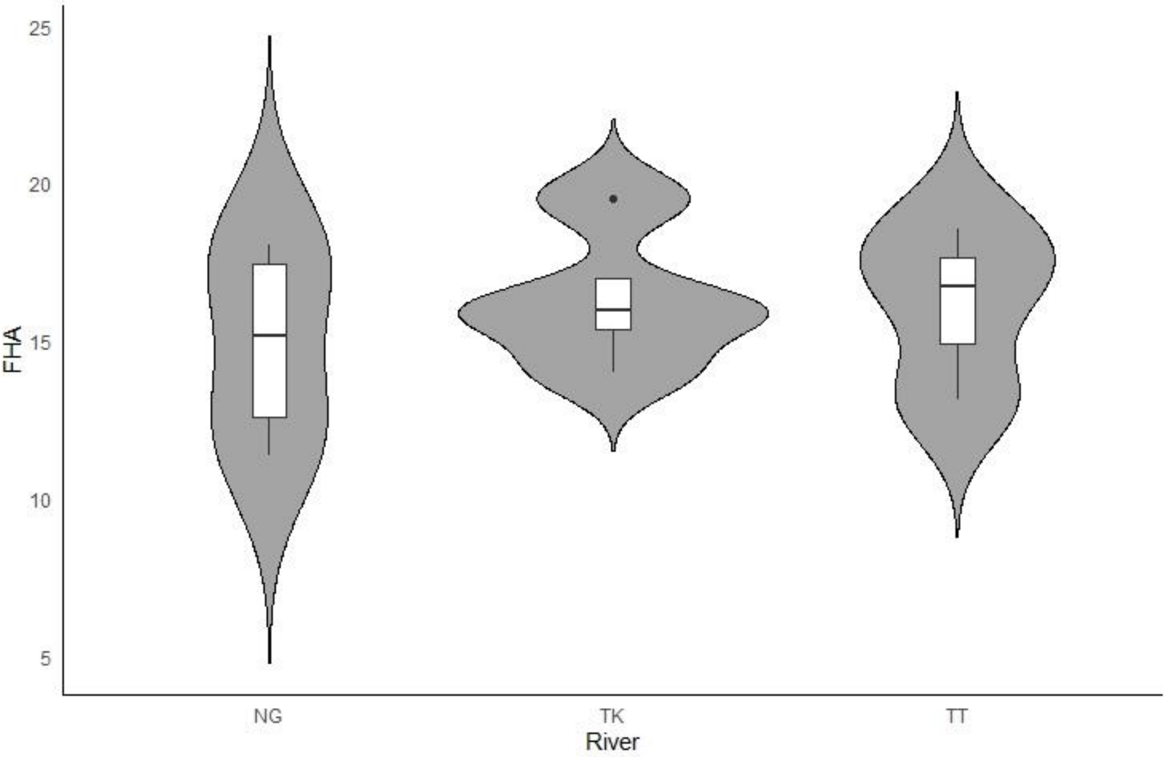


Figure 3.2: Violin plots for the forest health assessment scores for each river, showing the interquartile range (box), range (vertical line), median (centre line of boxes), outliers (dots), and data distribution (kernel density plot).

A Levene's test gave a *F* value of 0.84 and a *p* value of 0.47, indicating that the variance of the forest health score data was homogenous. A Shapiro-Wilk test gave a *W* value of 0.91 and a *p* value of 0.26, indicating that the data was normally distributed. A one-way ANOVA gave a *p* value of 0.75 (Table 3.3), indicating that the forest health scores were not statistically different between the rivers and that overall, the forests associated with the three rivers were all of similar health.

Table 3.3: One-way ANOVA table for the forest health scores of the Ngaruroro, Tutaekuri and Tukituki Rivers.

Variable	Sum of Squares	*df*	Mean Square	F	P
River	4.25	2	2.33	0.30	0.75
Residuals	62.18	8	7.77		

3.1.5 Soils

Visual soils assessments were used to assess the soils at each site. While the soils differed between sites, there were a few traits that were shared. No more than five earthworms were found during any of the soil assessments. Many of the holes dug contained no earthworms at all. No more than 1 % of each site was affected by soil erosion, potentially due to the relatively consistent vegetation cover. The top of the soil was relatively smooth and unbroken at all sites, potentially due to stock exclosure. All assessments were undertaken during the summer when the seasonal conditions were warm and dry.

3.1.5.1 Ngaruroro River

Loamy and sandy soils were present along the Ngaruroro River, as demonstrated by Figure 3.3 below. Images C and G from Figure 3.3 demonstrate the presence of rocks and shingle in some of the Ngaruroro River soils. Some of the soils, particularly NG-7 plot 1 were quite hard and difficult to dig up (Figure 3.3 J). Soils were generally dry except for plot 7 at NG-3 where the soil was moist and for the whole of NG-5 where the soil was slightly moist. Topsoil or A horizon depth was generally no deeper than 20 cm, except for NG-5 where all of the topsoil was deeper than 20 cm. Moder was the dominant humus type at NG-3 and NG-7, where a layer of leaf litter was consistent and between 2 and 5 cm deep. Moder humus was also present at one of the NG-5 plots. The remaining NG-5 plots contained mull humus type as there was not a continuous leaf litter layer and decomposition rates were fast. Mull humus was also the dominant humus type at NG-6. Soils at NG-3 were either dominated by friable aggregates or contained equal parts of friable aggregates and clods. Soils at NG-5 and NG-7 contained equal parts friable aggregates and clods while soils at NG-6 were dominated by finer friable aggregates with no significant clodding present. Many macropores were present within the soil at NG-3, NG-6, and NG-7. No or coarse macropores were present in the soil at NG-5. Topsoil colour was relatively pale at NG-3, NG-6, and NG-7. At plot 3 of NG-3 the soil was a very pale grey colour (Figure 3.3 B). Dark brown coloured topsoil was present at NG-5. For the most part, mottles were generally absent from the soils at the Ngaruroro River sites.

3.1.5.2 Tutaekuri river

All of the Tutaekuri River sites contained predominantly loamy soils that were dry to slightly moist (Figure 3.4). Plots 5 and 6 at TK-6 contained some rocks in the soil, as demonstrated in Figure 3.4 H and I. The soil at plot 2 of TK-6 was also quite hard and difficult to dig. A horizon depth was variable at each site and ranged from <12 cm to >20 cm. Mull humus was the dominant humus type at TK-4 and was present at TK-7. Moder humus was the dominant humus type at TK-6 and was present at TK-5 and TK-7. Mor humus was present at TK-5 where the leaf litter was >10 cm deep underneath the *K. robusta* stand that had a clear grazing history and limited regeneration. The soil at TK-6 contained equal parts finer friable aggregates and coarse firm clods. One plot, each at TK-4 and TK-7, also contained equal parts friable aggregates and clods. The remaining plots at TK-4 and TK-7 and all of the plots at TK-5 were dominated by soils that contained no significant clodding and significant proportions of friable aggregates. Many macropores were present within the soils at all of the Tutaekuri River sites. The topsoil of the Tutaekuri River sites was darker than the Ngaruroro River sites (Figures 3.3 and 3.4). At TK-4 the topsoil was dark except for one plot that was slightly paler. At TK-5 one plot had dark topsoil and the rest had slightly paler topsoil. At TK-6 all of the topsoil assessed was dark-coloured. At TK-7 the topsoil was darkly coloured except for one plot where the topsoil was significantly paler compared to the other plots. Mottles were generally absent from the soils at all of the Tutaekuri River sites.

3.1.5.3 Tukituki river

The soils at TT-4 and TT-5 were generally loamy and slightly moist (Figure 3.5). One plot at TT-4 contained sandy soil and one plot at TT-5 contained dry soil. The soil at MK-3 was different from the other Tukituki River plots and was clayey and wet. Topsoil depth was variable between plots and ranged from <12 cm to >20 cm at all of the sites. Moder and mull humus types were present at both TT-4 and MK-3. TT-5 was dominated by mor humus and decomposition rates were much slower at the site. Significantly more leaf litter was also present at TT-5 plots compared to the other two sites. This was especially present in the native podocarp stand within TT-5 that appeared to have only recently been fenced. Soils at TT-4 contained either no significant clodding or equal parts coarse clods and friable aggregates. The soils at both TT-5 and MK-3 were dominated by coarse and firm clods. Many macropores were present within the soils at TT-4 and TT-5 except for plot 2 at TT-4 where fewer macropores were present. No or coarse macropores were present at MK-3. The colour of the topsoil at TT-4 was dark except for plot 2 which contained slightly paler topsoil. The topsoil at TT-5 was slightly paler than the dark topsoil at TT-4. The topsoil at MK-3 was variable and ranged from dark to pale. Mottles were generally absent from the soils at TT-4, TT-5, and plot 5 at MK-3. The remaining plots at MK-3 contained up to 10% fine orange and grey mottles.

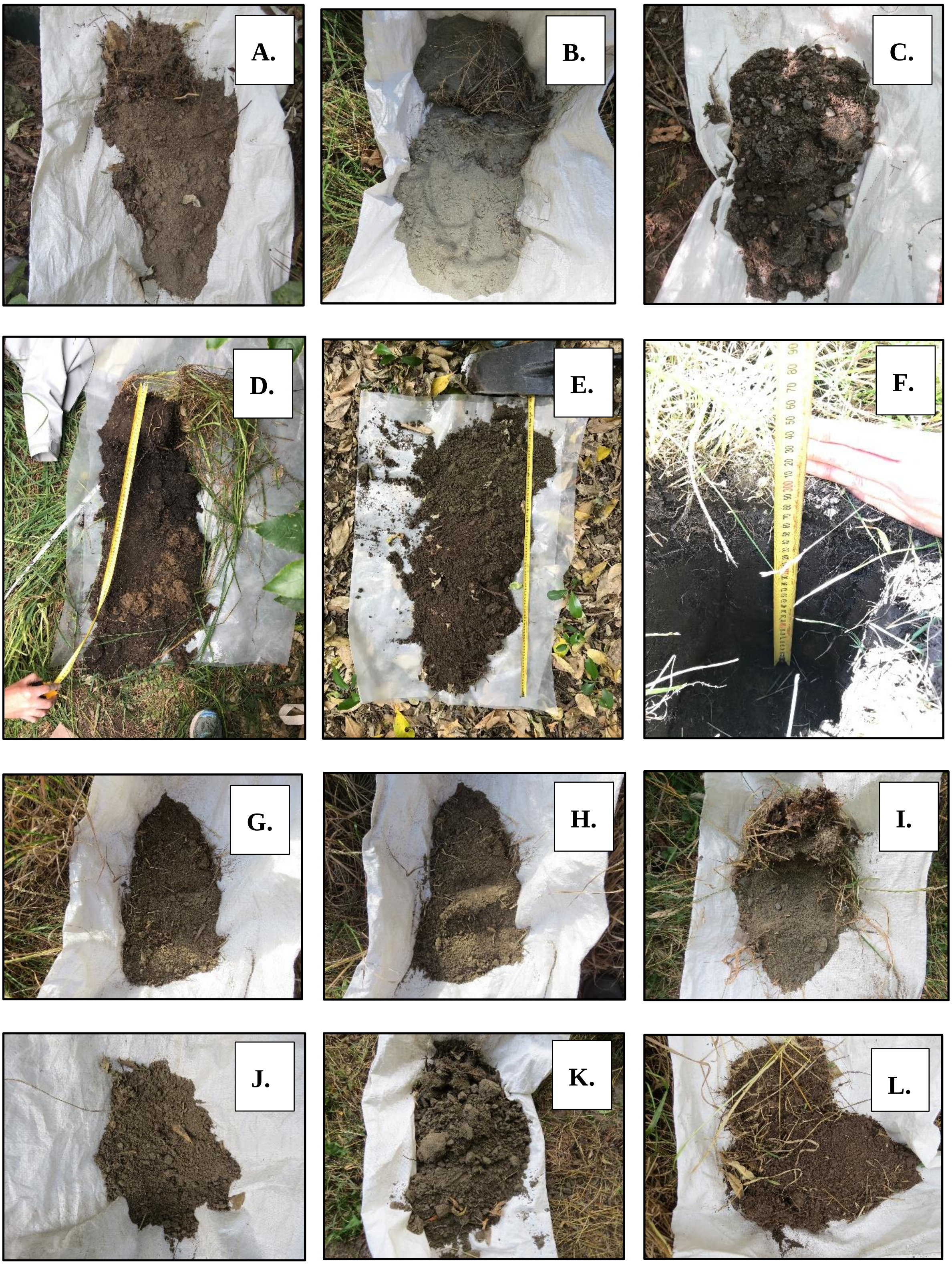


Figure 3.3: Soils from the Ngaruroro River. A to C are from NG-3 plots 1, 3 and 7. D to F are from NG-5 plots 1, 2, and 4. G to I are from NG-6 plots 3, 2 and 1. J to L are from NG-7 plots 1, 2 and 3.

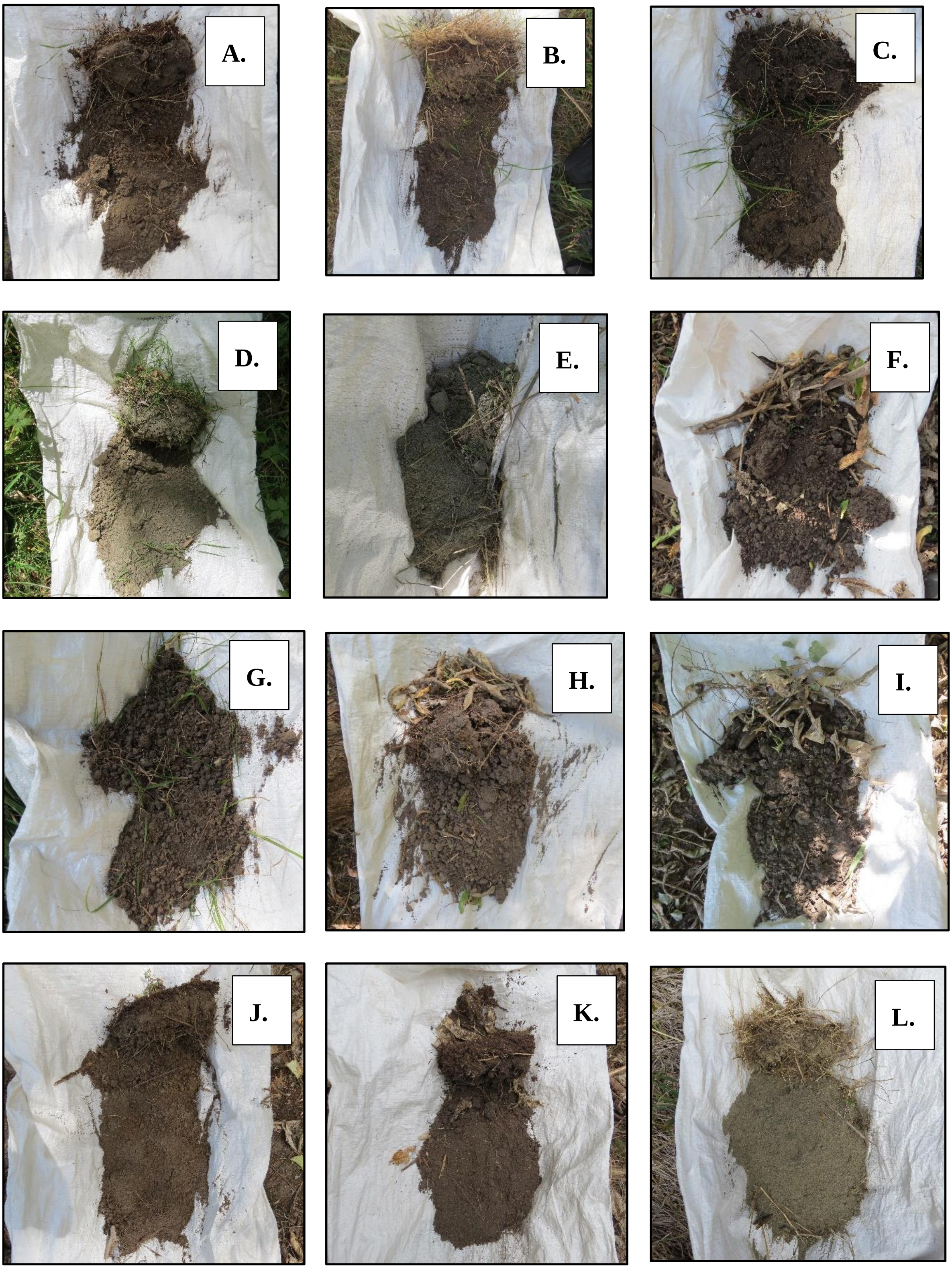


Figure 3.4: Soils from the Tutaekuri River. A to C are from TK-4 plots 1, 2 and 3. D to F are from TK-5 plots 1, 2 and 5. G to I are from TK-6 plots 2, 5 and 6. J to K are from TK-7 plots 1, 2 and 3.

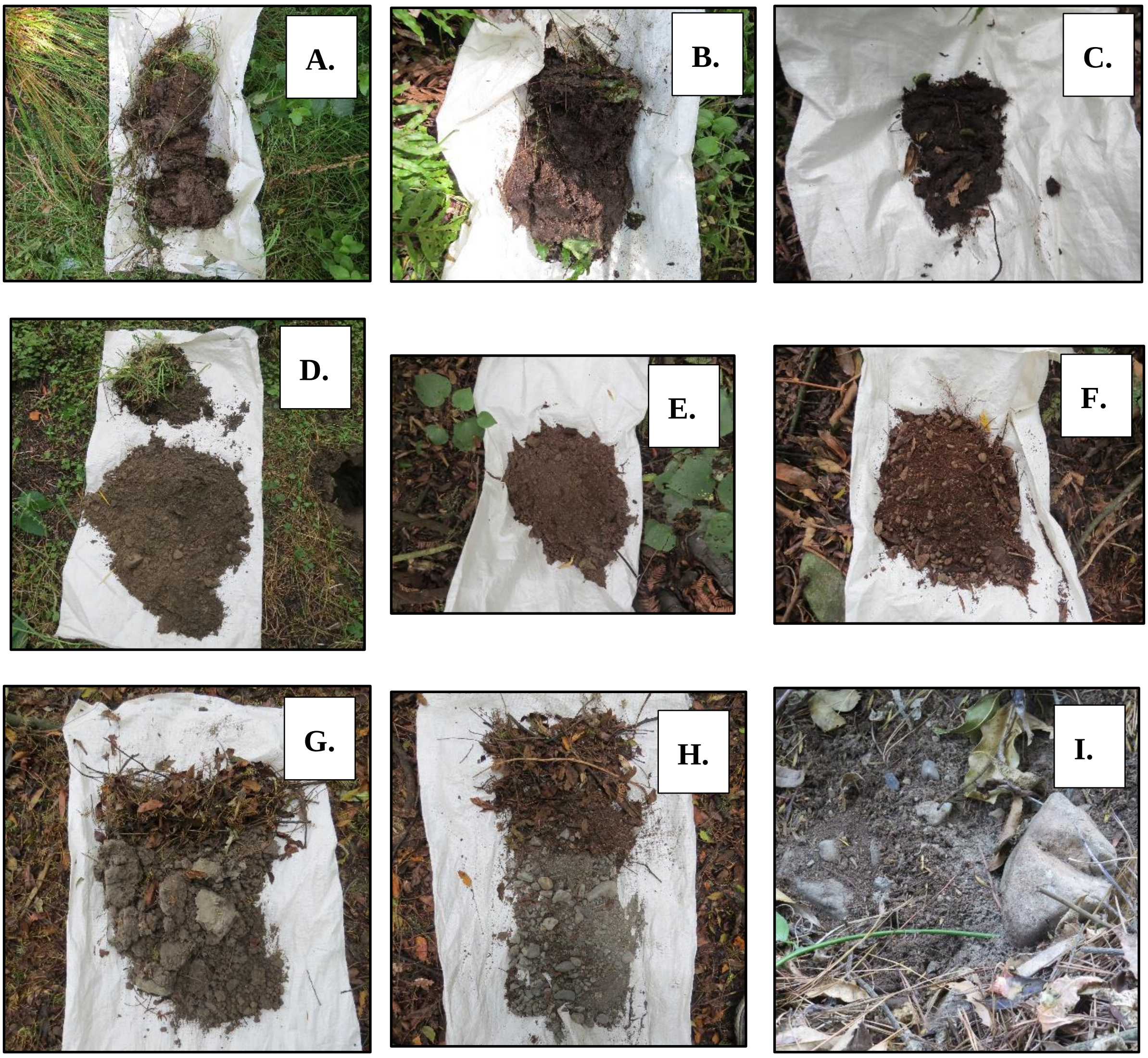


Figure 3.5: Soils from the Tukituki River. A to C are from MK-3 plots 5, 1 and 2. D to F are from TT-4 plots 5, 2 and 4. G to I are from TT-5 plots 1, 2 and 5.

3.1.5.4 Ranking scores

The mean ranking scores for the Ngaruroro River sites were 27.00±1.00 for NG-3, 28.30±1.53 for NG-5, 28.30±1.15 for NG-6, and 31.30±2.31 for NG-7. The mean ranking scores for the Tutaekuri River sites were 31.70±4.51 for TK-4, 27.00±2.00 for TK-5, 29.70±1.15 for TK-6, and 30.30±4.93 for TK-7. The mean ranking scores for the Tukituki River sites were 30.70±5.77 for TT-4, 20.70±1.15 for TT-5, and 18.70±3.06 for MK-3.

A Levene's test gave a *F* value of 0.49 and a *p* value of 0.88 indicating that the variance of the soil ranking score data was homogenous. A Shapiro-Wilk test gave a *W* value of 0.98 and a *p* value of 0.79, indicating that the soil ranking score data was normally distributed. A one-way ANOVA gave a *p* value of 0.01, indicating that the differences in soil ranking scores between sites were statistically significant (Table 3.4).

Table 3.4: One-way ANOVA table for the soil ranking scores of the 11 plots along the Ngaruroro, Tutaekuri and Tukituki Rivers.

Variable	Sum of Squares	*df*	Mean Square	*F*	*p*
Site	570.10	10	27.01	6.03	0.01
Residuals	208.00	22	9.45		

A Tukey-HSD test indicated that the differences in the soil ranking scores between MK-3 and NG-3, NG-5, NG-6, TK-4, TK-5, TK-6, TK-7, and TT-4 and those between TT-5 and NG-6, TK-4, TK-6, TK-7, and TT-4 were statistically significant (Table 3.5). As outlined above, MK-3 score significantly lower than NG-3, NG-5, NG-6, TK-4, TK-5, TK-6, TK-7, and TT-4 in the visual soil assessment. This is likely due to the significant amount of water and poor drainage at MK-3. While it was possible to walk across the majority of the site there where many places where the observer's feet would visibly press water from the soil while walking. As outlined above, TT-5 scored significantly lower than NG-6, TK-4, TK-6, TK-7, and TT-4 in the visual soil assessment. This is likely due to shallow topsoil depths, inhibited decomposition of the leaf litter, and the presence of coarse firm clods within the soil at TT-5.

Table 3.5: Tukey HSD table using the adjusted *p* value, for the soil ranking scores of the 11 plots along the Ngaruroro, Tutaekuri and Tukituki Rivers. Significant relationships are represented by the colour red.

Plot	MK-3	NG-3	NG-5	NG-6	NG-7	TK-4	TK-5	TK-6	TK-7	TT-4	TT-5
MK-3		0.08	0.03	<0.01	0.49	<0.01	0.08	<0.01	<0.01	<0.01	1.00
NG-3	0.08		1.00	0.81	0.99	0.74	1.00	0.99	0.95	0.92	0.34
NG-5	0.03	1.00		0.98	0.87	0.95	1.00	1.00	1.00	1.00	0.14
NG-6	0.01	0.81	0.98		0.23	1.00	0.81	1.00	1.00	1.00	0.01
NG-7	0.49	0.99	0.87	0.23		0.18	0.99	0.57	0.41	0.34	0.92
TK-4	0.01	0.74	0.95	1.00	0.18		0.74	1.00	1.00	1.00	<0.01
TK-5	0.08	1.00	1.00	0.81	0.99	0.74		0.99	0.95	0.92	0.34
TK-6	0.01	0.99	1.00	1.00	0.57	1.00	0.99		1.00	1.00	0.05
TK-7	0.01	0.95	1.00	1.00	0.41	1.00	0.95	1.00		1.00	0.03
TT-4	0.01	0.92	1.00	1.00	0.34	1.00	0.92	1.00	1.00		0.02
TT-5	1.00	0.34	0.14	0.01	0.92	0.01	0.34	0.05	0.03	0.02	

3.1.6 Birds

A total of 270 birds were seen or heard during the five-minute bird counts; 52 were seen and 219 were heard. Of these birds, 111 were not identified; 14 were seen and 97 were heard. During the counts, 19 species were identified, 8 of which were endemic, 7 were native and 8 were exotic. *Rhipidura fuliginosa* was the most common bird at all sites with 1 seen and 35 heard for a total of 36. *R. fuliginosa* was also commonly seen and heard outside of the five-minute counts, during time at each plot and when moving between plots. Other species commonly seen included *Turdus merula* (27 total, 1 seen, 26 heard), *Gerygone igata* (23 total, 4 seen, 19 heard), *Prosthemadera novaeseelandiae* (15 heard, 0 seen), and *Zosterops lateralis* (14 total, 6 seen, 8 heard). None of the birds identified had threatened status. Further information on the bird counts can be found in Appendices Three and Four.

3.1.7 Flora

A total of 127 plant species were present in the RECCE plots. Of these, 52 were endemic, 14 were native and 61 were exotic. Of the endemic and native species, 30 were trees and shrubs, 21 were ferns or fern allies, 6 were lianes or climbers, 3 were herbs and 6 were monocots. Only one threatened species was present, *K. robusta*, which has been classified as Threatened - Nationally Vulnerable (de Lange *et al.*, 2017). The most common species were *R. fruticosus*, which was found in 21 of the 33 plots, *M. ramiflorus*, which was present in 19 plots, *C. robusta*, which was present in 12 plots, *K. robusta* and *S. fragilis*, which were both found in 10 plots. A species list for all of the sites can be found in Appendix Five. As demonstrated by the vegetation classification in Table 3.6 below, vegetation in the majority of plots formed a treeland that was dominated by a mixture of exotic and native species.

Table 3.6: Vegetation classification for each plot, including the floristic and structural name.

Plot	Vegetation classification	Structural Class
MK-3_1	*S. fragilis*, *R. fructicosus*	Treeland
MK-3_2	*S. cinerea*, *C. robusta*	Treeland
MK-3_5	*S. fragilis*, *C. robusta*, *C. australis*	Forest
NG-3_2	*S. tetraptera*, *Crataegus monogyna*, *M. ramiflorus*, *Aristotelia serrata*	Treeland
NG-3_3	Exotic grass	Grassland
NG-3_7	*S. fragilis*, *A. serrata*, *Coriaria arborea var. arborea*	Treeland
NG-5_1	*M. ramiflorus*, *Ulex europaeus*	Shrubland
NG-5_2	*S. fragilis*, *C. laevigatus*, *M. ramiflorus*	Treeland
NG-5_4	Exotic grass	Grassland
NG-6_1	*S. fragilis*, *Populus deltoides*	Treeland
NG-6_2	Exotic grass	Grassland
NG-6_3	Exotic grass	Grassland
NG-7_1	*M. ramiflorus*	Treeland
NG-7_2	*S. fragilis*, *M. ramiflorus*	Treeland
NG-7_3	*M. ramiflorus*	Treeland
TK-4_1	*K. robusta*	Treeland
TK-4_2	*K. robusta*	Treeland
TK-4_3	*S. fragilis*, *K. robusta*	Treeland
TK-5_1	*S. fragilis*	Treeland
TK-5_2	*Betula pendula*	Treeland
TK-5_3	*C. australis, M. ramiflorus*	Treeland
TK-6_2	*K. robusta*, *M. ramiflorus*	Treeland
TK-6_5	*M. ramiflorus*	Treeland
TK-6_6	*M. ramiflorus, K. robusta, A. excelsus* subsp. *excelsus*	Treeland
TK-7_1	*K. robusta*	Forest
TK-7_2	*K. robusta*	Treeland
TK-7_3	*Buddleja davidii, Cortaderia selloana*	Shrubland/Grassland
TT-4_2	*S. eleagnos*, *S. fragilis*	Treeland
TT-4_4	*M. ramiflorus*	Forest
TT-4_5	*M. ramiflorus*	Treeland
TT-5_1	*A. excelsus* subsp. *excelsus, M. ramiflorus, D. dacrydioides*	Forest
TT-5_2	*A. excelsus* subsp. *excelsus, D. dacrydioides*	Treeland
TT-5_5	*P. totara, D. dacrydioides, Pinus radiata*	Treeland

3.1.8 Ecological references

The presence, or lack thereof, of diagnostic species was assessed and compared to the predicted pre-human forest type at each site. As Singers (2018) is a regional model, it is expected that site scale variability would not always be recognized in the predictions of pre-human forest cover.

3.1.8.1 Ngaruroro river

None of the diagnostic species were present at the site at the time of assessment for NG-3 (Table 3.7). *P. totara* is a lowland, montane, and lower subalpine forest tree that occurs on well-drained alluvial plains, with fertile soils and seasonal droughts (Dawson & Lucas, 2011). *A. excelsus subsp. excelsus* is a widespread coastal and lowland forest tree that favours well-drained, fertile, alluvial soils (Dawson & Lucas, 2011). *D. dacrydioides* is a lowland forest tree that often occurs on floodplains and river terraces with moist, free-draining soils (Dawson & Lucas, 2011). *P. taxifolia* is also a lowland forest tree that dominates sites with alluvial soils that are waterlogged in the winter and dry in the summer (Dawson & Lucas, 2011). As NG-3 is comprised of sloped and flat segments, it is likely that the site could be suitable for the diagnostic species of the predicted forest types.

No native podocarp species were present at NG-5 or NG-7 at the time of assessment. Taking into consideration the characteristics and preferences of the diagnostic species, it would be more appropriate to expect *D. dacrydioides, P. totara, P. taxifolia* forest on an alluvial floodplain rather than on a riparian hillside like NG-5 and NG-7. The presence of *A. excelsus subsp. excelsus* and *M. laetum* at both sites better indicate an *A. excelsus subsp. excelsus, M. laetum* forest type which has been mapped on steep coastal faces in the Hawkes Bay region (Singers, 2018).

The diagnostic species were not present at NG-6 the time of assessment. Due to the characteristics and preferences of the diagnostic species, it would be ecologically appropriate to expect *D. dacrydioides*, *P. totara*, *P. taxifolia* forest at the site, as it lies on a remnant floodplain.

Table 3.3: Predicted forest types for the Ngaruroro River sites from Singers (2018). MF1 is P. totara, A. excelsus subsp. excelsus forest, MF4 is D. dacrydioides forest, WF2-2 is D. dacrydioides, P. totara, P. taxifolia forest.

Forest type	NG-3	NG-5	NG-6	NG-7
MF1	✓	-	-	✓
MF4	✓	-	-	-
WF2-2	✓	✓	✓	✓

3.1.8.2 Tutaekuri river

None of the diagnostic species, except for *A. excelsus subsp. excelsus* at TK-6, were present at the sites (Table 3.8). As all of the Tutaekuri River sites contained at least one sloped segment, it is likely that the sites could be suitable for *P. totara* and *A. excelsus subsp. excelsus*.

Table 3.4: Predicted pre-human forest types from Singers (2018) for the Tutaekuri River sites. MF1 is P. totara, A. excelsus subsp. excelsus forest.

Forest type	TK-4	TK-5	TK-6	TK-7
MF1	✓	✓	✓	✓

3.1.8.3 Tukituki river

The presence of *P. totara*, *A. excelsus subsp. excelsus*, and *D. dacrydioides* at TT-4, and the presence of all four diagnostic species at TT-5 support the predicted forest types (Table 3.9). Further evidence to support these predictions includes both sites containing sloped and terrace segments to support the diagnostic species preferences, and TT-5 having an average annual rainfall of 1312.57 mm. *D. dacrydioides*, *P. totara*, *P. taxifolia* forest is known to be more widespread in areas where the rainfall is greater than 1100 mm (Singers, 2018).

No diagnostic species were present at MK-3 (Table 3.9). However, the moist soil and flat conditions could be suitable for the diagnostic species, *D. dacrydioides*.

Table 3.5: Predicted pre-human forest types for the Tukituki River sites from Singers (2018). MF1 is P. totara, A. excelsus subsp. excelsus forest, MF4 is D. dacrydioides forest, WF2-2 is D. dacrydioides, P. totara, P. taxifolia forest.

Forest type	TT-4	TT-5	MK-3
MF1	✓	✓	-
MF4	-	-	✓
WF2-2	✓	✓	-

3.2 Variable relationships

A scatterplot matrix was used to explore the relationships between the RECCE, forest health, and soil assessment data. The strength of relationships was assessed to determine which variables would be used in the regression tree models. Some of the more significant relationships that were of interest to this study are explored below, the remaining relationships can be found in Appendix Six.

3.2.1 Saplings and seedlings

Saplings appeared to have moderately positive relationships with fencing and land use (r = 0.52), indicating that the more secure the fencing the higher the stem density of saplings per hectares. Consequently, sites surrounded by recreation were more likely to have a higher number of sapling stems per hectare compared to plantation forestry, which had a medium stem density per hectare for saplings, and non-dairy farming which had lower stem density of saplings per hectare. Seedlings had a weakly positive relationship with fencing (r = 0.33), indicating that in general, more intact fencing resulted in a higher stem density of seedlings per hectare. Seedlings had a weak to moderate relationship with canopy height, with an r value of 0.44. Sites containing older, taller trees were more likely to have higher stem densities of seedlings per hectare.

3.2.2 Canopy Cover

Canopy cover had weakly positive relationships with native species richness and the sum of native species importance, giving r values of 0.35 and 0.42, respectively. Sites with a higher percentage canopy cover were more likely to have greater species richness and species sum of native species importance compared to those with a lower percentage canopy cover. TK-7 plot 1 had a relatively high canopy cover of 85 %, and a high native species richness and importance of 11 and 52, respectively.

3.2.3 Land use

Weakly to moderately positive relationships were seen between land use and the richness and importance of exotic species, with r values of 0.42 and 0.51, respectively. Higher richness and sum of exotic species importance was associated with sites surrounded by recreation. Sites surrounded by plantation forestry were associated with a medium richness and sum of exotic species importance. Low richness and sum of importance were associated with non-dairy farming. Plot 4 at TT-4 was surrounded by non-dairy farming and had no exotic species present within the plot and subsequently an exotic species importance of 0.

3.2.4 Rainfall

Rainfall appeared to have moderately positive relationships with native species richness and the sum of native species importance, with an r value of 0.57 for both. Higher annual rainfall resulted in greater richness and importance of native species. An r value of 0.31 indicated that the relationship between canopy cover and rainfall was weakly positive. In general, higher rainfall coincided with a greater percentage canopy cover. Plot 7 at NG-3 had high annual rainfall of 1039.17 mm. The plot also had a relatively high native species richness of 9, a relatively high native species importance of 53, and a relatively high canopy cover of 85 %.

3.2.5 Slope

Steeper slopes had a weakly positive relationship with the richness and sum of importance for native species, with r values of 0.43 and 0.47, respectively. Sites with a steeper slope generally had higher native species richness and sum of native species importance. For example, plot 5 at TT-5 had the steepest slope and highest species richness and sum of importance for native species of all of the sites, with a slope of 80°, a species richness of 17 and a sum of importance of 93.

3.2.6 Aspect

Aspect had weakly to moderately negative relationships with the importance of native species (r = -0.33), rainfall (r = -0.37), road density (r = -0.50), and fencing (r = -0.52). For example, plot 1 at NG-7 was west facing (277°), had an exotic species importance of 2, which was among the lowest, an annual rainfall of 702.49 mm, which was also among the lowest, a medium to low road density of 0.42 km^2, and poor fencing that did not surround the whole site.

3.2.7 Physiography

Physiography had a weakly negative relationship with the importance of exotic species (r = -0.33) and road density (r = -0.38). Physiography had a weakly positive relationship with soil assessment scores (r = 0.31) and a strongly positive relationship with slope (r = 0.76). These relationships indicate that ridges are associated with low importance of exotic species, low road densities, better quality soils, and steeper slopes. Faces may be associated with medium to low importance of exotic species, good to moderate quality soils, moderate to low road densities, and steep-moderately steep slopes. Terraces may be associated with a high importance of exotic species, low quality soils, high road densities, and shallow slopes. For example, NG-6 plot 1 was located on a terrace, had the highest importance of exotic species at 43, a medium to low road density of 0.52 km², a high soil score of 30, and a shallow slope of 5°.

3.2.8 Elevation

Moderately positive relationships between elevation, native species richness ($r = 0.65$) and the sum of native species importance ($r = 0.61$) were observed. TT-5 plot 5 had the highest richness and sum of importance of native species as mentioned above. The plot also had the highest elevation of all plots sampled at 306 m a.s.l, indicating that higher richness and importance of native species is associated with higher elevations. Canopy cover had a weakly positive relationship with elevation, with an r value of 0.31. Plot 2 at TT-5 had the second highest elevation at 302 m, and a canopy cover of 90 % which was among the highest of all the plots. Moderate to highly positive relationships between elevation and rainfall ($r = 0.72$), road density ($r = 0.68$), and aspect ($r = 0.61$), indicated that higher elevations may be associated with higher annual rainfall, road density and aspect. For example, NG-3 plot 2 had a high annual rainfall of 1039.17 mm, a relatively high elevation of 156 m, a medium to low road density of 0.87 km², and a south facing aspect (177°).

3.2.9 Mesotopographic index

Weakly to moderately positive relationships were observed between mesotopographic index and the sum of native species importance ($r = 0.37$), canopy cover ($r = 0.64$). For example, plot 1 at TT-5 had a mesotopographic index of 76, the highest of all the plots. The plot also had a sum of native species importance of 42.50, a canopy cover of 95 %, and an annual rainfall of 1312.57 mm, which were high compared to the other plots.

3.3 Variable importance

Bagged regression tree models were used to determine which of the explanatory variables were the most important for the six response variables assessed. The models were then used to determine the response curves (presented in partial dependence plots) between the most important explanatory variables and the corresponding response variable. Below, the four to six most important response curves for each response variable are given and the remaining partial dependence plots can be found in Appendix Seven.

3.3.1 Native species richness

The six most important explanatory variables for native species richness were slope, elevation, mesotopographic index, rainfall, road density, and the distance from the river in that order (Figure 3.6). The root mean square error (RMSE) was 0.82 and the model explained 76 % of the variance.

In general, increasing slope, elevation, mesotopographic index, rainfall, and road density led to increases in native woody species richness (Figure 3.7). Increasing distance from the river led to decreased native woody species richness (Figure 3.7). The most notable increases in native woody species richness occurred between a slope of 15° and 30°, an elevation between 150 m and 175 m, a mesotopographic index between 35 and 55, an annual rainfall between 625 mm and 675 mm and between 900 mm and 950 mm, and a road density between 0.40 km² and 0.60 km² (Figure 3.7). The most notable decreases in native woody species richness occurred between 60 m and 300 m from the river and between 200 m and 225 m from the river (Figure 3.7).

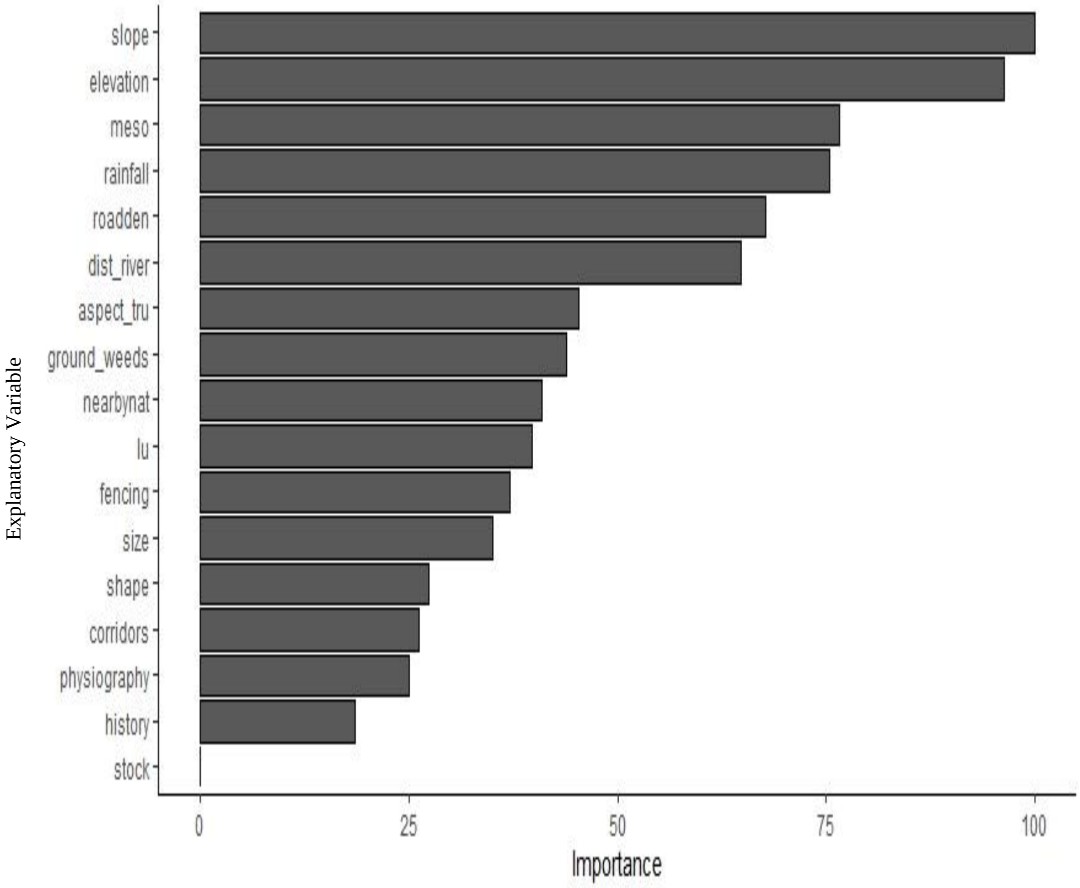
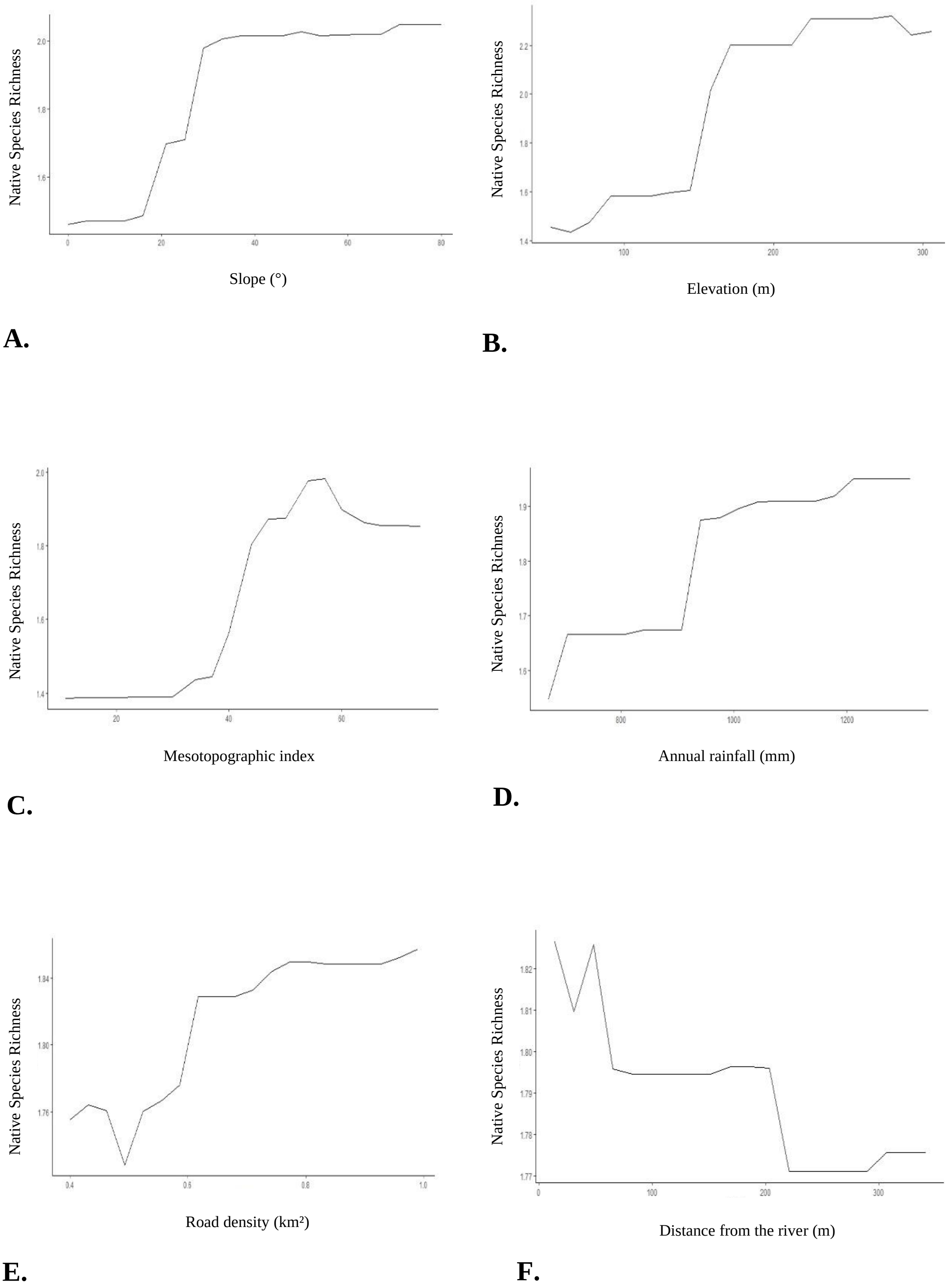


Figure 3.6: Variable importance plot for woody native species richness.



A.

B.

C.

D.

E.

F.

Figure 3.7: PDPs for the relationship between Slope (A), Elevation (B), Mesotopographic index (C), Annual rainfall (D), Road density (E), Distance from the river (F) and native species richness. Native species richness data was arcsinh transformed.

3.3.2 Exotic species richness

The bagged regression tree models indicated that the six most important explanatory variables for exotic species richness were elevation, slope, road density, mesotopographic index, rainfall, and distance from the river (Figure 3.8). The model gave an RMSE of 0.70 and explained 72 % of the variance.

In general, exotic woody species richness increased with increasing elevation, slope, road density, and annual rainfall and decreased with increasing mesotopographic index (Figure 3.9). The most notable increases in exotic woody species richness occurred between an elevation of 25 m and 150 m, between a slope of 0° and 40°, between a road density of 0.75 km² and 0.80 km², between an annual rainfall of 1000 mm and 1025 mm, and between 200 m and 225 m from the river (Figure 3.10). The most notable decreases in exotic woody species richness occurred between a mesotopographic index between 66 % and 68 %, and between 50 m and 200 m from the river (Figure 3.9).

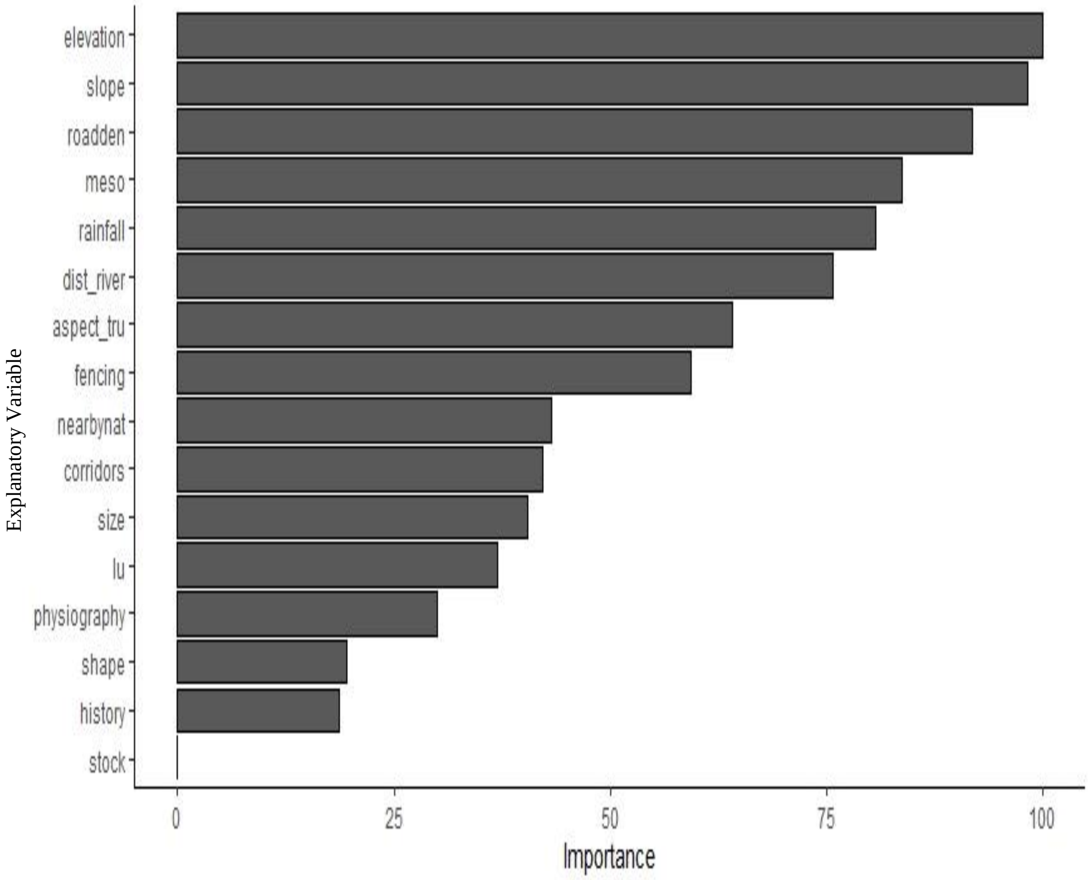


Figure 3.8: Variable importance plot for woody exotic species.

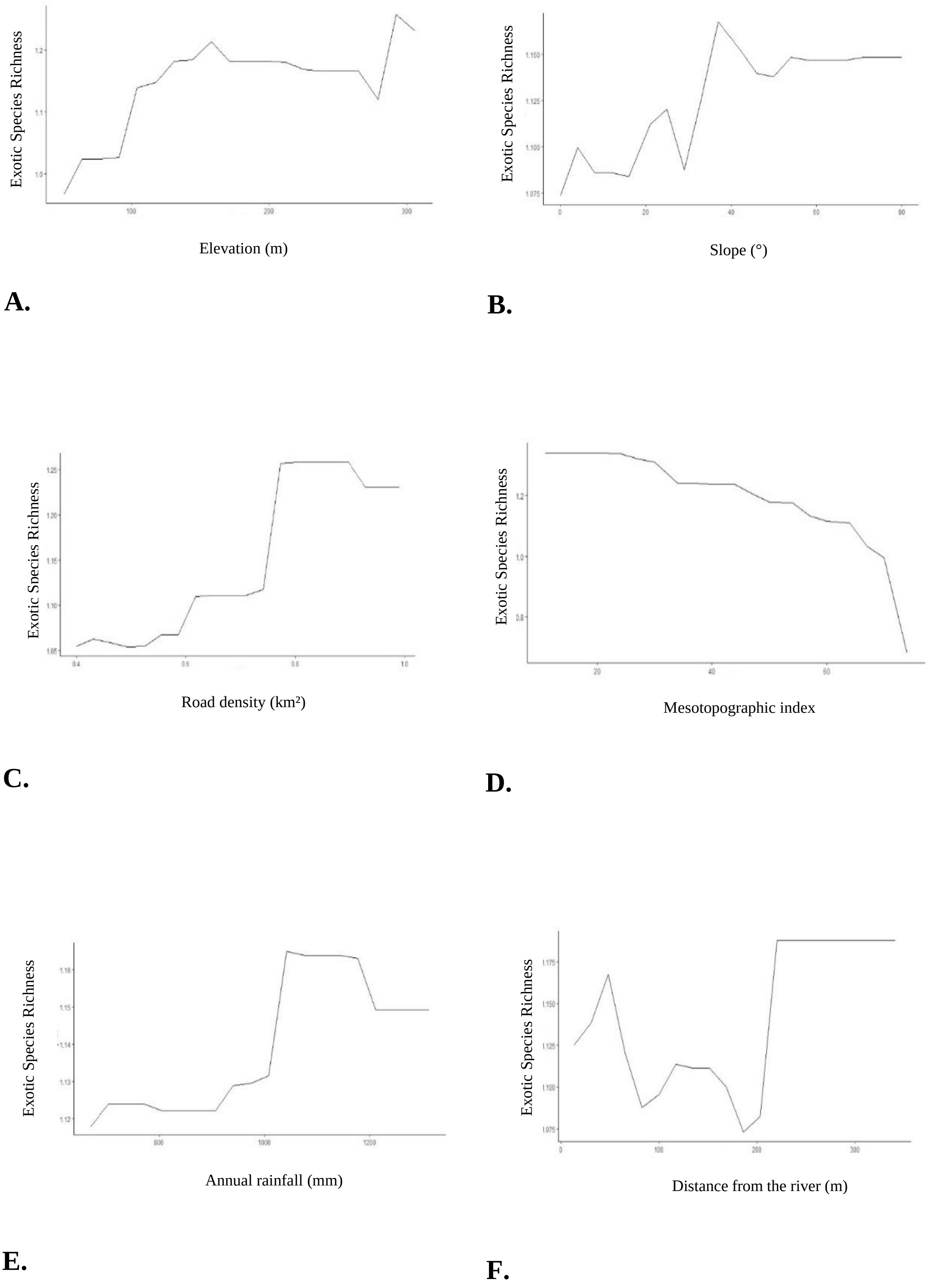


Figure 3.9: PDPs for the relationship between Elevation (A), Slope (B), Road density (C), mesotopographic index (D), Annual rainfall (E), Distance from the river (F), and Exotic species richness. Exotic species richness data was arcsinh transformed.

3.3.3 Importance of native woody species

The bagged regression tree models indicated that the five most important explanatory variables for the importance of native species were elevation, slope, rainfall, distance from the river, and mesotopographic index (Figure 3.10). The model explained 87 % of the variance and gave a RMSE of 1.43.

In general, the importance of native woody species increased with increasing elevation, slope, rainfall, distance from the river, and mesotopographic index (Figure 3.11). The most notable increases in the importance of native woody species occurred between an elevation of 150 m a.s.l and 175 m a.s.l, a slope between 15° and 25°, an annual rainfall between 625 mm and 650 mm and between 900 mm and 1200 mm, between 25 m and 50 m and between 100 m and 125 m from the river, and a mesotopographic index between 30 and 50 (Figure 3.11).

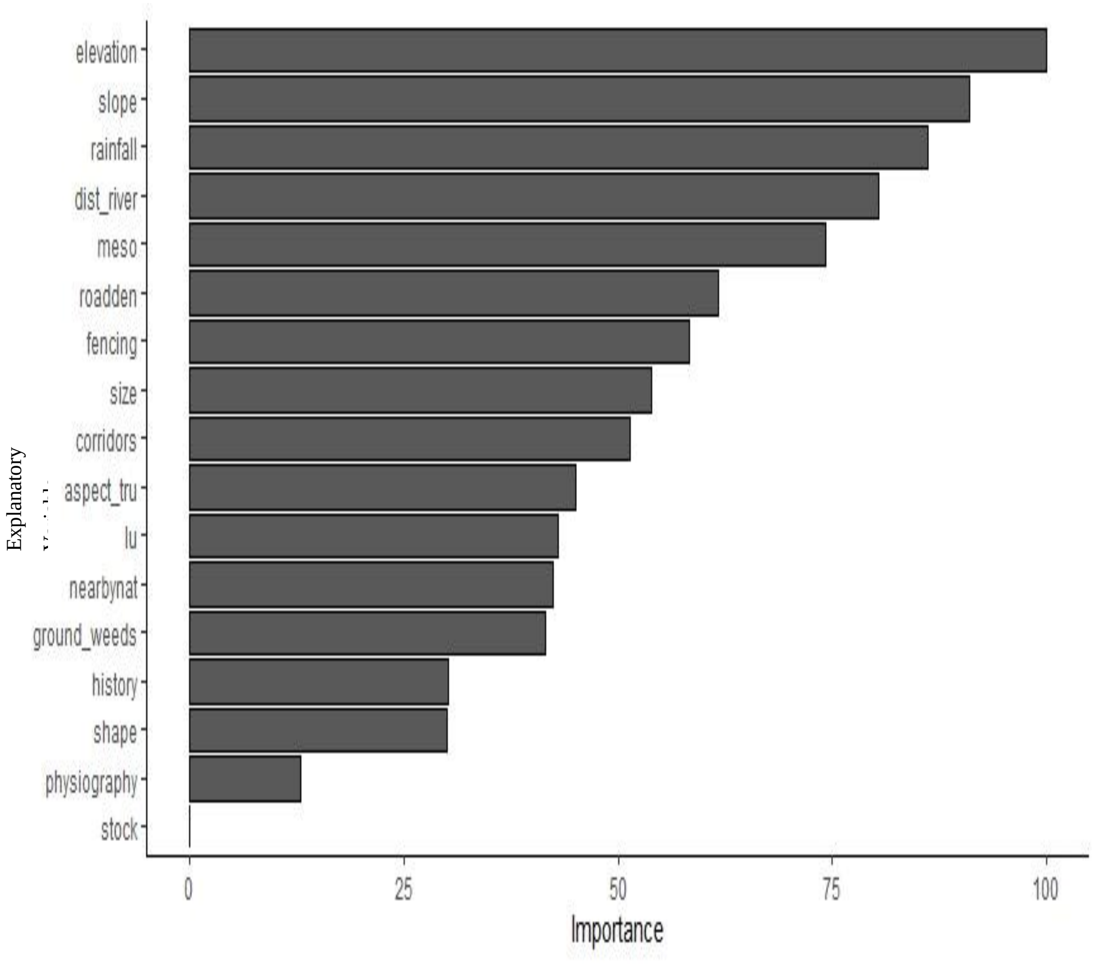


Figure 3.10: Variable importance plot for the importance of native woody species.

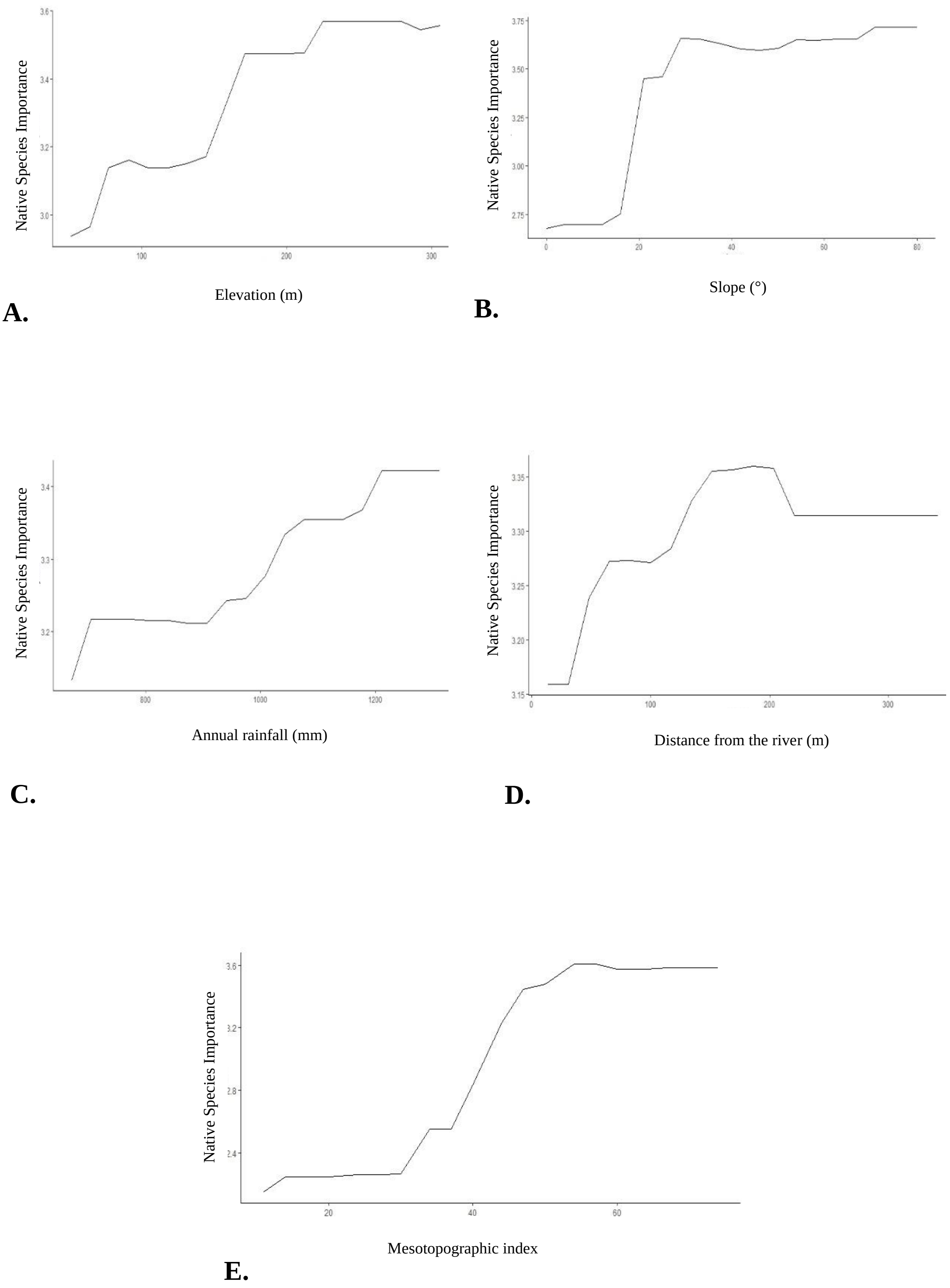


Figure 3.11: PDPs for the relationship between Elevation (A), Slope (B), Annual rainfall (C), Distance from the river (D), Mesotopographic index (E), and Native species importance. Native species richness data was arcsinh transformed.

3.3.4 Importance of exotic species

Slope, distance from the river, elevation, and road density were demonstrated to be the four most important explanatory variables for the importance of exotic woody species (Figure 3.12). The model explained 82 % of the variance and gave an RMSE of 1.32.

In general, the importance of exotic woody species increased with increasing slope, elevation, and road density, and decreased with increasing distance from the river (Figure 3.13). The most notable increases in the importance of exotic woody species occurred between a slope of 0° and 50°, between an elevation of 25 m and 150 m, and between a road density of 0.75 km² and 0.78 km² (Figure 3.13). The most notable decreases in the importance of exotic woody species occurred between 40 m and 190 m from the river (Figure 3.13).

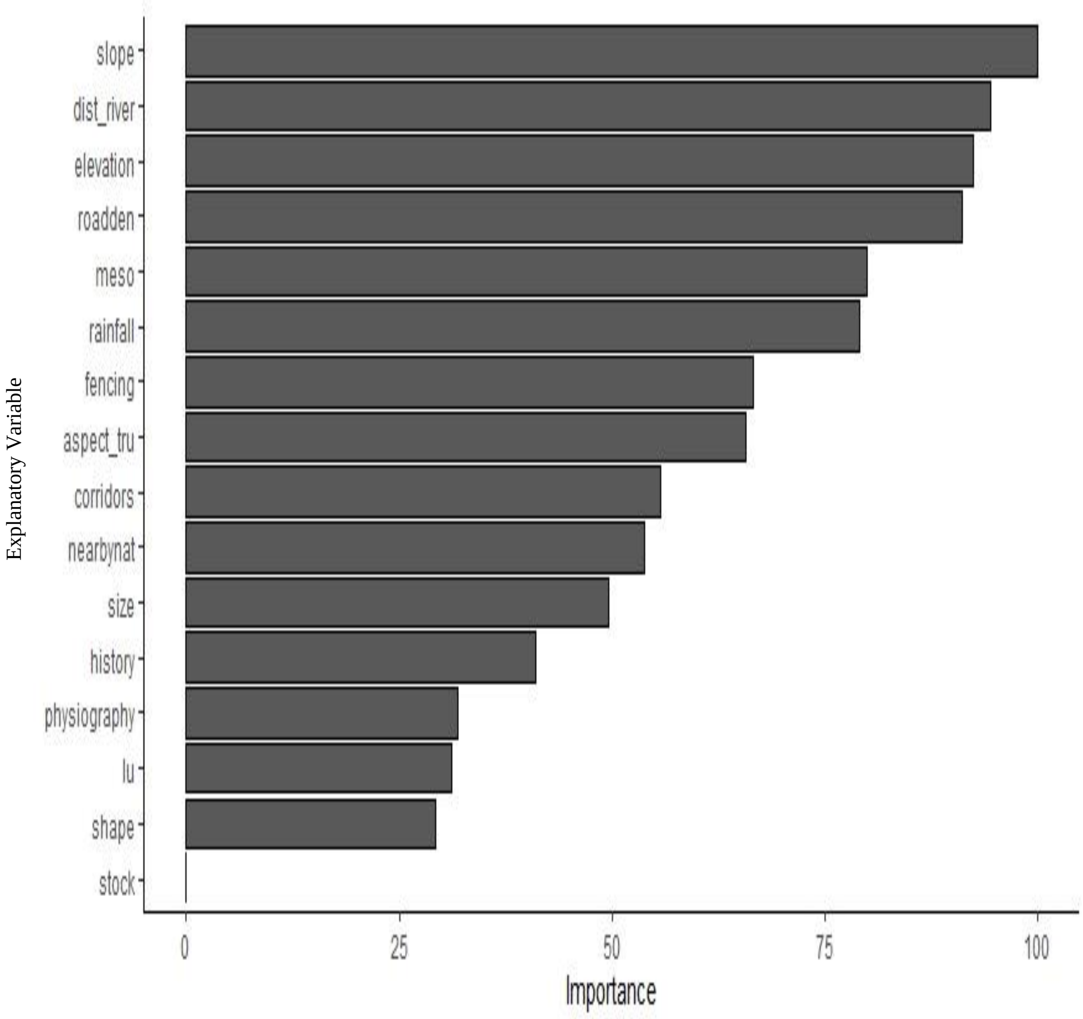


Figure 3.12: Variable importance plot for the importance of exotic woody species.

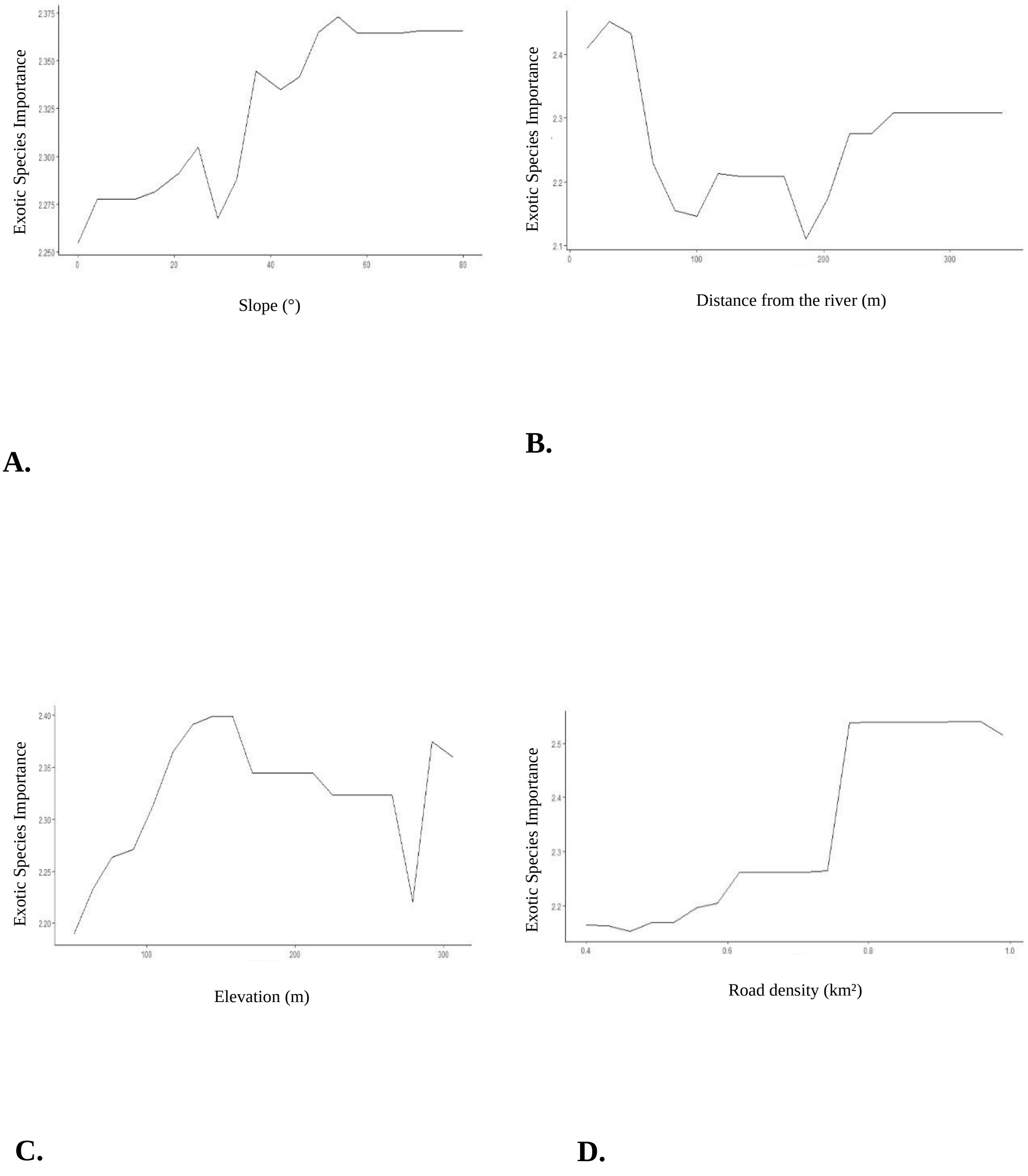


Figure 3.13: PDPs for the relationship between Slope (A), Distance from the river (B), Elevation (C), Road density (D), and Exotic species richness. Exotic species richness data was arcsinh transformed.

3.3.5 Understory density

The five most important explanatory variables for understory density were rainfall, elevation, slope, distance to the river, and mesotopographic index (Figure 3.14). The model explained 93 % of the variance and gave an RMSE of 1.38.

In general, understory density decreased with increasing rainfall and mesotopographic index and increased with increasing elevation and distance from the river (Figure 3.15). the most notable decreases in understory density occurred at an annual rainfall of 1200 mm, between a slope of 0° and 5°, and between a mesotopographic index of 45 and 78 (Figure 3.15). The most notable increases in understory density occurred between an elevation of 25 m and 50 m, between a slope of 28 ° and 55°, and between 25 m and 215 m from the river (Figure 3.15).

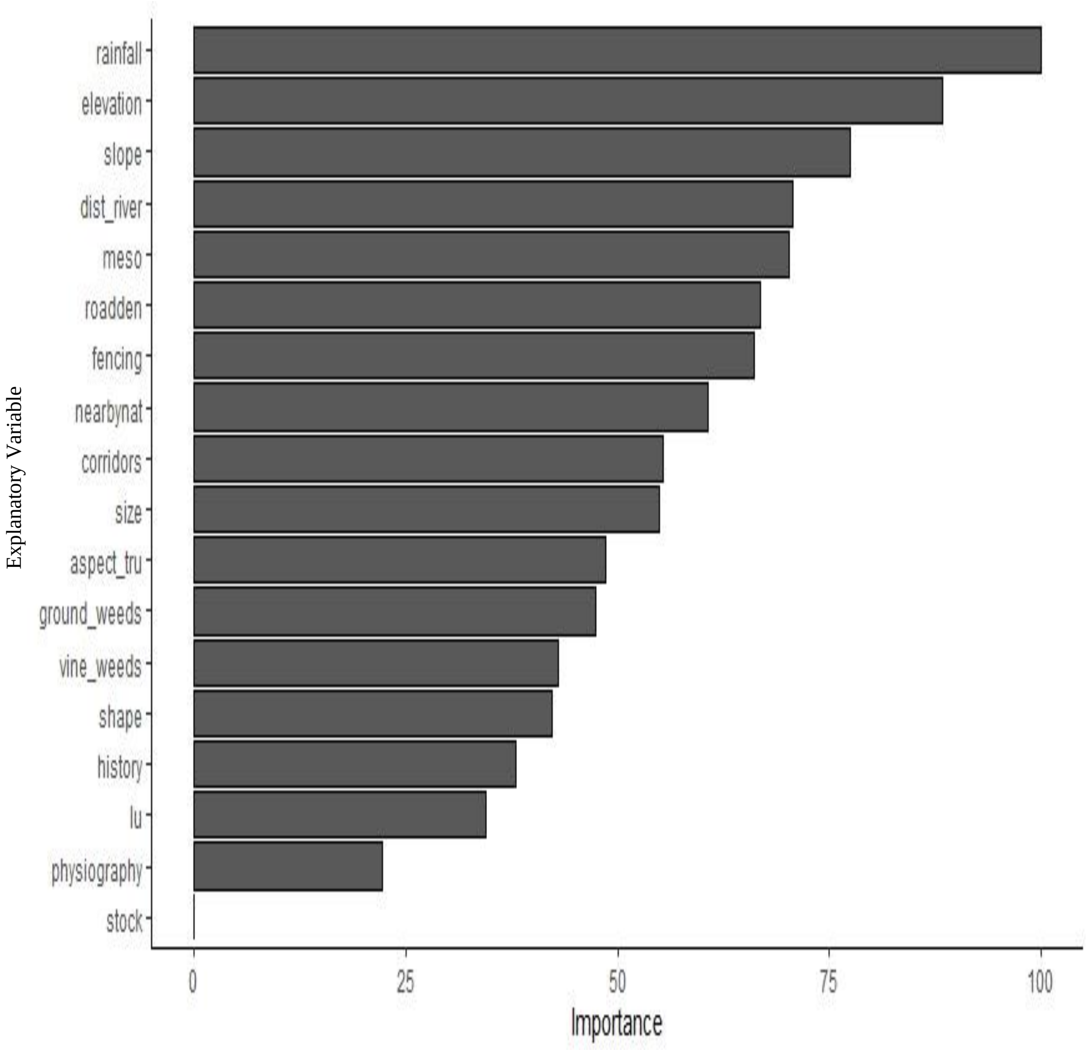


Figure 3.14: Variable importance plot for understory density.

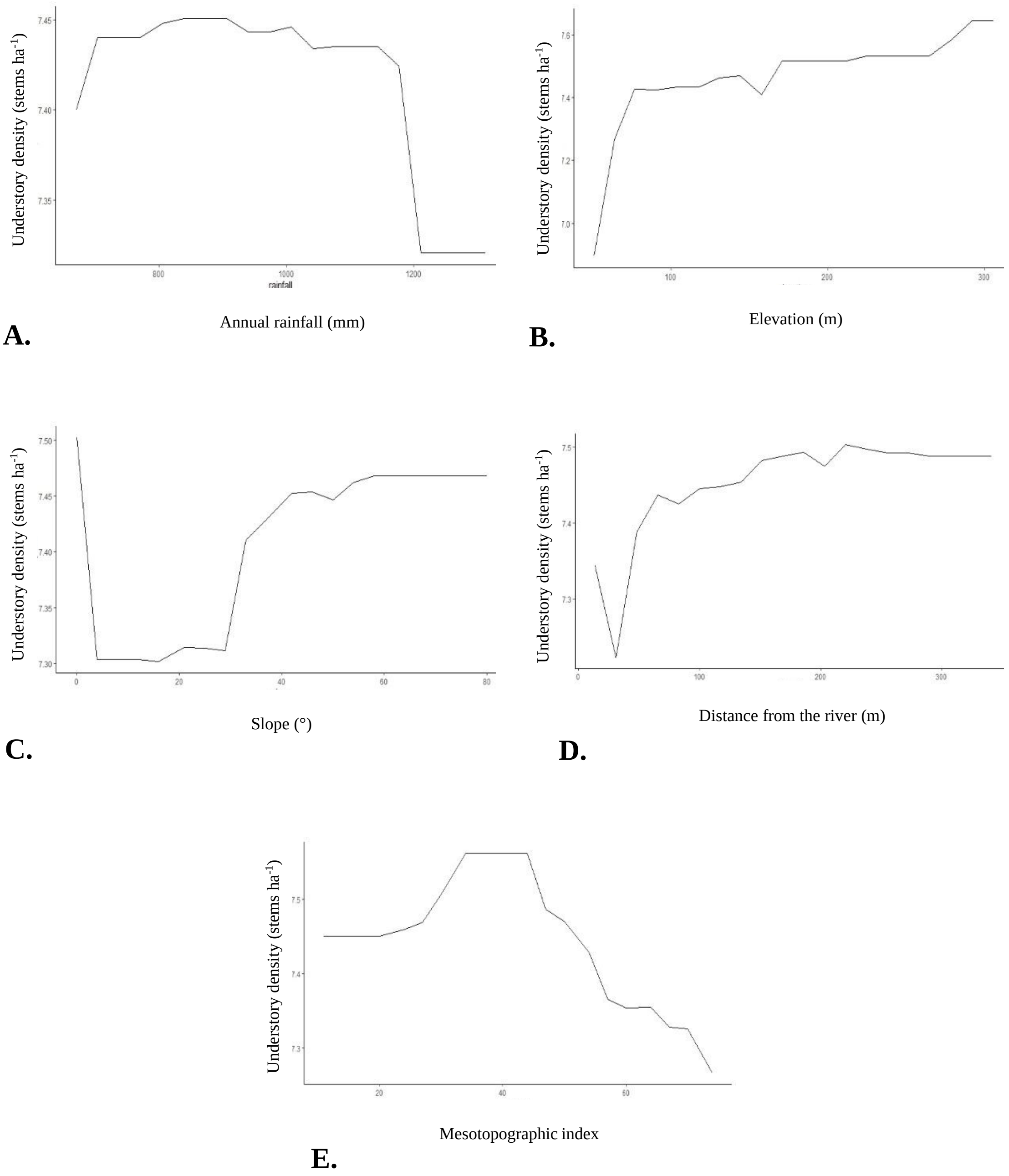


Figure 3.15: PDPs for the relationship between Annual rainfall (A), Elevation (B), Slope (C), Distance from the river (D), Mesotopographic index (E), and Understory density. Understory density data was arcsinh transformed.

3.3.6 Canopy cover

Mesotopographic index, elevation, slope, distance from the river, and annual rainfall were the five most important explanatory variables for canopy cover (Figure 3.16). An RMSE of 0.75 was given for the model which explained 78% of the variance.

In general, canopy cover increased with an increasing mesotopographic index, decreased with increasing slope and distance from the river, and remained relatively constant with increasing elevation and annual rainfall (Figure 3.17). The most notable increases in canopy cover occurred between a mesotopographic index of 5 and 35, between an elevation of 40 m and 60 m, between a slope of 0° and 5°, and between an annual rainfall of 200 mm and 300 mm (Figure 3.17). The most notable decreases in canopy cover occurred between 20 m and 140 m from the river (Figure 3.17).

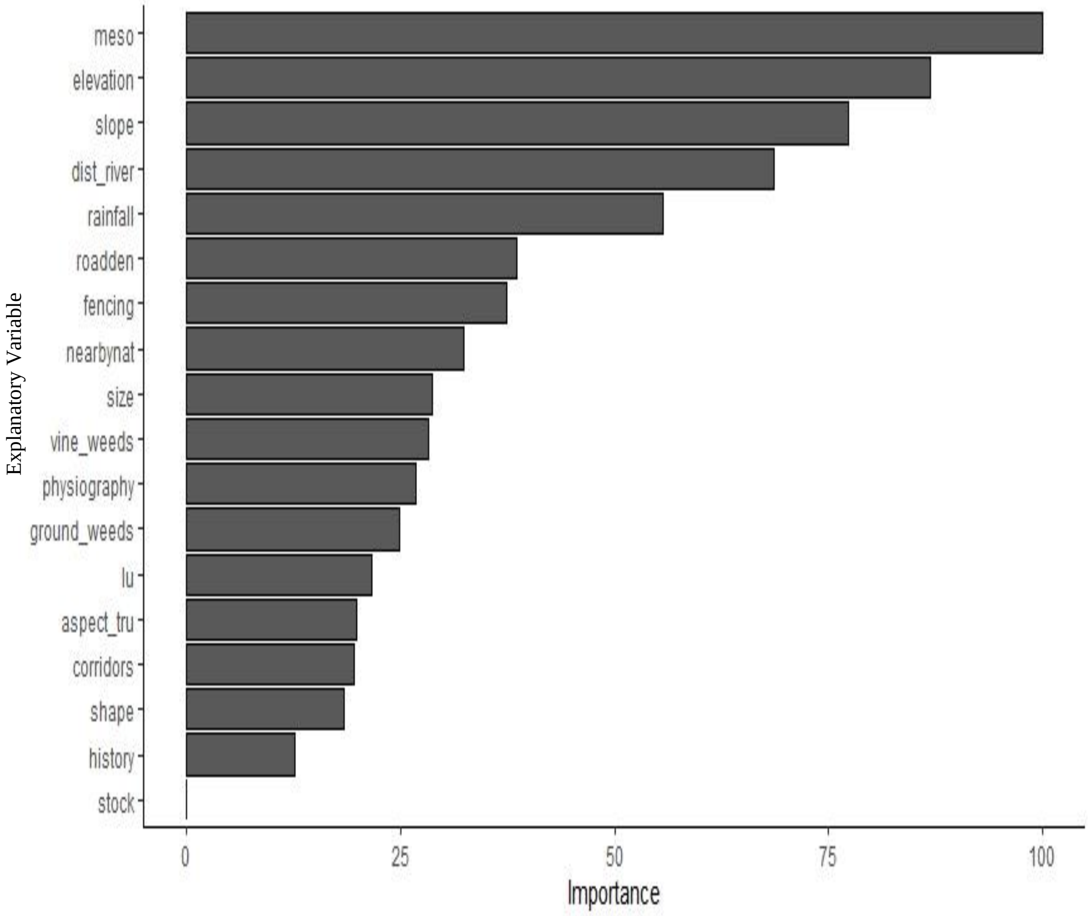


Figure 3.16: Variable importance plot for canopy cover.

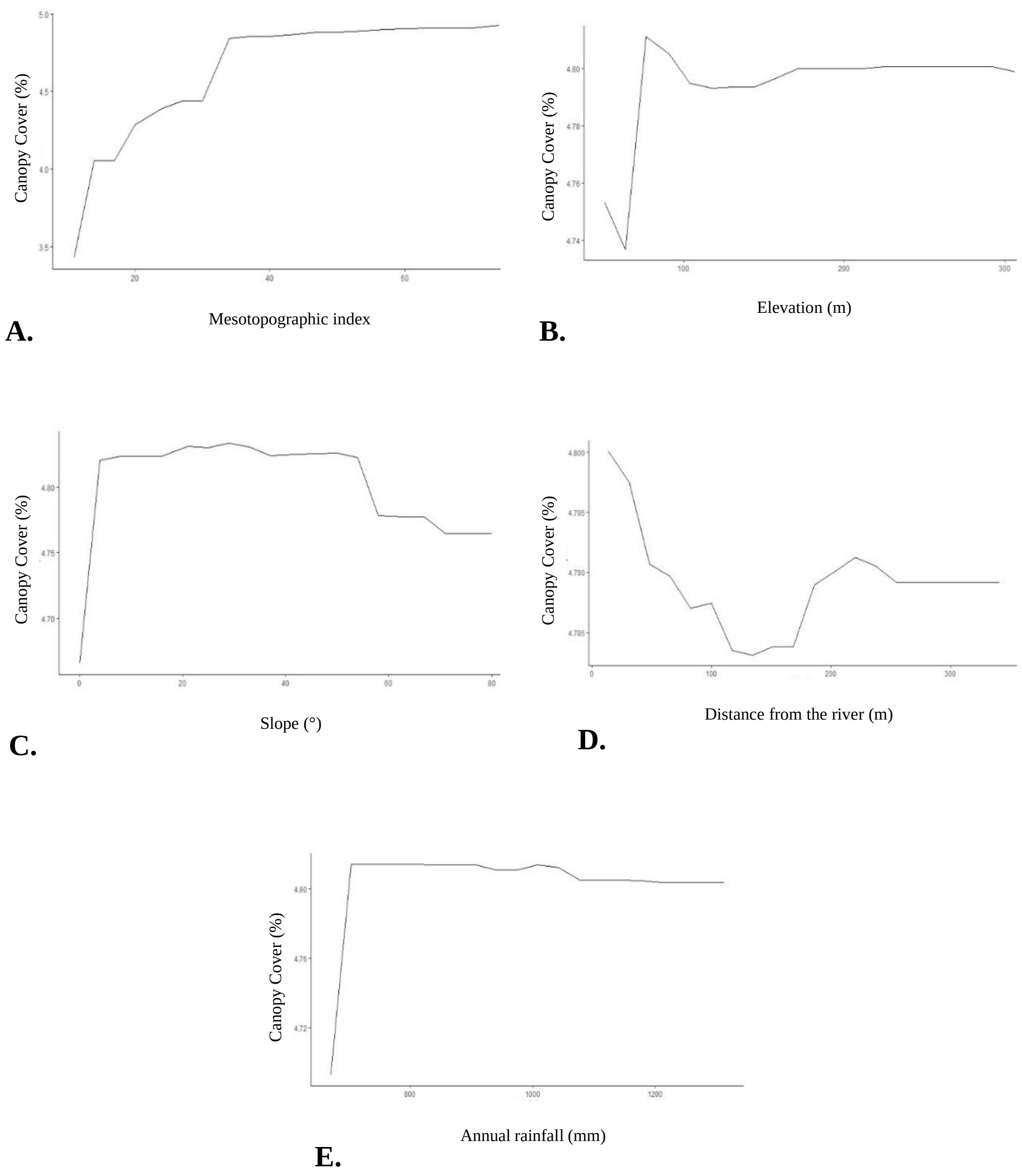


Figure 3.17: PDPs for the relationship between Mesotopographic index (A), Elevation (B), Slope (C), Distance from the river (D), Annual rainfall (E), and Canopy cover. Canopy cover data has been arcsinh transformed.

3.3.7 Important explanatory variables

The six explanatory variables that were consistently the most important for the structure, composition, and ecological health of the sites included in this study were annual rainfall, distance from the river, elevation, mesotopographic index, road density, and slope.

3.3.7.1 Annual rainfall

Annual rainfall was consistently among the top six most important explanatory variables for the structure, composition and ecological health response variables included in the tree models. The key change points were 900 mm, 1025 mm, 1050 mm, 1200 mm, and 300 mm. At 900 mm, native species richness began to plateau after increasing. At 1025 mm, exotic species richness began to plateau. At 1050 mm, exotic species importance stopped increasing and started to decline. At 1200 mm, understory density began to decline. At 300 mm, the drastic increase in canopy cover levelled out. TK-7 and TT-5 sites had an annual rainfall above 1050 mm. TK-7 had a mean native species richness and importance, exotic species richness and importance, understory density, and canopy cover of 5.00 and 29.33, 1.67 and 8.76, 1534.72 stems per hectare per plot, and 60 %, respectively. TT-5 had a mean native species richness and importance, exotic species richness and importance, understory density, and canopy cover of 9.00 and 60.17, respectively, 0.67 and 4.67, respectively, 412.33 stems per hectare, and 88.33 %, respectively. These values were high for native species and canopy cover, and low for exotic species understory density compared to the other sites.

3.3.7.2 Distance from the river

Distance from the river was consistently among the top six most important explanatory variables. The key change points were 65 m, 200 m, 190 m, and 165 m. At 65 m, native species richness began to plateau after declining. At 200 m, native species richness and importance started to decline. At 190 m, exotic species richness and importance started to increase after declining. At 165 m, canopy cover started to increase after declining. MK-3 plot 1, which was 257.35 from the river, had a native species richness of 1.00 and importance of 6.00, an exotic species richness of 4.00 and importance of 38, with an understory density of 1075, and a canopy cover of 70 %. These results were low, high, and relatively high, respectively.

3.3.7.3 Elevation

Consistently among the top three most important explanatory variables was elevation. Key change points occurred at 175 m a.s.l., 150 m a.s.l., 290 m a.s.l, and 50 m a.s.l. At 175 m a.s.l, increases in native species richness began to plateau. At 150 m a.s.l, a sharp increase in native species importance was observed, increases in exotic species richness began to plateau, and exotic species richness began to decrease after increasing. At 290 m a.s.l., exotic species richness began to increase again. At 50 m a.s.l., the increases in understory density and canopy cover began to even out. Plot 7 at NG-3 had an elevation of 151 m a.s.l. The plot had a native species richness of 9 and importance of 53, an exotic species richness of 4 and importance of 18, an understory density of 1815.28 stems per hectare, and a canopy cover of 85 %.

3.3.7.4 Mesotopographic index

Among the top five most important explanatory variables for structure, composition and ecological health was mesotopographic index. The key change points were 30, 35, 45, and 55. At a mesotopographic index of 30, the rate of increase for native species importance increased rapidly before levelling out at 50. At a mesotopographic index of 45, exotic species importance began to decline as did understory density. Canopy cover stopped increasing at a mesotopographic index of 35. Increases in native species richness began to plateau at a mesotopographic index of 55. Plot 2 at TT-4 had a mesotopographic index of 44, a native and exotic species richness of 5 and 4, respectively, a native and exotic species importance of 16 and 20, respectively, an understory density of 4017.73 stems per hectare, and a canopy cover of 85 %.

3.3.7.5 Road density

Road density was consistently among the top six most important explanatory variables. Key change points occurred at 0.40 km², 0.60 km², 0.75 km², and 0.90 km ². At 0.40 km², native species richness began to increase. At 0.60 km², increases in native species importance stopped. At 0.75 km², understory density changed from increasing to decreasing and increases in exotic species richness began to plateau. At 0.90 km², increases in exotic species importance stopped and where canopy cover began to decrease. A road density 0f 0.93 km² was observed at plot 5 of MK-3. This site had a native species richness of 3, an exotic species richness of 4, a native and exotic species importance of 26 for both, an understory density of 3617.67 stems per hectare, and a canopy cover of 65 %.

3.3.7.6 Slope

Consistently among the top three most important explanatory variables was slope. Key change points occurred at 15°, 30°, 40°, and 50°. Between a slope of 0° and 5°, understory density drastically decreased, and canopy cover drastically increased. The biggest increases in native species importance occurred between a slope of 15° and 30°. Understory density began to increase at 30° where increases in native species richness began to plateau and a sharp decrease then increase in exotic species richness was observed. Decreases in exotic species richness began to plateau at 40°. Exotic species importance generally increased until a slope of 50° except for a decline between a slope of 25° and 30°. Canopy cover began to decrease at a slope of 55°. TK-6 plot 2 had a slope of 30°, a native and exotic species richness of 3 and 1, respectively, a native and exotic species importance of 19 and 5, respectively, with an understory density of 2900 stems per hectare, and a canopy cover of 60 %.

Chapter Four

Discussion

The following chapter explores the restoration potential and needs of the 11 sites surveyed during this research, based on the current community structure and species composition of the sites. The restoration potential and needs are explored based primarily on the most important explanatory variables from the bagged regression tree models as well as the risk of future clearance and the similarities with ecological references.

4.1 Important explanatory variables for species composition and community structure

As outlined in section 3.3 the bagged regression tree models indicated that six most important explanatory variables for the species composition and community structure of the remnants included in this study were annual rainfall, distance from the river, elevation, mesotopographic index, road density, and slope. These results are congruent with past efforts to classify New Zealand forest and shrubland types (Develice & Burke, 1989; Wiser *et al.*, 2011). In 1989, Develice and Burke assessed the relationships between plant communities and environmental gradients within podocarp-hardwood forests in the Maungataniwha Range located in Northland, New Zealand. A total of nine community types were generated from the study that were shaped by the elevation above sea level, landform, aspect, and the location on the slope (Develice & Burke, 1989). In 2011, Wiser *et al*. created a classification of forest and shrubland communities in New Zealand based on species composition and community structure. The different vegetation types were shaped by location, elevation above sea level, mean annual temperatures, mean annual precipitation, and slope (Wiser *et al.*, 2011).

Sites with the most desirable species composition and community structure would have a high importance of native species, a low importance of exotic species, a high understory density, and a high percentage canopy cover. Based on the results from the PDPs, sites with an annual rainfall between 1050 mm and 1200 mm, an elevation above 150 m a.s.l, a mesotopographic index of 45 or above, a road density of 0.60 km^2 or below, a slope between 15° and 30°, that were within 190 m from the water's edge would have the most desirable composition and structure of all those included in this research.

One of these important variables that appears often in the literature is elevation (Gracia *et al*., 2007; Lopatin *et al*., 2016). Elevation appears as an important variable for composition and structure in past studies (Gracia *et al*., 2007; Lopatin *et al*., 2016). In Spanish temperate forests, Gracia *et al*. (2007), found that the overall richness and diversity of understory shrub species decreased as elevation increased. Analysis of covariance results gave a F value of 5.8 and p value of <0.01 for elevation and species richness, and a F value of 3.1 and p value of 0.03 for elevation and diversity, indicating that the variances were statistically significant (Gracia *et al*., 2007). Important explanatory variables for community structure in Monte Oscuro temperate forests, located in central Chile, were assessed by Lopatin *et al*. (2016) using Light Detection and Ranging (LiDAR) data. The results from both generalised linear models and random forest models indicated that the three most important explanatory variables for community structure were mean canopy height, elevation in m a.s.l, and the standard deviation of the slope, in that order, except for tree species richness where elevation was the most important predictor (Lopatin *et al*., 2016). Prediction maps demonstrated that high species richness for all species, including, trees, shrubs, and herbs, was observed at lower elevations (Lopatin *et al*., 2016). This is in contrast with the present study where species richness increased with increasing elevation. In Monte Oscuro, high species richness at low elevations was linked to past land use (Lopatin *et al*., 2016). A history of logging at low elevation sites resulted in a mixture of early and late successional species, as well as the known distribution patterns of the species present (Lopatin *et al*., 2016). Interestingly, the prediction maps demonstrated that species richness was also high in areas close to rivers, which was also linked to the preferences and known distribution of the species and forest types present. (Lopatin *et al*., 2016). These results relate to those of the present study where native species richness increased with decreasing distance from the river. Future studies could assess this effect further. Perhaps native woody species are retained close to the water’s edge to mitigate erosion and flood risks (Marden, Rowan & Phillips, 2005), or perhaps the river promotes a level of humidity which is beneficial for the establishment and growth of native rainforest species.

The relative importance of the differing explanatory variables has implications for restoration management, and these implications are discussed in turn, in section 4.2 below.

4.1.1 Model performance

Model performance for the six bagged regression tree models was generally good. RMSE values were generally low compared to the response variable data, and all R^2 values were greater than 0.70. While the RMSE values were not normalised and could not be directly compared between models, the best performing model was that of understory density and the lowest performing model was that of canopy cover.

When assessing the importance of explanatory variables for predicting forest loss to urban development within temperate forests in New England, models for different time periods showed differing performance (Thorn *et al*., 2016). Boosted regression tree models gave a R^2 of 0.018 for cross validation, a R^2 of 0.088 for the training models, a mean residual deviance of 0.012, and an estimated standard error of the cross-validation deviance of 0.0004, for the 2006 - 2011 time period (Thorn *et al*., 2016). For the 2001 - 2011 time period, boosted regression tree models gave a R^2 of 0.069 and 0.128 for cross validation and the training model respectively, a mean residual deviance of 0.028, and an estimated standard error of the cross-validation deviance of 0.0007, (Thorn *et al*., 2016). The 2006 - 2011 time period explained less of the variance, indicating that there were more important variables not included in the model for that time period (Thorn *et al*., 2016).

Lopatin *et al*. (2016) compared and contrasted the performance of generalised linear models and random forest models for determining the most important explanatory variables for species richness. The generalised linear models gave a coefficient of determination (R^2) of 0.66, 0.50, 0.52, and 0.50 for the total, tree, shrub, and herb species richness, respectively (Lopatin *et al*., 2016). Normalised root mean square errors (nRMSE) from the generalised linear models were 16.26 %, 19.08 %, 19.89 %, and 21.31 % for the total, tree, shrub, and herb species richness, respectively (Lopatin *et al*., 2016). The bias for the generalised linear models were 0.05, 0.06, 0.08, and 0.09 for the total, tree, shrub, and herb species richness, respectively (Lopatin *et al*., 2016). This indicated better performance and lower bias compared to the R^2, *nRMSE*, and bias values for the random forest models which gave R^2 values of 0.55, 0.33, 0.45, and 0.46, *nRMSE* values of 18.30 %, 21.90 %, 18.95 %, and 21.00, and bias values of 0.07, 0.08, 0.09, and 0.13 for the total, tree, shrub, and herb species richness respectively (Lopatin *et al*., 2016). In the case of the species richness at Monte Oscuro, the generalized linear models outperformed the random forests (Lopatin *et al*., 2016).

To further improve the performance of the models, future research could utilize different explanatory variables than the ones used. Alternatively, other model types could be adopted. The algorithm for random forests was put forward by Breiman in 2001. Random forests are an extension of bagging regression tree models that follow the same principles (Breiman, 2001). The key difference is that random forests add in more randomness to the tree-building phase (Breiman, 2001). The added randomness reduces the problem of tree correlation, and further reduces the variance of the base learner that is created from the training data set from the base learning algorithm (Breiman, 2001). Boosting is another ensemble method that utilizes AdaBoost algorithms (Dietterich, 2000; Freund & Schapire, 1996). Where bagging and random forests take the average of the models created, boosting sequentially creates stronger models (Dietterich, 2000; Freund & Schapire, 1996). Bagging and random forests are ideal for models with low bias and high variance and boosting is ideal for models with high bias and low variance (Boehmke & Greenwell, 2020). For the models in the present study, the use of a random forest algorithm may further improve the model performance.

4.2 Restoration potential and needs

Site degradation can result in changes to species composition such as invasions, loss of specialist species, and the gain of generalist species (Clewell *et al*., 2013; Hobbs & Norton, 2004). Degradation can also lead to the reduction of community structure, beneficial soil properties, and nutrient retention, as well as changes in the microclimate, and moisture regimes (Clewell *et al*., 2013). In general, sites that are more degraded require a higher intensity of effort to be restored (Clewell *et al*., 2013). Four restoration methods which require increasing intensity of effort are prescribed natural regeneration, assisted natural regeneration, partial reconstruction, and complete reconstruction (McDonald, 2000; Prach *et al*., 2007; Clewell *et al*., 2013; Chazdon & Uriarte, 2016; Stanturf *et al*., 2014). In the present study, sites that are less degraded where a lower intensity of effort would be required for restoration, and therefore fewer restoration needs, are assumed to have a higher restoration potential.

4.2.1 Annual rainfall

In the present study, sites with an annual rainfall between 1050 mm and 1200 mm had a relatively high native species richness and importance, low exotic species richness and importance, high understory density, and high canopy cover (henceforth referred to as a desirable species composition and community structure). These rainfall values could be used to inform restoration management. Sites with an annual rainfall between 1050 mm and 1200 mm would likely require a lower intensity of effort, have fewer restoration needs, and require fewer resources, compared to those with an annual rainfall outside of the desirable range. Sites with an annual rainfall outside of the desirable range may require greater investments and more interventions. Where the aim is to restore more degraded sites, restoration projects could focus on sites outside of the 1050 mm to 1200 mm annual rainfall range. In the present study, site MK-3 had the lowest annual rainfall of all the sites and could be considered for a project targeting more degraded sites. Restoration in the favourable rainfall belt could be more passive (require fewer investments and interventions). In the present study, site TK-7 had an annual rainfall within the desirable range and restoration of forest composition and structure at this site could be less intensive than at sites with rainfall <1050 mm and >1200 mm per annum.

4.2.2 Distance from the river

Sites within 190 m from the river’s edge had the most desirable species composition and community structure in the present study. These results suggest that sites, or portions of a site, further than 190 m from the river’s edge may require a more active approach (greater investments and more interventions) for restoration compared to those within 190 m from the river’s edge where forest composition and structure is more native dominated and diverse. The 190 m threshold may be used to inform decisions regarding investments in restoration. In the present study, site NG-7 was furthest from the river’s edge and sites NG-3 and NG-5 were present right up to the river’s edge. These three sites could be considered for projects targeting more degraded and less degraded sites. Of the plots surveyed, the centre of plot 1 at site TK-7 was closest to the river’s edge, and the centre of plot 3 at site NG-7 was the furthest, and almost double the 190 m threshold, from the river’s edge. These results demonstrate that portions of TK-7 and NG-7 could be considered for more passive (invest less) and active (invest more) restoration, respectively.

4.2.3 Elevation

Sites that currently have a more desirable species composition and community structure in the present study, had an elevation above 150 m a.s.l, as demonstrated by the bagged regression trees and PDPs. In terms of restoration management, these results are consistent with regeneration of rainforest species in exotic plantation clear-fells where native angiosperms regenerated at greater densities with increasing elevation (Forbes *et al.*, in press), suggesting that sites with an elevation below 150 m a.s.l. could be made a priority for active restoration requiring intensive investment and intervention. These results also suggest that sites with an elevation above 150 m a.s.l. could be made a priority for passive restoration. Eighteen of the 33 plots had an elevation below 150 m a.s.l. Plot 2 at site NG-5 had the lowest elevation indicating, that at least a portion of the site could be considered for more intensive restoration projects. Plot 5 at site TT-5 had the highest elevation that was approximately double the 150 m a.s.l. threshold, indicating that at least a portion of the site could be considered for more passive restoration projects.

4.2.4 Mesotopographic index

Results from the bagged regression tree models and PDPs suggest that sites with a mesotopographic index of 45 or above had the best community structure and species composition of the sites included in the present study. These results suggest that sites with moderate to high protection were more likely to have a more desirable community structure and species composition and would likely require lower investments, intensity of effort and interventions to restore. Restoration projects that aim to restore more degraded sites and utilize more active methods could prioritise sites that have a mesotopographic index below 45. Plot 4 at site NG-5 had the lowest mesotopographic index and protection of all the sites surveyed, indicating that a portion of the site could be considered for active restoration projects targeting more degraded sites. Restoration projects where the aim is to restore sites that are less degraded and utilize more passive methods could prioritise sites that have a mesotopographic index of 45 or greater. Plot 1 at site TT-5 had the highest mesotopographic index and therefore protection, indicating that at least a portion of the site could be included in passive restoration projects targeting less degraded sites.

4.2.5 Road density

A road density of 0.60 km^2 or below was associated with sites that contained a more desirable species composition and community structure in the present study. These results suggest that sites surrounded by fewer roads may be less degraded and require lower investments, fewer interventions, and have a higher restoration potential compared to sites with a road density greater than 0.60 km^2. It also suggests that sites with a road density of 0.60 km^2 or below could be prioritised in passive restoration projects, and sites with a road density greater than 0.60 km^2 could be prioritised in active restoration projects targeting more degraded sites that require more investments and interventions. In the present study, site TK-5 had the lowest road density and site MK-3 had one of the highest. These results suggest that TK-5 and MK-3 could be included in restoration projects where the aim is to utilize more active or intensive efforts and passive or less intensive efforts, respectively.

4.2.6 Slope

In the present study, sites with a slope between 15° and 30°, or a rolling to very steep slope, had a more desirable species composition and community structure, suggesting that sites outside of this desirable range would require more investments, interventions, and a greater intensity of effort. Restoration projects targeting more degraded sites where the aim is to include more interventions, greater investments, and more active methods, could target sites outside of the desirable slope range. For example, plot 3 at site TK-7 had one of the shallowest slopes and plot 1 at site NG-7 had one the steepest slopes of all the sites surveyed. These results suggest that more active restoration projects could involve at least a portion of sites TK-7 and NG-7. Restoration projects targeting less degraded sites where the aim is to include fewer interventions and investments, and utilize more passive methods, could target sites within the 15° to 30° slope range. For example, plot 1 at site NG-5 had a slope within the desirable range, indicating that less intensive and more passive restoration efforts would be required at a portion of the site.

4.2.7 Improving species composition and community structure

One of the key aims of ecological restoration is aiding the successional trends that would occur naturally in a healthy system (Clewell *et al*., 2013). Succession refers to the changes in species composition and community structure that occur over time (Walker *et al*., 2010). Primary succession occurs after large scale disturbances and secondary succession occurs after less severe disturbances where not all of the vegetation was removed (Walker *et al*., 2010). One way of aiding succession is through the manipulation of the current species composition and community structure and may be achieved through the removal of exotic or other undesirable species, and the introduction of desirable and site-appropriate native species (Clewell *et al*., 2013; Forbes *et al*., 2020).

Exotic species were present at all of the sites and were dominant in many of the plots surveyed, as demonstrated by the current vegetation classification in Table 3.3. Many of the sites were also home to secondary or modified primary forest. In order to shift the dominance of exotic species, creating a vegetation classification that is dominated by native and site-appropriate species, and to aid in the successional processes at each site, passive or active restoration efforts could take place. A few of these efforts, including the use of nurse plants in passive efforts (Callaway *et al*., 1991; Forbes, 2017; Burrows *et al*., 2015; Sullivan *et al*., 2007), canopy manipulation as a more active approach (Tulod *et al*., 2019), and the use of ecological references (Clewell *et al*., 2013) to inform decisions regarding the addition of desired species are discussed below.

4.2.7.1 Addition of desirable species

Approximately 70 % of New Zealand's indigenous forest plants are bird dispersed (Williams 2006; Wotton & Kelly 2012). Because of this, dispersal generally occurs within several hundred metres of the source, meaning that proximity to seed sources is important for forest health, structure, and composition (Williams 2006; Wotton & Kelly 2012). Proximity to seed sources would be of little issue to sites like TT-4 and TT-5, which are in relatively close proximity to Inglis Bush and other bush fragments in the surrounding landscape. This is in comparison to isolated sites with low native species richness and importance like NG-6, where poor proximity to seed sources is a big issue. The issue of seed sources, particularly for late-successional and emergent species, may be addressed through methods such as enrichment planting of seedlings and saplings (Forbes *et al*., 2020). Important factors affecting the success rate of interventions such as enrichment planting include planting densities, seed predation, herbivory, competition with exotic and weed species, canopy cover, and light conditions (Forbes *et al*., 2020).

4.2.7.1.1 Use of nurse plants

Nurse plants have been shown to increase the survival and growth rates of native species (Callaway *et al*., 1991; Forbes, 2017; Burrows *et al*., 2015; Sullivan *et al*., 2007), particularly where abiotic conditions are harsh (Padilla & Pugnaire, 2006; Gomex-Aparicio et al., 2004). The services that nurse plants offer include decreasing the amount of solar radiation, retaining moisture, and increasing nutrients in the soil, and protection against herbivory (Callaway *et al*., 1991). Nurse plants may also speed up the restoration process (Svirz *et al*., 2012). Present within temperate forests in Patagonia, Argentina, is the invasive and exotic shrub species *Rosa rubiginosa* (Svirz *et al*., 2012), which was also present at MK-3, NG-3, and TT-4. *R. rubiginosa* has demonstrated the ability to act as a nurse plant, with between one and six native species and one to two exotic species being found regenerating underneath the shrub (Svirz *et al*., 2012). Between 45 - 70 % and 5 -

15 % of *R. rubiginosa* assessed were found to have native and exotic species, respectively, regenerating beneath them (Svirz *et al*., 2012). Of four tree species native to Patagonia that were planted under *R. rubiginosa,* two showed higher survival rates where *R. rubiginosa* was present as a nurse plant, while the other two showed no difference in survival between areas with and without the nurse plant (Svirz *et al*., 2012). These results indicated that *R. rubiginosa* could be used as a restoration tool (Svirz *et al*., 2012).

Non-harvest *Pinus radiata* plantations in New Zealand have also demonstrated the ability to facilitate forest succession and act as a passive restoration tool (Forbes *et al*., 2019). In Kinleith Forest, located in the central North Island of New Zealand, increasing stand age and decreasing light availability has been shown to change the indigenous composition from a dominance of light-demanding colonists to a dominance of shade-tolerant forest tree species (Forbes *et al*., 2019). Results from a chronosequence demonstrated that in the first 15 years, the understory was dominated by light-demanding colonist species such as *C. arborea* and *A. serrata* (Forbes *et al*., 2019). As the canopy cover increased the dominance shifted to more shade tolerant species such as *Schefflera digitata*, *M. ramiflorus*, and *Brachyglottis repanda* (Forbes *et al*., 2019). By the 44th year the understory was dominated by generalist shade-tolerant forest tree species such as *B. tawa*, *Hedycarya arborea* and *Litsea calicaris* (Forbes *et al*., 2019). Native woody species richness was associated with stand age ($F = 9.75$, $p = 0.02$), indicating that as the planted exotic stand aged the richness of native woody species increased (Forbes *et al*., 2019). Across 89 years canopy cover increased from 0 % to 92 % and the percentage of photosynthetically active radiation decreased from 100 % to 25 % (Forbes *et al*., 2019). Distance to seed sources and light availability may still be an issue where exotic plantations are used as nurses for the restoration of native forests, and interventions such as canopy manipulations and enrichment planting may be required (Forbes *et al*., 2019).

Salix spp. are another exotic species to New Zealand that have been used successful as nurse plants, including in riparian restoration projects (Kuzovkina & Quigley, 2004; Forbes, 2017). At least one *Salix* spp. was present at all of the sites except for TK-6. Exotic shrub species such as *Cytisus scoparius* and *U. europaeus* have been demonstrated to facilitate the regeneration of native species in New Zealand (Burrows *et al*., 2015; Sullivan et al., 2007). Nurse plants could be used as a passive restoration method at the sites included in the present study. *Salix* spp., and shrubs such as *U. europaeus* that were present at MK-3, NG-5, NG-6, and TK-6, and *R. fructicosus* which was present at all 11 sites, could be utilized for this purpose.

4.2.7.1.2 Canopy manipulation

The light conditions for the regeneration of canopy and emergent species in New Zealand is variable (Knowles & Beveridge 1982; Lusk & Ogden 1992; Wyse et al. 2018). The regeneration of some of the canopy and emergent species appears to be linked with increased light levels and small-scale disturbances such as canopy gaps (Knowles & Beveridge 1982; Lusk & Ogden 1992; Wyse et al. 2018). Past studies have demonstrated the positive effects of canopy manipulation for late-successional species (Tulod *et al*., 2019). Canopy manipulation may be achieved by the creation of artificial canopy gaps through the removal of existing trees (Tulod *et al*., 2019). Tulod *et al.* (2019) trialled different treatments of establishing the light-demanding *P. totara* (Ebbett & Ogden, 1998), under early successional *K. robusta* in Tiromoana Bush, North Canterbury, New Zealand. The treatments included, artificial gap creation, ringbarking, and a control (Tulod *et al*., 2019). Artificial gap creation was achieved by felling a small number of *K. robusta.* A small number of *K. robusta* were ringbarked at the forest edge between *K. robusta* and grassland. The control was comprised of a dense *K. robusta* canopy (Tulod *et al*., 2019). The mean relative height growth of *P. totara* seedlings was significantly faster and approximately twice as fast underneath the artificial gaps (1.41±0.14) compared to that of the ringbarking (0.78±0.09, p = 0.01), forest edge (0.81±0.25, p = <0.01), and control (0.42±0.00, p = <0.01) treatments (Tulod *et al*., 2019). Results indicated that the conditions created by the artificial canopy gaps were important for the establishment of *P. totara* (Tulod *et al*., 2019). Based on these results, native species richness and importance could be increased at the *K. robusta* stands along the Tutaekuri River, as well as at NG-6, through the use of artificial canopy gaps and enrichment planting. These methods would facilitate successional processes and improve species composition and community structure at these sites and aid in their long-term restoration.

4.2.7.1.3 Use of ecological references

Ecological references are often used in restoration projects (Clewell *et al*. 2013). Such references serve as models for the planning and implementation stages of a project and may be used as a guide for improving the community structure and species composition of a restoration site (Clewell *et al*. 2013). Information regarding species composition, community structure, and interactions with the surrounding landscape, to name a few, can often be extrapolated from an ecological reference (Clewell *et al*. 2013). Temporal changes in environmental conditions must be kept in mind when considering the use of an ecological reference (Clewell *et al*. 2013). In the present study, the predicted pre-human vegetation types were chosen as ecological references for the 11 sites. Three forest types, *P. totara*, *A. excelsus* subsp. *excelsus* forest, *D. dacrydioides* forest, and *D. dacrydioides, P. totara*, *P. taxifolia* forest, were consistently predicted for the sites (Singers, 2018). These forest types are based off the Singers and Rogers (2014) classification and are largely shaped by factors including elevation and annual rainfall.

The *P. totara*, *A. excelsus* subsp. *excelsus* forest type (MF1) is considered to be 'extremely rare and threatened' making any remnants of this forest type ecologically significant (Singers, 2018). Based on predictions, this forest type would have covered 313,479 ha in pre-human times within the Hawke's Bay region (Leathwick, 2017). This area has reduced over time and the MF1 forest type currently covers 17,260 ha (Leathwick, 2017). The letters M and F in the vegetation type code indicate that this forest type is part of the mild forest group whose mean summer temperature ranges from 15 - 17° C, and whose climate can be described as semi-arid (Singers & Rogers, 2014). MF1 can be found in warm to mild, drought prone areas occupying low hill country, and older river terraces, with brown and pallic soils (Singers & Rogers, 2014; Singers, 2018). MF1 will be found no higher than 500 m a.s.l. (Singers, 2018). Like the name suggests, the two dominant species for the MF1 forest type are *P. totara* and *A. excelsus* subsp. *excelsus. P. totara, P. taxifolia, D. dacrydioides,* and *Knightia excelsa* can be found within the emergent layer of this forest type (Singers & Rogers, 2014). Within the subcanopy layer, abundant *A. excelsus* subsp. *excelsus* and *M. ramiflorus* can be found along with *Nestegis* spp., *Plagianthus regius* subsp. *regius, S. tetraptera, Pittosporum eugenioides* (Singers & Rogers, 2014).

Eight of the remnants included in the present study were predicted to have been covered in the MF1 forest type prior to human arrival (Singers, 2018). Two of these sites TT-4 (Figure 4.1) and TT-5 contained both of the diagnostic species, *P. totara, A. excelsus* subsp. *excelsus*. Also present at both of the sites were *K. excelsa, D. dacrydioides, M. ramiflorus, S. tetraptera,* and *P. eugenioides,* giving further evidence that these two sites currently fit the MF1 forest type. With the exception of *A. excelsus* subsp. *excelsus* at TK-6, no diagnostic species for the MF1 forest type were present at NG-3, NG-7, or the Tutaekuri River sites where the forest type was predicted to have been present historically

(Singers, 2018). The presence of *M. ramiflorus* at all of the sites, *S. tetraptera* at NG-3, NG-7, TK-6, and TK-7, and *P. regius* subsp. *regius* at TK-5, could indicate that these sites would be suitable for the MF1 forest type. Further evidence of this is the fact that at least a portion of all 6 sites contained a hillslope. These results suggest that the MF1 forest type could be used as an ecological reference for the restoration of NG-3, NG-7, the Tutaekuri River sites TT-4 and TT-5.

Figure 4.1: Mature *P. totara* at site TT-4.

Remnants of the swamp forest type, *D. dacrydioides* forest (MF4; Figure 4.2), are few in number within the Hawke's Bay region (Singers, 2018). It is likely that the MF4 forest types would have covered 30,905 ha of the Hawke's Bay in pre-human times (Leathwick, 2017). Presently, this area has drastically reduced to 398 ha (Leathwick, 2017). Areas containing the MF4 forest type will have a similar semi-arid climate to the MF1 forest type (Singers & Rogers, 2014). The MF4 forest type can be found in areas with poor-draining gley and organic soils and seasonally high moisture deficits, that are drought-prone and have an annual rainfall below 800 mm (Singers & Rogers, 2014; Singers, 2018). Recent alluvial terraces are where the MF4 forest can be expected (Singers & Rogers, 2014). *D. dacrydioides* dominates the MF4 forest type (Singers & Rogers, 2014).

Other species usually present within this forest type include, *P. taxifolia*, *P. regius* subsp. *regius*, *S. tetraptera*, *Elaeocarpus hookerianus*, *M. ramiflorus*, and *P. eugenioides* (Singers & Rogers, 2014). The subcanopy is usually sparse, and commonly found in the understory are divaricating shrubs (Singers & Rogers, 2014). Importantly, the absence of *Laurelia novae-zelandiae* at a site and in the pollen record, is an important factor for identification of the MF4 forest type as this is the differentiation between MF4 and *D. dacrydioides*, *L. novae-zelandiae* forest (WF8; Singers, 2018).

Two of the remnants in the present study, NG-3 and MK-3, were predicted to have been covered, at least in part, by the MF4 forest type in pre-human times (Singers, 2018). *D. dacrydioides* was not present at either site. With the exception of *M. ramiflorus*, none of the other species associated with the MF4 forest type were present at NG-3 or MK-3. While NG-3 had terrace segments, the soils were well drained, and the annual rainfall was greater than 800 mm. Based on these results, MK4 may not be a suitable ecological reference for NG-3. At MK-3, the annual rainfall was below 800 mm, the soils were saturated with water and had poor drainage. The site was situated on a terrace, and a known MF4 remnant, the Tukituki Scenic Reserve (Singers & Rogers, 2014), is located approximately 4 km away from the site, giving evidence that the MF4 forest type could be used as an ecological reference for the restoration of MF4.

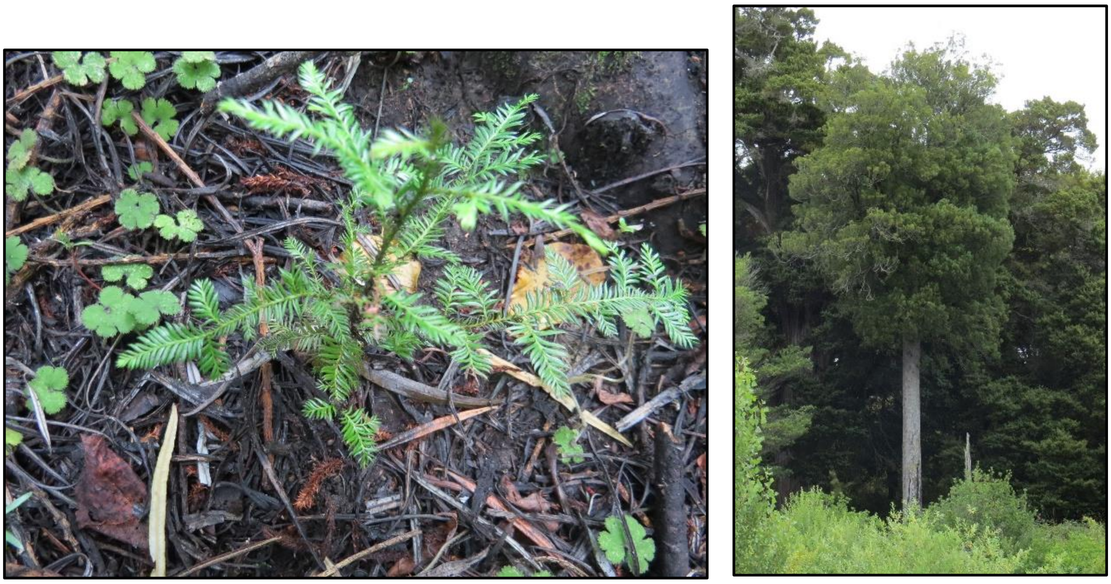


Figure 4.2: Juvenile (left) and mature (right) *D. dacrydioides* at site TT-4.

D. dacrydioides, *P. totara*, *P. taxifolia* forest (WF2-2) in pre-human times, likely covered 59,747 ha within the Hawke's Bay region (Leathwick, 2017). Presently, the forest type has been reduced to 2,192 ha (Leathwick, 2017). Similar to MF4, WF2-2 occurs at sites with gley soils that are imperfectly drained and an annual rainfall >1100 mm (Singers, 2017, Leathwick, 2017). In pre-human times, WF2-2 would have occurred on sites with Holocene age river deposits, and along rivers and streams with alluvial soils (Leathwick, 2017). WF2-2 was not included in the Singers and Rogers (2014) classification. Singers (2018) put forward the potential description of *D. dacrydioides*, *P. totara*, *P. taxifolia*, *E. hookerianus, N. cunninghamii, N. lanceolata*, *A. excelsus* subsp. *excelsus*, *B. tawa, S. microphylla*, and divaricating shrubs, among others.

Within the present study, all of the Ngaruroro Rivers sites, as well as TT-4 and TT-5 (Figure 4.3) were predicted to have been covered in WF2-2 in pre-human times (Singers, 2018). The Ngaruroro River sites, and TT-4 had an annual rainfall of <1100 mm, and well drained soils. None of the Ngaruroro River sites, with the exception of *A. excelsus* subsp. *excelsus* at NG-5 and NG-7, contained any of the diagnostic species or species known to be present within the WF2-2 forest type. Found within TT-4 were two of the diagnostic species *D. dacrydioides*, *P. totara*, as well as *A. excelsus* subsp. *excelsus*. However, none of the other WF1 species were present at the site. These results suggest that the WF2-2 forest type may not be a suitable ecological reference for the Ngaruroro River sites and TT-4. TT-5 had an annual rainfall >1100 mm, and while the soils had good drainage there was silt and gravel present in some of the plots. All three diagnostic species and *A. excelsus* subsp. *excelsus* were present at TT-5. Based on these results, the WF2-2 forest type could be used as an ecological reference for the restoration of TT-5.

Figure 4.3: *P. taxifolia* at site TT-5.

The extent of *A. excelsus* subsp. *excelsus, M. laetum* forest (WF1) within the Hawke's Bay has been greatly reduced over time, with very little remaining in the region (Singers, 2018). The forest type presently covers 63.1 ha of land, compared to the 2,908 ha that the forest type likely covered in pre-human times (Leathwick, 2017). The WF, or warm forests, experience mean summer temperatures between 17.5 and 22.5° C (Singers & Rogers, 2014). WF1 can usually be found on the slopes and crests of coastal hills and cliffs (Singers & Rogers, 2014). Broadleaved species including, *A. excelsus* subsp. *excelsus, M. laetum, M. ramiflorus, P. arboreus, M. australis, Pennantia corymbosa, S. tetraptera*, and *Olearia paniculata*, are included in the WF1 forest type (Singers & Rogers, 2014). *D. dacrydioides, P. totara*, and *P. taxifolia*, may also be occasionally found within the forest type (Singers & Rogers, 2014). Presently, many WF1 remnants are now dominated by *C. laevigatus* (Singers & Rogers, 2014, Singers, 2018), which was likely introduced to such sites by human means (Stowe, 2003).

While none of the sites within the present study were predicted to have been covered by the WF1 forest type in pre-human times, some of the sites may be suited to this forest type. NG-5 (Figure 4.4) and NG-7 both contained *A. excelsus* subsp. *excelsus, M. laetum*, and *C. laevigatus* and were situated on hillslopes. Both sites contained *M. ramiflorus* and *S. tetraptera*, and NG-7 contained *M. australis*. These results suggest that the WF1 forest type could be used as an ecological reference for the restoration of NG-5 and NG-7.

Figure 4.4: *A. excelsus* at site NG-5.

The ecological references mentioned above could be used to inform restoration projects involving the 11 sites in the present study and future studies could further explore the suitability of the forest types mentioned above, for the restoration of the sites included in this research. For example, further analysis of the soils, soil types, mean summer temperatures, water deficits, and pollen records could take place.

4.2.7.2 Removal of non-desirable species

In order to further improve the species composition and community structure and shift the dominance from exotic to native species, non-desirable species, such as exotic and site inappropriate species may need to be removed. Traditional methods of removal include chemical, mechanical, and physical control (Kelton & Price, 2009). More progressive methods include biocontrol, which involves the release of biological control species (Schwarzländer *et al*., 2018), the use of invertebrates for weed seed granivory, and the use of pathogenic fungi (Petit *et al*., 2018).

Removal of non-desirable species may also be required where nurse plants are used. Svirz *et al*. (2012) acknowledged that once the native species were of an appropriate size, weed control of the exotic nurse species would need to take place. At this point, a more active approach may need to be adopted and may include the direct removal of all or a portion of the nurse species.

Problematic species such as *C. vitalba*, *R*, *fructicosus*, and *C. selloana*, could be made a priority for removal. The removal of *Salix* spp., particularly after use as nurse species, could be used as an opportunity to test the efficacy of native species for erosion and flood protection.

4.2.8 Risk of forest clearance

As outlined in section 1.2.1 of this thesis, past studies have demonstrated that slope, road density, urban development, and adjacent land use are key predictors of forest loss in temperate forests (Ewers et al., 2006; Echeverría et al., 2007; Thorn et al., 2016; Monks et al., 2019).

If the remnants in the present study follow the trends outlined by Monks *et al*. (2019), then sites like MK-3 and NG-6 that were relatively flat may be at risk of being cleared earlier than the other sites, and sites like TK-5 with a higher average slope, may be at risk of being cleared later than the other sites. The effect of slope on clearance risk would need to be tested in future studies.

As the Ewers *et al*. (2006) study also covered the whole of New Zealand including the Hawke’s Bay region, it is likely that road density may be used as a predictor of forest loss and fragmentation for the sites included in the present study. If this is the case then sites with a high road density, such as MK-3, are at a high risk of being cleared and sites with a low road density, such as NG-7 or TK-6, are likely to experience further fragmentation. For example, MK-3 had one of the highest road densities of the sites included in this research and was in close proximity to a town, Waipukurau, while TK-6 had one of the lowest road densities. Based on the results of Ewers *et al*. (2006) and Thorn *et al*. (2016), it may be likely that MK-3 is at a higher risk of being cleared than TK-6 based on road density alone. Further research is required to understand this risk.

Surrounding land use was not important for explaining the current community structure and species composition of the sites surveyed. However, past studies have demonstrated that in recent times the surrounding land use most closely associated with forest clearance was dairy farming (Ewers *et al.,* 2006; Monks et al., 2019). None of the sites included in the present study were surrounded by dairy farming. Future studies could assess the effects of dairy farming in native riparian forest remnants in the Hawke’s Bay region. In the present study, non-dairy farming was associated with high native species importance and canopy cover, and low exotic species importance and understory density. Plantation forestry was associated with low native species richness and importance, high exotic species richness and importance, as well as medium understory density and canopy cover. Recreation was associated with low native species importance and canopy cover, and high exotic species importance and understory density. Future studies could further explore the relationships between surrounding land use and the community structure and composition of the sites surveyed in this study and assess the probability of clearance for those sites.

4.3 Recommendations for management

Restoration projects involving the 11 sites included in the present study should aim to improve the species composition and community structure of the sites. This should include increasing the native species richness and importance, decreasing the exotic species richness and importance, and increasing the understory density and canopy cover. Methods may be passive such as the use of nurse plants, or active such as canopy manipulation, the control and removal of non-desirable species, and the use of enrichment planting to introduce missing species and to mitigate the effects of lack of seed sources. Key aims of such restoration projects should be to shift the structure of the sites from grassland, shrubland, or treeland to forest, and to shift the dominance from exotic to native species. These aims would result in a new and improved vegetation classification for the sites, compared to the current one.

Restoration projects seeking to utilize more active methods could target sites like NG-6 and MK-3, which have the lowest restoration potential of the 11 sites. These two sites have the least to build on, as the sites contain poor species composition and community structure compared to the other sites. Both NG-6 and MK-3 are also isolated from seed sources, meaning that enrichment planting would be a requirement for the restoration of these two sites.

Restoration projects seeking to employ more passive methods could involve the use of nurse plants. Sites containing potential nurse plants such as *Salix* spp., *U. europaeus*, and *R. fructicosus* may have a higher restoration potential compared to those without, as the presence of nurse plants allows for the introduction of later successional species with reduced competition from light-demanding weeds. This said, the nature of interactions between these exotic species and native woody species needs further investigation to be sure facilitation will occur in the local conditions (abiotic and biotic). Sites such as NG-5 and TK-5 that contain all three of the suggested nurse species could be made a priority for passive restoration projects.

Sites such as NG-3 and TK-7, where the explanatory variables mostly fit the desired levels, could be made a priority for passive restoration projects as these sites already have the most to build on in terms of community structure and species composition, giving them a higher potential for restoration success without the use of active interventions.

Sites TT-4 and TT-5 currently contain all of the diagnostic species from the regionally significant *D. dacrydioides*, *P. totara*, *P. taxifolia* forest type (WF2-2) and *P. totara*, *A. excelsus* subsp. *excelsus* forest type (MF1). These two sites are also in close proximity to the managed forest remnant, Inglis Bush. TT-4 and TT-5 could eventually be planted to join one another as well as Inglis Bush, to create a site of high value.

Being surrounded by non-dairy farming, and having relatively steep slopes, NG-7 and TK-6 may be at a lower risk of clearance in the future, increasing their restoration potential. With a high road density and shallow slope, MK-3 may be at a high risk of being cleared in the future, reducing the restoration potential of the site. Legal protection could be sought for sites like MK-3 with a high risk of clearance in order to prevent future clearance and ensure that restoration would be long term.

4.4 Conclusions and recommendations

Overall, the riparian forest remnants surveyed demonstrated moderate forest health, good soil quality, and a mixture of good and poor community structure and species composition.

Bagged regression tree models indicated that the most important explanatory variables were annual rainfall, elevation, mesotopographic index, road density, slope, and distance from the river. These results are congruent with past studies in temperate forests. In general, sites with a high annual rainfall, moderate to high elevation, high mesotopographic index, moderate to low road density, moderate slope, and were closer to the water's edge had a more desirable species composition and community structure.

The results from the present study indicate that greater restoration investments and more active methodologies are more likely to be needed at sites or portions of a site with an annual rainfall outside of the 1050 mm to 1200 mm desirable range, that are present further than 190 m from the river's edge, have an elevation less than 150 m a.s.l., have a mesotopographic index of greater than 45, a road density of 0.60 km ^{2} or below, and have a slope outside of the 15° to 30° range. At such sites, restoration efforts would need to target the improvement of species composition and community structure and would need to take a more active approach. These efforts could include the addition of desirable species and the removal of undesirable species such as exotic or weeds species. This could be achieved through the use of ecological references, canopy manipulation, nurse plants, weed control and removal, and enrichment planting.

Based on the current community structure and species composition, the sites with the highest restoration potential were TT-4 and TT-5, which could be included in restoration projects seeking to utilize more passive methods that require fewer investments. The sites with the lowest restoration potential were MK-3 and NG-6, which could be included in restoration projects seeking to use more active methods involving greater investments.

Future research could further explore the relationships between the explanatory and response variables measured and adopt other methods for generating models such as random forests to improve model performance. Future research could assess the role that population density and dairy farming/land use intensity play on riparian forest remnants in the Hawke's Bay region. Clearance risk, and the suitability of the ecological references suggested in this research could be further explored in the future. Experiments could be conducted in future studies to determine the efficacy of nurse plants in facilitating recruitment of native woody species in the local conditions and how these compare to results from elsewhere in New Zealand. The use of native species in place of commonly used exotic tree species, such as those from the *Salix* genus, for erosion protection and flood control could be trialled and tested in future research.

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Appendix One: The 26 sites selected through the site selection process and their associated site selection data. Notes from the field checks and whether the site was discarded from the study are also included.

Site Name	Coordinates (NZTM)	Size (ha)	Distance from river (m)	Road Density (km²)	Adjacent land use	Rainfall Depth (mm)	Soil Depth (cm)	Slope Direction (°)	Slope Steepness (°)	Used in study?	Notes:
MK-3	1895938.79 5567915.01	1.09	84.56	0.93 (Medium-Low)	Recreation (Golf Course)	683.4 (Medium-Low)	Deep (>100)	0 (N)	1 (Undulating)	Yes	Waipukurau Golf Club. MK-1 and MK-2, which were also on the golf course land, were ruled out before being assessed against the selection criteria.
NG-1	1931813.92 5609165.29	4.99	345.94	1.58 (High)	Farming non-dairy	614.689 (Low)	Deep (>100)	0 (N)	0 (Undulating)	No	Pakowhai Regional Park. Scattered natives, mostly planted.
NG-2	1923757.20 5610931.66	3.70	38.19	1.17 (High-Medium)	Dairy Farming & Farming non-dairy	657.989 (Medium-Low)	Deep (>100)	0 (N)	1 (Undulating)	No	No natives
NG-3	1897903.88 5616054.40	71.53	0.00	0.87 (Medium-Low)	Plantation Forestry & Farming non-dairy	1039.167 (Medium-High)	Deep & Shallow (>100 & 20-45)	142 (S)	32 (Very Steep)	Yes	Natives mixed in with exotics.

Appendix One (continued): The 26 sites selected through the site selection process and their associated site selection data. Notes from the field checks and whether the site was discarded from the study are also included.

Site Name	Coordinates (NZTM)	Size (ha)	Distance from river (m)	Road Density (km²)	Adjacent land use	Rainfall Depth (mm)	Soil Depth (cm)	Slope Direction (°)	Slope Steepness (°)	Used in study?	Notes:
NG-4	1892622.00 5614988.94	41.30	0.00	0.22 (Low)	Dairy Farming	1165.467 (High)	Moderately deep & very shallow (45-100 & <20)	53 (E)	32 (Very Steep)	No	Natives present. Too steep to survey.
NG-5	1916842.12 5608355.41	0.89	0.00	0.52 (Medium-Low)	Farming non-dairy	670.478 (Medium-Low)	Very Shallow (<20 cm)	161 (S)	9 (Undulating)	Yes	Surveyed during the summer of 2018/2019.
NG-6	1913427.91 5605707.28	0.42	28.36	0.52 (Medium-Low)	Farming non-dairy	670.478 (Medium-Low)	Very Shallow (<20 cm)	0 (N)	1 (Undulating)	Yes	Selected during the summer of 2018/2019.
NG-7	1911222.05 5606119.74	0.26	317.88	0.42 (Low)	Farming non-dairy	702.489 (Medium-Low)	Very Shallow & Moderately Deep (<20 cm & 45-100)	242 (W)	30 (Very Steep)	Yes	Selected during the summer of 2018/2019.

Appendix One (continued): The 26 sites selected through the site selection process and their associated site selection data. Notes from the field checks and whether the site was discarded from the study are also included.

Site Name	Coordinates (NZTM)	Size (ha)	Distance from river (m)	Road Density (km²)	Adjacent land use	Rainfall Depth (mm)	Soil Depth (cm)	Slope Direction (°)	Slope Steepness (°)	Used in study?	Notes:
NG-Spare-1	1914392.92 5606236.88	62.23	0.00	0.74 (Medium-Low)	Dairy Farming	670.478 (Medium-Low)	Very Shallow (<20 cm)	0 (N)	1 (Undulating)	No	Too close to NG-6 and NG-7
NG-Spare-2	1908248.07 5609532.32	14.33	0.00	0.49 (Low)	Dairy Farming	702.489 (Medium-Low)	Very Shallow (<20 cm)	0 (N)	1 (Undulating)	No	Only access is via a vineyard, Omapere road
TK-1	1918266.63 5623249.23	26.01	0.00	0.58 (Medium-Low)	Plantation Forestry & Dairy Farming	814.567 (Medium-Low)	Very shallow (<20 cm)	0 (N)	4 (Undulating)	No	Access from HBRC Mangaone public access point. No natives seen from road/track.
TK-2	1915755.73 5622962.84	24.54	0.00	0.25 (Low)	Farming non-dairy & Dairy Farming	878.756 (High-Medium)	Moderately deep, Very shallow & Shallow (0-100)	128 (E)	10 (Rolling)	No	Access from HBRC Dartmoor public access point. Plot 1 and 2 approx. 2km from access point.

Appendix One (continued): The 26 sites selected through the site selection process and their associated site selection data. Notes from the field checks and whether the site was discarded from the study are also included.

Site Name	Coordinates (NZTM)	Size (ha)	Distance from river (m)	Road Density (km²)	Adjacent land use	Rainfall Depth (mm)	Soil Depth (cm)	Slope Direction (°)	Slope Steepness (°)	Used in study?	Notes:
TK-3	1913824.49 5625065.34	5.33	23.90	0.47 (Low)	Dairy Farming	977.444 (High-Medium)	Moderately deep & Shallow (20-100)	26 (N)	53 (Very Steep)	No	Natives under a pine stand. Too steep to survey.
TK-4	1908358.86 5626814.31	0.86	0.00	0.42 (Low)	Farming non-dairy	1024.989 (High-Medium)	Very shallow (<20 cm)	53 (E)	16 (Rolling)	Yes	Access via Waiwhenua farm stay. Kanuka stand.
TK-5	1915063.89 5624060.86	8.84	11.38	0.40 (Low)	Farming non-dairy	878.756 (High-Medium)	Very Shallow (<20 cm)	136 (S)	37 (Very Steep)	Yes	Access via Fish and Game access. Kanuka stand.
TK-6	1914471.95 5625134.38	14.42	0.00	0.40 (Low)	Farming non-dairy	977.444 (High-Medium)	Moderately Deep (45-100)	180 (S)	53 (Very Steep)	Yes	Natives behind band of poplars and pampas grass. Upstream of TK-5
TK-7	1905776.28 5629395.61	0.78	2.26	0.57 (Medium-Low)	Farming non-dairy	1070.733 (High)	Moderately deep (45-100)	0 (N)	4 (Undulating)	Yes	Kanuka stand. Close to Dampney Road.
TK-Spare-1	1927354.65 5614995.31	1.17	46.33	1.40 (High-Medium)	Farming non-dairy	694.600 (Medium-Low)	No data	0 (N)	0 (Undulating)	No	Lennox park. Native plantings: cabbage trees and flax.

Appendix One (continued): The 26 sites selected through the site selection process and their associated site selection data. Notes from the field checks and whether the site was discarded from the study are also included.

Site Name	Coordinates (NZTM)	Size (ha)	Distance from river (m)	Road Density (km²)	Adjacent land use	Rainfall Depth (mm)	Soil Depth (cm)	Slope Direction (°)	Slope Steepness (°)	Used in study?	Notes:
TK-Spare-2	1908000.23 5628156.93	10.15	26.20	0.36 (Low)	Dairy Farming	1024.989 (High-Medium)	Moderately deep & Shallow (20-100)	233 (W)	14 (Rolling)	No	Access via a quarry.
TT-1	1933798.73 5594840.74	13.84	0.00	0.93 (High-Medium)	Farming non-dairy & Dairy Farming	702.956 (Medium-Low)	Moderately deep & Very shallow (<20 & 5-100)	189 (S)	5 (Undulating)	No	Farmer didn't give permission to cross land. Could not see natives from road.
TT-2	1918468.47 5573214.72	2.70	8.17	0.44 (Low)	Dairy Farming	761.244 (Medium-Low)	Moderately deep (45-100)	257 (W)	26 (Steep)	No	A few natives underneath a pine plantation.
TT-3	1900172.28 5567986.24	4.33	102.12	1.75 (High)	Dairy Farming	636.156 (Low)	Very Shallow (<20)	0 (N)	0 (Undulating)	No	Tukituki Scenic Reserve.
TT-4	1882788.68 5577058.29	12.69	0.00	0.64 (Medium-Low)	Farming non-dairy	996.9 (High-Medium)	Moderately deep & Shallow (20-100)	0 (N)	3 (Undulating)	Yes	Access via Fish and Game access.

Appendix One (continued): The 26 sites selected through the site selection process and their associated site selection data. Notes from the field checks and whether the site was discarded from the study are also included.

Site Name	Coordinates (NZTM)	Size (ha)	Distance from river (m)	Road Density (km²)	Adjacent land use	Rainfall Depth (mm)	Soil Depth (cm)	Slope Direction (°)	Slope Steepness (°)	Used in study?	Notes:
TT-5	1882085.91 5578522.68	5.03	0.00	0.99 (Medium-Low)	Farming non-dairy	1312.567 (High)	Shallow (20-45)	45 (N)	4 (Undulating)	Yes	Upstream of TT-4
TT-Spare-1	1937363.17 5607567.15	4.84	76.58	1.63 (High)	Dairy Farming & Farming non-dairy	595.857 (Low)	Shallow (20-45)	0 (N)	0 (Undulating)	No	No natives.
TT-Spare-2	1936578.62 5604775.87	12.64	0.00	1.73 (High)	Farming non-dairy	595.857 (Low)	Very shallow (<20)	0 (N)	0 (Undulating)	No	Couldn't see natives from track; mostly willows, grass, and vines.

Appendix Two: RECCE plot data from all sites and plots.

Plot	River	Date	Plot size (m)	GPS ref.	GPS ref.	Precision (m)
MK-3_1	Tukituki	30/01/2020	10 x 10	1895940	5567888	4
MK-3_2	Tukituki	30/01/2020	10 x 10	1896000	5567928	20
MK-3_5	Tukituki	29/01/2020	10 x 10	1895861	5567959	10
NG-3_2	Ngaruroro	5/02/2020	10 x 10	1897447	5616020	11
NG-3_3	Ngaruroro	6/02/2020	10 x 10	1897944	5616019	19
NG-3_7	Ngaruroro	6/02/2020	10 x 10	1897332	5615994	7
NG-5_1	Ngaruroro	11/12/2018	10 x 10	1916884	5608430	4
NG-5_2	Ngaruroro	11/12/2018	10 x 10	1916815	5608306	16
NG-5_4	Ngaruroro	18/12/2018	10 x 10	1916903	5608622	3
NG-6_1	Ngaruroro	22/01/2020	10 x 10	1913418	5605689	4
NG-6_2	Ngaruroro	22/01/2020	10 x 10	1913408	5605749	1
NG-6_3	Ngaruroro	22/01/2020	10 x 10	1913391	5605749	7
NG-7_1	Ngaruroro	21/01/2020	10 x 10	1911218	5606105	1
NG-7_2	Ngaruroro	22/01/2020	10 x 10	1911228	5606084	1
NG-7_3	Ngaruroro	22/01/2020	10 x 10	1911208	5606145	4
TK-4_1	Tutaekuri	14/02/2020	10 x 10	1908296	5626829	0
TK-4_2	Tutaekuri	14/02/2020	10 x 10	1908357	5626800	0
TK-4_3	Tutaekuri	14/02/2020	10 x 10	1908376	5626810	0
TK-5_1	Tutaekuri	11/02/2020	10 x 10	1915257	5624077	3
TK-5_2	Tutaekuri	11/02/2020	10 x 10	1915357	5624073	7
TK-5_3	Tutaekuri	11/02/2020	10 x 10	1914957	5623973	3
TK-6_2	Tutaekuri	12/02/2020	10 x 10	1914641	5625011	4
TK-6_5	Tutaekuri	12/02/2020	10 x 10	1914143	5625211	0
TK-6_6	Tutaekuri	12/02/2020	10 x 10	1914241	5625111	4
TK-7_1	Tutaekuri	13/02/2020	10 x 10	1905751	5629356	0
TK-7_2	Tutaekuri	13/02/2020	10 x 10	1905781	5629394	0
TK-7_3	Tutaekuri	13/02/2020	10 x 10	1905831	5629394	0
TT-4_2	Tukituki	15/01/2020	10 x 10	1882708	5577150	1
TT-4_4	Tukituki	16/01/2020	10 x 10	1883109	5576851	2
TT-4_5	Tukituki	15/01/2020	10 x 10	1882509	5577250	8
TT-5_1	Tukituki	7/02/2020	10 x 10	1882013	5578528	2
TT-5_2	Tukituki	7/02/2020	10 x 10	1882064	5578528	7
TT-5_5	Tukituki	7/02/2020	10 x 10	1881864	5578628	8

Appendix Three: Bird species seen and heard during the five-minute bird counts at each plot.

Plot	Species	Seen	Heard	Total
MK-3_1	*Alauda arvensis*	0	1	1
	Gerygone igata	0	2	2
	Rhipidura fuliginosa	0	1	1
	UNID	0	2	1
	Zosterops lateralis	0	1	1
MK-3_2	*R. fuliginosa*	1	1	2
	UNID	2	3	5
MK-3_5	*A. arvensis*	0	1	1
	G. igata	0	1	1
	R. fuliginosa	0	1	1
	Turdus merula	0	12	12
	UNID	0	4	1
NG-3_2	*Himantopus himantopus*	1	2	3
	Larus dominicanus	0	2	2
	Prosthemadera novaeseelandiae	0	2	2
	R. fuliginosa	0	1	1
	UNID	0	1	1
NG-3_3	*Circus approximans*	1	0	1
	Gymnorhina tibicen	1	2	3
	L. dominicanus	0	1	1
	P. novaeseelandiae	0	1	1
	R. fuliginosa	0	1	1
	Turdus philomelos	1	0	1
	UNID	4	4	8
NG-3_7	*P. novaeseelandiae*	0	1	1
	T. merula	0	2	2
	UNID	0	3	3
	Z. lateralis	0	3	3
NG-5_1	*G. igata*	0	1	1
	R. fuliginosa	0	1	1
	UNID	0	1	1
NG-5_2	*A. arvensis*	1	0	1
	Carduelis carduelis	1	0	1
	Carduelis chloris	1	0	1
	L. dominicanus	1	0	1
	R. fuliginosa	1	0	1
	T. merula	1	0	1
NG-5_4	*Acridotheres tristis*	1	0	1
	UNID	1	0	1
NG-6_1	*L. dominicanus*	0	2	2
	UNID	0	3	1

Appendix Three (continued): Bird species seen and heard during the five-minute bird counts at each plot.

Plot	Species	Seen	Heard	Total
NG-6_2	*A. arvensis*	0	2	2
	Egretta novaehollandiae	1	0	1
	Emberiza citrinella	1		1
	G. tibicen	0	1	1
	L. dominicanus	1	1	2
	UNID	3	1	3
NG-6_3	*Phasianus colchicus*	0	1	1
	UNID	0	2	1
	Z. lateralis	2	0	2
NG-7_1	UNID	0	6	6
NG-7_2	*G. igata*	0	1	1
	R. fuliginosa	0	2	2
	Todiramphus sanctus	0	1	1
	UNID	0	4	4
	Z. lateralis	4	0	4
NG-7_3	*R. fuliginosa*	0	3	3
	UNID	0	3	3
TK-4_1	*H. himantopus*	1	1	2
	R. fuliginosa	0	3	3
	UNID	3	3	6
TK-4_2	*G. igata*	2	1	3
	G. tibicen	0	2	2
	R. fuliginosa	0	1	1
	UNID	0	4	4
TK-4_3	*G. igata*	1	1	2
	H. himantopus	0	1	1
	R. fuliginosa	0	3	3
	T. merula	0	1	1
	UNID	0	5	1
TK-5_1	*G. igata*	0	1	1
	T. merula	0	1	1
	UNID	0	6	6
TK-5_2	*G. igata*	1	0	1
	Hirundo neoxena	2	0	2
	UNID	0	3	3
TK-5_5	*G. igata*	0	1	1
	H. himantopus	0	2	2
	R. fuliginosa	2	1	3
	UNID	0	2	2

Appendix Three (continued): Bird species seen and heard during the five-minute bird counts at each plot.

Plot	Species	Seen	Heard	Total
TK-6_2	*G. igata*	0	2	2
	G. tibicen	0	1	1
	P. novaeseelandiae	0	2	2
	R. fuliginosa	1	2	3
	T. merula	0	1	1
	UNID	0	3	3
TK-6_5	*G. igata*	0	1	1
	R. fuliginosa	0	1	1
	UNID	0	3	3
	Z. lateralis	0	3	3
TK-6_6	*Ninox novaeseelandiae*	1	0	1
	P. novaeseelandiae	0	1	1
	T. merula	0	2	2
	UNID	0	2	2
TK-7_1	*P. novaeseelandiae*	0	1	1
	R. fuliginosa	1	1	2
	UNID	0	3	3
TK-7_2	*R. fuliginosa*	2	1	3
TK-7_3	*G. igata*	0	1	1
	P. novaeseelandiae	0	1	1
	R. fuliginosa	0	1	1
	UNID	1	0	1
TT-4_2	*G. igata*	0	1	1
	P. novaeseelandiae	0	1	1
	R. fuliginosa	1	2	3
	UNID	0	2	2
TT-4_4	*P. novaeseelandiae*	0	2	2
	R. fuliginosa	0	2	2
	T. merula	0	1	1
	UNID	0	4	4
TT-4_5	*G. igata*	0	1	1
	R. fuliginosa	1	2	3
	UNID	0	2	2
TT-5_1	*G. igata*	0	2	2
	G. tibicen	0	1	1
	Hemiphaga novaeseelandiae	0	1	1
	R. fuliginosa	0	2	2
	T. merula	0	1	1
	UNID	0	3	3

Appendix Three (continued): Bird species seen and heard during the five-minute bird counts at each plot.

Plot	Species	Seen	Heard	Total
TT-5_2	*G. tibicen*	0	1	
	P. novaeseelandiae	0	2	2
	R. fuliginosa	1	1	2
	T. merula	0	2	2
	UNID	0	5	5
TT-5_5	*G. igata*	0	2	2
	P. novaeseelandiae	0	1	1
	R. fuliginosa	0	1	1
	T. merula	0	3	3
	UNID	0	2	2
	Z. lateralis	0	1	1

Appendix Four: Five-minute bird count data.

Plot	Date	Start time	Temperature	Wind	Other Noise	Sun	Precipitation type	Precipitation value	Notes:
MK-3 P1	30/01/2020	9:58:00	4	0	1	5	N	0	
MK-3 P2	30/01/2020	11:19:00	4	0	1	5	N	0	
MK-3 P5	29/01/2020	17:04:00	3	0	1	0	R	1	*C. approximans*, *R. fuliginosa* & *Z. lateralis* seen during time at plot.
NG-3 P2	5/02/2020	15:42:00	4	0	1	5	N	0	Sitting in a *Melicytus ramiflorus* after the count: 2x *G. igata*, *R. fuliginosa*, & 2x *Z. lateralis*.
NG-3 P3	6/02/2020	10:14:00	4	0	1	5	N	0	Bird song continuous
NG-3 P7	6/02/2020	13:06:00	4	0	1	5	N	0	*G. igata* seen in plot on arrival
NG-5 P1	11/12/2018	12:15:00	3	0	1	5	N	0	*Chrysococcyx lucidus* heard from plot
NG-5 P2	11/12/2018	12:48:00	6	1	1	5	N	0	
NG-5 P4	18/12/2018	13:04:00	6	0	1	5	N	0	*Ardea modesta* seen.
NG-6 P1	22/01/2020	14:38:00	5	0	1	5	N	0	
NG-6 P2	22/01/2020	12:59:00	5	0	1	5	N	0	
NG-6 P3	22/01/2020	12:27:00	5	0	1	5	N	0	
NG-7 P1	21/01/2020	15:28:00	4	0	1	0	N	0	Overcast. *R. fuliginosa*, P. novaeseelandiae, *G. igata* seen at plot
NG-7 P2	21/01/2020	16:51:00	3	0	1	0	N	0	Overcast. *N. novaeseelandiae*, *R. fuliginosa*, *Z. lateralis*, P. novaeseelandiae seen at plot
NG-7 P3	22/01/2020	10:39:00	4	0	1	5	N	0	P. novaeseelandiae, *R. fuliginosa*, *Circus approximans*, *Callipepla californica*, *E. citrinella*, *G. tibicen* seen at and around plot. *G. igata* heard at plot.

Appendix Four (continued): Five-minute bird count data.

Plot	Date	Start time	Temperature	Wind	Other Noise	Sun	Precipitation type	Precipitation value	Notes:
TK-4 P1	14/02/2020	8:29:00	3	0	1	5	N	0	Potential *H. himantopus* nesting site; displaying territorial behaviour and regularly scanning the surrounding area.
TK-4 P2	14/02/2020	9:20:00	3	0	1	5	N	0	
TK-4 P3	14/02/2020	9:52:00	3	0	1	5	N	0	
TK-5 P1	11/02/2020	14:31:00	4	0	1	5	N	0	*Tadorna variegata*, *H. himantopus* seen by the plot.
TK-5 P2	11/02/2020	15:21:00	4	0	1	5	N	0	
TK-5 P5	11/02/2020	16:58:00	4	0	1	5	N	0	*P. novaeseelandiae* and 2x *R. fuliginosa* seen at plot
TK-6 P2	12/02/2020	10:37:00	3	0	1	5	N	0	*R. fuliginosa* & *P. novaeseelandiae* seen at plot. Continuous birdsong during the whole time spent at plot.
TK-6 P5	12/02/2020	12:56:00	3	0	1	5	N	0	*P. colchicus*, *R. fuliginosa*, and *G. igata* seen at and around plot.
TK-6 P6	12/02/2020	14:23:00	3	0	1	5	N	0	H. novaeseelandiae, *P. novaeseelandiae*, *G. igata* and *N. novaeseelandiae* seen at or around the plot.
TK-7 P1	13/02/2020	11:53:00	3	0	1	5	N	0	
TK-7 P2	13/02/2020	13:05:00	4	0	1	5	N	0	
TK-7 P3	13/02/2020	14:21:00	5	0	1	5	N	0	
TT-4 P2	15/01/2020	17:47:00	3	0	0	0	N	0	H. novaeseelandiae heard and many *R. fuliginosa* seen. Overcast

Appendix Four (Continued): Five-minute bird count data.

Plot	Date	Start time	Temperature	Wind	Other Noise	Sun	Precipitation type	Precipitation value	Notes:
TT-4 P4	16/01/2020	12:25:00	3	0	0	0	N	0	H. novaeseelandiae sitting in mahoe tree. 3x *R. fuliginosa* seen. Overcast
TT-4 P5	15/01/2020	14:09:00	4	0	0	0	N	0	*R. fuliginosa* & H. novaeseelandiae seen and heard during time at site
TT-5 P1	7/02/2020	11:25:00	3	0	0	0	N	0	Overcast. Almost continuous calls with some quiet spells.
TT-5 P2	7/02/2020	12:52:00	3	0	1	0	N	0	Overcast
TT-5 P5	7/02/2020	15:16:00	3	0	1	5	N	0	

Appendix Five: Species list for all sites, presented in alphabetical order based on species name.

Structural Class	NVS code	Species	Authority	Threat Classification	Bio Status	MK-3	NG-3	NG-5	NG-6	NG-7	TK-4	TK-5	TK-6	TK-7	TT-4	TT-5
Dicotyledonous Trees & Shrubs	ACAMEL	Acacia melanoxylon (blackwood)	R.Br.		Exotic				✓							
Dicotyledonous Trees & Shrubs	ACEPSE	Acer pseudoplatanus (sycamore)	L.		Exotic		✓									
Ferns	ADICUN	Adiantum cunninghamii (common maidenhair)	Hook.	Not Threatened	Endemic		✓			✓			✓	✓	✓	
Dicotyledonous Trees & Shrubs	ALEEXC	Alectryon excelsus subsp. excelsus (titoki)	Gaertn.	Not Threatened	Endemic			✓		✓			✓		✓	✓
Dicotyledonous Trees & Shrubs	AMEALN	Amelanchier alnifolia (saskatoon)	Coville		Exotic							✓				
Dicotyledonous Trees & Shrubs	ARISER	Aristotelia serrata (wineberry)	(J.R.Forst. et G.Forst.) W.R.B.Oliv.	Not Threatened	Endemic		✓							✓		
Ferns	ASPBUL	Asplenium bulbiferum (hen and chicken fern)	G. Forst.	Not Threatened	Endemic			✓							✓	✓

Appendix Five (continued): Species list for all sites, presented in alphabetical order based on species name.

Structural Class	NVS code	Species	Authority	Threat Classification	Bio Status	MK -3	NG -3	NG -5	NG -6	NG -7	TK -4	TK -5	TK -6	TK -7	TT -4	TT -5
Ferns	ASPFLB	*Asplenium flabellifolium* (necklace fern)	*Cav.*	Not Threatened	Native						✓					
Ferns	ASPOBL	*Asplenium oblongifolium* (shinning spleenwort)	*Colenso*	Not Threatened	Endemic		✓									
Monocotyledonous Herbs	COLHAS	*Astelia hastata* (widow maker)	*Colenso*	Not Threatened	Endemic											✓
Ferns	BLECHA	*Austroblechnum laneceolatum* (nini)	*(R.Br.) Gasper et V.A.O.Dittrich*	Not Threatened	Native	✓	✓					✓				✓
Ferns	AZOFIL	*Azolla rubra* (pacific azolla)	*R.Br.*	Not Threatened	Native	✓										
Dicotyledonous Trees & Shrubs	BERGLA	*Berberis glaucocarpa* (barberry)	*Stapf*		Exotic					✓						
Dicotyledonous Trees & Shrubs	BETPEN	*Betula pendula* (silver birch)	*Roth*		Exotic							✓				
Dicotyledonous Trees & Shrubs	BRAREP	*Brachyglottis repanda* (rangiora)	*J.R.Forst. et G.Forst.*	Not Threatened	Endemic		✓	✓				✓	✓	✓	✓	✓

Appendix Five (continued): Species list for all sites, presented in alphabetical order based on species name.

Structural Class	NVS code	Species	Authority	Threat Classification	Bio Status	MK-3	NG-3	NG-5	NG-6	NG-7	TK-4	TK-5	TK-6	TK-7	TT-4	TT-5
Dicotyledonous Trees & Shrubs	BUDDAV	Buddleja davidii (buddleia)	Franch.		Exotic									✓	✓	
Dicotyledonous Lianes and Related Trailing Plants	CALSIL	Calystegia silvatica subsp. disjuncta (great bindweed)	Brummit		Exotic		✓		✓	✓		✓				
Dicotyledonous Lianes and Related Trailing Plants	CALTUG	Calystegia tuguriorum (NZ bindweed)	(G.Forst.) Hook.f.	Not Threatened	Native		✓	✓	✓			✓				
Dicotyledonous Herbs - Composites	CARNUT	Carduus nutans (nodding thistle)	L.		Exotic		✓	✓		✓						
Sedges	CARDIV	Carex divulsa (grey sedge)	Stokes		Exotic			✓								
Sedges	CARGEM	Carex geminata (cutty grass)	Schkuhr	Not Threatened	Endemic								✓			
Sedges	CARVIR	Carex virgata (pukio)	Sol. ex Boott	Not Threatened	Endemic	✓										

Appendix Five (continued): Species list for all sites, presented in alphabetical order based on species name.

Structural Class	NVS code	Species	Authority	Threat Classification	Bio Status	MK-3	NG-3	NG-5	NG-6	NG-7	TK-4	TK-5	TK-6	TK-7	TT-4	TT-5
Dicotyledonous Herbs - Composites	CIRARV	*Cirsium arvense* (californian thistle)	*(L.) Scop.*		Exotic							✓				
Dicotyledonous Herbs - Composites	CIRVUL	*Cirsium vulgare* (scotch thistle)	*(Savi) Ten.*		Exotic	✓	✓			✓			✓		✓	
Dicotyledonous Lianes and Related Trailing Plants	CLEPAN	*Clematis paniculata* (white clematis)	*J.F.Gmel.*	Not Threatened	Endemic			✓								
Dicotyledonous Lianes and Related Trailing Plants	CLEVIT	*Clematis vitalba* (old man's beard)	*L.*		Exotic	✓		✓	✓	✓					✓	✓
Dicotyledonous Herbs other than Composites	CLINNEP	*Clinopodium nepeta* (lesser calamint)	*(L.) Kuntze*		Exotic						✓		✓			
Dicotyledonous Herbs other than Composites	CONARV	*Convulvulus arvensis* (field bindweed)	*L.*		Exotic		✓		✓	✓					✓	✓
Dicotyledonous Trees & Shrubs	COPGRA	*Coprosma grandifolia* (kanono)	*Hook.f.*	Not Threatened	Endemic										✓	

Appendix Five (continued): Species list for all sites, presented in alphabetical order based on species name.

Structural Class	NVS code	Species	Authority	Threat Classification	Bio Status	MK -3	NG -3	NG -5	NG -6	NG -7	TK -4	TK -5	TK -6	TK -7	TT -4	TT -5
Dicotyledonous Trees & Shrubs	COPROB	*Coprosma robusta* (karamu)	*Raoul*	Not Threatened	Endemic	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓
Dicotyledonous Trees & Shrubs	COPROT	*Coprosma rotundifolia* (round-leaved coprosma)	*A.Cunn.*	Not Threatened	Endemic						✓			✓		✓
Monocotyledonous Trees and Shrubs	CORAUS	*Cordyline australis* (cabbage tree)	*(Forst.f.) Endl.*	Not Threatened	Endemic	✓		✓	✓	✓		✓	✓		✓	✓
Dicotyledonous Trees & Shrubs	CORAVA	*Coriaria arborea var. arborea* (tree tutu)	*R.Linds.*	Not Threatened	Endemic		✓							✓	✓	✓
Grasses	CORSEL	*Cortaderia selloana* (pampas grass)	*(Schult. & Schult.f.) Asch. & Graebn.*		Exotic					✓	✓	✓	✓	✓		
Dicotyledonous Trees & Shrubs	CORLAE	*Corynocarpus laevigatus* (karaka)	*J.R.Forst. et G.Forst.*	Not Threatened	Endemic			✓		✓					✓	
Dicotyledonous Trees & Shrubs	COTFRAN	*Cotoneaster franchetti* (cotoneaster)	*Bois*		Exotic			✓							✓	
Ferns	BLEFLU	*Cranfillia fluviatilis* (kiwakiwa)	*(R.Br.) Gasper et V.A.O.Dittrich*	Not Threatened	Native										✓	

Appendix Five (continued): Species list for all sites, presented in alphabetical order based on species name.

Structural Class	NVS code	Species	Authority	Threat Classification	Bio Status	MK-3	NG-3	NG-5	NG-6	NG-7	TK-4	TK-5	TK-6	TK-7	TT-4	TT-5
Dicotyledonous Trees & Shrubs	CRAMON	*Crataegus monogyna* (hawthorn)	*Jacq.*		Exotic		✓		✓		✓					
Dicotyledonous Herbs - Composites	CRECAP	*Crepis capillaris* (hawksbeard)	*(L.) Wallr.*		Exotic				✓							
ferns	CYACOL	*Cyathea colensoi* (rough tree fern)	*(Hook.f.) Domin*	Not Threatened	Endemic										✓	
Ferns	CYADEA	*Cyathea dealbata* (silverfern)	*(G.Forst.) Sw.*	Not Threatened	Endemic											✓
Ferns	CYAMED	Cyathea medullaris (mamaku)	*(G. Forst.) Sw.*	Not Threatened	Native			✓				✓			✓	✓
Sedges	CYPERA	*Cyperus eragrostis* (umbrella sedge)	*Lam.*		Exotic				✓							
Gymnosperm Trees & Shrubs	DACDAC	*Dacrycarpus dacrydioides* (kahikatea)	*(A.Rich.) de Laub.*	Not Threatened	Endemic										✓	✓

Appendix Five (continued): Species list for all sites, presented in alphabetical order based on species name.

Structural Class	NVS code	Species	Authority	Threat Classification	Bio Status	MK-3	NG-3	NG-5	NG-6	NG-7	TK-4	TK-5	TK-6	TK-7	TT-4	TT-5
Dicotyledonous Herbs other than Composites	DAUCAR	*Daucus carota* (wild carrot)	*L.*		Exotic				✓						✓	
Dicotyledonous Herbs other than Composites	DIGPUR	*Digitalis purpurea* (purple foxglove)	*L.*		Exotic								✓			
Dicotyledonous Herbs - Composites	CONSUM	Erigeron sumatrensis	*Retz.*		Exotic							✓			✓	
Dicotyledonous Herbs - Composites	CONSUM	*Erigeron sumatrensis* (broad-leaved fleabane)	*Retz.*		Exotic		✓									
Dicotyledonous Herbs other than Composites	ERYGUT	*Erythranthe guttata* (seep monkeyflower)	*(DC.) G.L.Nesom*		Exotic	✓										
Grasses	EXOTICGRASS	Exotic Grass			Exotic	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓
Dicotyledonous Herbs other than Composites	FOEVUL	*Foeniculum vulgare* (fennel)	*Mill.*		Exotic				✓	✓						

Appendix Five (continued): Species list for all sites, presented in alphabetical order based on species name.

Structural Class	NVS code	Species	Authority	Threat Classification	Bio Status	MK-3	NG-3	NG-5	NG-6	NG-7	TK-4	TK-5	TK-6	TK-7	TT-4	TT-5
Dicotyledonous Herbs other than Composites	GALAPA	*Galium aparine* (cleavers)	*L.*		Exotic			✓								
Dicotyledonous Trees & Shrubs	GENRUP	*Geniostoma ligustrifolium var. ligustrifolium* (hangehange)	*A.Cunn.*	Not Threatened	Endemic		✓							✓	✓	✓
Dicotyledonous Lianes and Related Trailing Plants	HEDHEL	*Hedera helix* (english ivy)	*L.*		Exotic			✓								
Dicotyledonous Trees & Shrubs	HEDARB	*Hedycarya arborea* (pigeonwood)	*J.R.Forst. et G.Forst.*	Not Threatened	Endemic										✓	✓
Dicotyledonous Herbs other than Composites	HYDMVM	*Hydrocotyle moschata var. moschata* (hairy pennywort)	*G.Forst.*	Not Threatened	Endemic								✓		✓	

Appendix Five (continued): Species list for all sites, presented in alphabetical order based on species name.

Structural Class	NVS code	Species	Authority	Threat Classification	Bio Status	MK-3	NG-3	NG-5	NG-6	NG-7	TK-4	TK-5	TK-6	TK-7	TT-4	TT-5
Dicotyledonous Herbs other than Composites	HYPAND	*Hypericum androsaemum* (tutsan)	*L.*		Exotic										✓	
Monocotyledonous Herbs	IRIFOE	Iris foetidissima	*L.*		Exotic										✓	
Dicotyledonous Trees & Shrubs	KNIEXC	*Knightia excelsa* (rewarewa)	*R.Br.*	Not Threatened	Endemic										✓	✓
Dicotyledonous Trees & Shrubs	KUNROB	*Kunzea robusta* (kanuka)	*de Lange et Toelken*	Threatened - Nationally Vulnerable	Endemic				✓		✓	✓	✓	✓	✓	
Dicotyledonous Herbs - Composites	LACMUR	*Lactuca muralis*wall lettuce)	*(L.) Gaertn.*		Exotic					✓			✓		✓	
Dicotyledonous Herbs - Composites	LACVIR	*Lactuca virosa* (acrid lettuce)	*Habl.*		Exotic				✓	✓					✓	

Appendix Five (continued): Species list for all sites, presented in alphabetical order based on species name.

Structural Class	NVS code	Species	Authority	Threat Classification	Bio Status	MK-3	NG-3	NG-5	NG-6	NG-7	TK-4	TK-5	TK-6	TK-7	TT-4	TT-5
Dicotyledonous Herbs - Composites	LAPCOM	*Lapsana communis* (nipplewort)	*L.*		Exotic					✓						
Grasses	LOLPER	*Lolium perenne* (ryegrass)	*L.*		Exotic			✓								
Dicotyledonous Lianes and Related Trailing Plants	LONJAP	*Lonicera japonica* (Japanese honeysuckle)	*Thunb.*		Exotic				✓	✓						
Dicotyledonous Trees & Shrubs	LUPARB	*Lupinus arboreus* (tree lupin)	*Sims*		Exotic		✓							✓	✓	
Dicotyledonous Herbs other than Composites	MALSYL	*Malva sylvestris* (large-flowered mallow)	*L.*		Exotic					✓						
Dicotyledonous Trees & Shrubs	MELRAM	*Melicytus ramiflorus* (mahoe)	*J.R.Forst. et G.Forst.*	Not Threatened	Endemic	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓
Dicotyledonous Herbs other than Composites	MELALB	*Melilotus albus* (white sweetclover)	*Medik.*		Exotic		✓					✓				

Appendix Five (continued): Species list for all sites, presented in alphabetical order based on species name.

Structural Class	NVS code	Species	Authority	Threat Classification	Bio Status	MK -3	NG -3	NG -5	NG -6	NG -7	TK -4	TK -5	TK -6	TK -7	TT -4	TT -5
Dicotyledonous Herbs other than Composites	MENPVP	*Mentha xpiperita var. piperita* (peppermint)	*L.*		Exotic				✓	✓		✓				
Dicotyledonous Lianes and Related Trailing Plants	MUEAUS	*Muehlenbeckia australis* (pohuehue)	*(G.Forst.) Meisn.*	Not Threatened	Native	✓	✓			✓			✓		✓	
Dicotyledonous Trees & Shrubs	MYOLAE	*Myoporum laetum* (ngaio)	*G.Forst.*	Not Threatened	Endemic			✓		✓						
Dicotyledonous Trees & Shrubs	MYRAUS	*Myrsine australis* (matipo)	*(A.Rich.) Allan*	Not Threatened	Endemic					✓	✓			✓	✓	✓
Dicotyledonous Herbs other than Composites	NEPCAT	*Nepeta cataria* (catnip)	*L.*		Exotic								✓			
Ferns	BLENOV	*Parablechnum novae-zelandiae* (kiokio)	*(T.C.Chambers et P.A.Farrant) Gasper et Salino*	Not Threatened	Endemic	✓	✓					✓	✓			✓
Ferns	LASGLA	*Parapolystichum glabellum* (smooth shield fern)	*(A. Cunn.) Labiak, Sundue & R. C. Moran*	Not Threatened	Endemic										✓	

Appendix Five (continued): Species list for all sites, presented in alphabetical order based on species name.

Structural Class	NVS code	Species	Authority	Threat Classification	Bio Status	MK-3	NG-3	NG-5	NG-6	NG-7	TK-4	TK-5	TK-6	TK-7	TT-4	TT-5
Dicotyledonous Herbs other than Composites	PARDEB	*Parietaria deblis* (NZ pellitory)	*G.Forst.*	Not Threatened	Native								✓			
Dicotyledonous Lianes and Related Trailing Plants	PARCVC	*Parsonsia capsularis var. capsularis* (New Zealand jasmine)	*(G.Forst.) R.Br.*	Not Threatened	Endemic									✓	✓	✓
Dicotyledonous Lianes and Related Trailing Plants	PASTET	*Passiflora tetrandra* (NZ passionflower)	*olander ex DC.*	Not Threatened	Endemic										✓	
Ferns	PELROT	*Pellaea rotundifolia* (round-leaved fern)	*(G. Forst.) Hook.*	Not Threatened	Native			✓		✓			✓	✓	✓	✓
Monocotyledonous Herbs	PHOHOO	*Phormium cookianum subsp. hookeri* (mountain flax)	*(Hook.f.) Wardle*	Not Threatened	Endemic					✓		✓	✓		✓	
Monocotyledonous Herbs	PHOTEN	*Phormium tenax* (harakeke)	*J.R.Forst. et G.Forst.*	Not Threatened	Endemic										✓	

Appendix Five (continued): Species list for all sites, presented in alphabetical order based on species name.

Structural Class	NVS code	Species	Authority	Threat Classification	Bio Status	MK-3	NG-3	NG-5	NG-6	NG-7	TK-4	TK-5	TK-6	TK-7	TT-4	TT-5
Dicotyledonous Trees & Shrubs	PHYOCT	*Phytolacca octandra* (inkweed)	*L.*		Exotic								✓			
Gymnosperm Trees & Shrubs	PINRAD	*Pinus radiata* (radiata pine)	*D.Don*		Exotic		✓	✓		✓						✓
Dicotyledonous Trees & Shrubs	PIPESE	*Piper excelsum subsp. excelsum* (kawakawa)	*G.Forst.*	Not Threatened	Endemic					✓			✓	✓	✓	
Dicotyledonous Trees & Shrubs	PITCRF	*Pittosporum crassifolium* (karo)	*Banks et Sol. ex A.Cunn.*	Not Threatened	Endemic						✓			✓		
Dicotyledonous Trees & Shrubs	PITEUG	*Pittosporum eugenioides* (lemonwood)	*A.Cunn.*	Not Threatened	Endemic										✓	✓
Dicotyledonous Trees & Shrubs	PITTEN	*Pittosporum tenuifolium* (kohukohu)	*Sol. ex Gaertn.*	Not Threatened	Endemic					✓	✓		✓			
Dicotyledonous Trees & Shrubs	PLARSR	*Plagianthus regius* subsp. *regius* (ribbonwood)	*(Poit.) Hochr.*	Not Threatened	Endemic				✓			✓				

Appendix Five (continued): Species list for all sites, presented in alphabetical order based on species name.

Structural Class	NVS code	Species	Authority	Threat Classification	Bio Status	MK-3	NG-3	NG-5	NG-6	NG-7	TK-4	TK-5	TK-6	TK-7	TT-4	TT-5
Ferns	PNEPEN	*Pneumatopteris pennigera* (gully fern)	*(G. Forst.) Holttum*	Not Threatened	Native							✓				
Grasses	POAANC	Poa anceps (Broad-leaved poa)	*G.Forst.*	Not Threatened	Endemic					✓						
Gymnosperm Trees & Shrubs	PODTOT	*Podocarpus totara* (totara)	*G.Benn. ex D.Don*	Not Threatened	Endemic										✓	✓
Ferns	POLNEO	*Polystichum neozelandicum subs. neozelandicum*	*Fée*	Not Threatened	Endemic						✓	✓	✓			
Ferns	POLSIL	*Polystichum silvaticum*	*(Colenso) Diels*	Not Threatened	Endemic										✓	
Dicotyledonous Trees & Shrubs	POPALB	*Populus alba* (silver poplar)	*L.*		Exotic			✓								
Dicotyledonous trees and shrubs	POPDEL	*Populus deltoides* (necklace poplar)	*W. Bartram ex Marshall*		Exotic				✓							
Dicotyledonous Trees & Shrubs	POPNIG	*Populus nigra* (lombardy poplar)	*L.*		Exotic		✓						✓			

Appendix Five (continued): Species list for all sites, presented in alphabetical order based on species name.

Structural Class	NVS code	Species	Authority	Threat Classification	Bio Status	MK-3	NG-3	NG-5	NG-6	NG-7	TK-4	TK-5	TK-6	TK-7	TT-4	TT-5
Gymnosperm Trees & Shrubs	PRUTAX	*Prumnopitys taxifolia* (matai)	*(D.Don) de Laub.*	Not Threatened	Endemic											✓
Dicotyledonous Trees & Shrubs	PRUSER	*Prunus serrulata* (japanese cherry)	*Lindl.*		Exotic	✓										
Dicotyledonous Trees & Shrubs	PSECRA	*Pseudopanax crassifolius* (lancewood)	*(Sol. ex A.Cunn.) C.Koch*	Not Threatened	Endemic										✓	✓
Ferns	PTEESC	*Pteridium esculentum* (bracken)	*(G. Forst.) Cockayne*	Not Threatened	Native	✓	✓						✓		✓	
Ferns	PTEMAC	*Pteris macilenta* (sweet fern)	*A. Rich.*	Not Threatened	Endemic					✓						
Ferns	PTETRE	*Pteris tremula* (shaking brake)	*R. Br.*	Not Threatened	Native	✓	✓	✓	✓	✓		✓	✓	✓		✓
Ferns	PYRELE	*Pyrrosia elaeagnifolia* (leather-leaf fern)	*(Bory) Hovenkamp*	Not Threatened	Endemic									✓		✓
Dicotyledonous Herbs other than Composites	RANREP	*Ranunculus repens* (buttercup)	*L.*		Exotic							✓	✓			

Appendix Five (continued): Species list for all sites, presented in alphabetical order based on species name.

Structural Class	NVS code	Species	Authority	Threat Classification	Bio Status	MK-3	NG-3	NG-5	NG-6	NG-7	TK-4	TK-5	TK-6	TK-7	TT-4	TT-5
Monocotyledonous Lianes	RIPSCA	*Ripogonum scandens* (supplejack)	*J.R.Forst. et G.Forst.*	Not Threatened	Endemic									✓	✓	✓
Dicotyledonous Trees & Shrubs	ROSRUB	*Rosa rubiginosa* (briar)	*L.*		Exotic	✓	✓	✓							✓	
Dicotyledonous Trees & Shrubs	RUBFRU	*Rubus fructicosus* (blackberry)	*G.N.Jones*		Exotic	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Dicotyledonous Trees & Shrubs	SALELA	*Salix eleagnos* (bitter willow)	*Scop.*		Exotic		✓							✓	✓	✓
Dicotyledonous Trees & Shrubs	SALCIN	*Salix cinerea* (grey willow)	*L.*		Exotic	✓				✓						
Dicotyledonous Trees & Shrubs	SALFRA	*Salix fragilis* (crack willow)	*L.*		Exotic	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓
Dicotyledonous Trees & Shrubs	SCHDIG	*Schefflera digitata* (pate)	*J.R.Forst. et G.Forst.*	Not Threatened	Endemic		✓									✓
Dicotyledonous Herbs - Composites	SENBIP	*Senecio bipinnatisectus* (Australian fireweed)	*Belcher*	Not threatened	Native	✓						✓			✓	
Dicotyledonous Herbs other than Composites	SOLCHE	*Solanum chenopodioides* (velvety nightshade)	*Lam.*		Exotic		✓	✓	✓	✓						

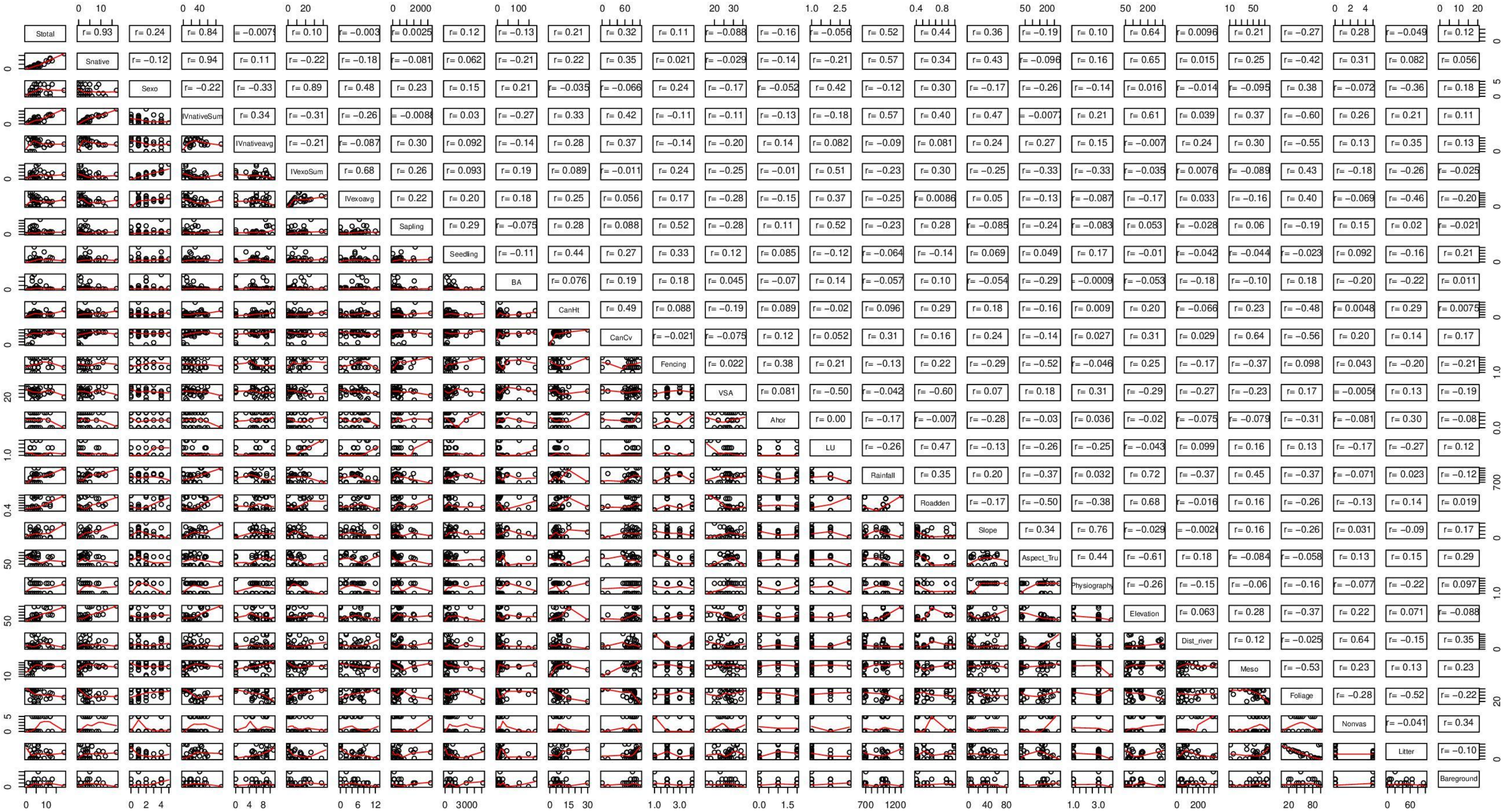
Appendix Five (continued): Species list for all sites, presented in alphabetical order based on species name.

Structural Class	NVS code	Species	Authority	Threat Classification	Bio Status	MK-3	NG-3	NG-5	NG-6	NG-7	TK-4	TK-5	TK-6	TK-7	TT-4	TT-5
Dicotyledonous Herbs other than Composites	SOLNIG	*Solanum nigrum* (black nightshade)	*L.*		Exotic	✓				✓			✓			
Dicotyledonous Trees & Shrubs	SOPTET	*Sophora tetraptera* (large-leaved kowhai)	*J.S.Mill.*	Not Threatened	Endemic	✓	✓	✓		✓			✓	✓	✓	✓
Dicotyledonous Herbs other than Composites	STASYL	*Stachys sylvatica* (hedge woundwort)	*L.*		Exotic										✓	
Dicotyledonous Herbs other than Composites	THYVUL	*Thymus vulgaris* (culniary thyme)	*L.*		Exotic		✓	✓								
Monocotyledonous Herbs	TRAFLU	*Tradescantia fluminensis* (wandering jew)	*Vell.*		Exotic								✓			
Dicotyledonous Trees & Shrubs	ULEEUR	*Ulex europaeus* (gorse)	*L.*		Exotic	✓		✓	✓			✓	✓			
Dicotyledonous Trees & Shrubs	URTFER	*Urtica ferox* (ongaonga)	*G.Forst.*	Not Threatened	Endemic								✓			

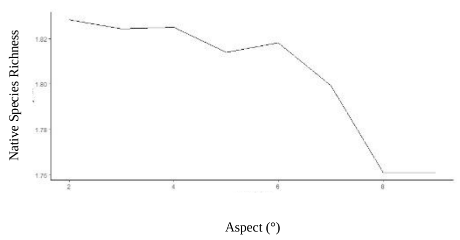
Appendix Five (continued): Species list for all sites, presented in alphabetical order based on species name.

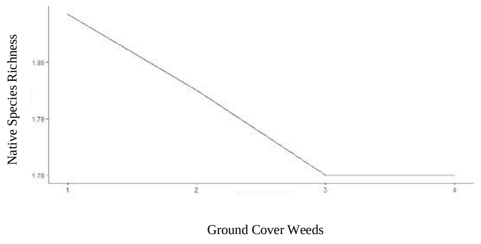
Structural Class	NVS code	Species	Authority	Threat Classification	Bio Status	MK-3	NG-3	NG-5	NG-6	NG-7	TK-4	TK-5	TK-6	TK-7	TT-4	TT-5
Dicotyledonous Herbs other than Composites	VERBON	*Verbena bonariensis* (purple-top vervain)	*L.*		Exotic		✓		✓							
Dicotyledonous Trees & Shrubs	HEBPAR	*Veronica parviflora* (hebe)	*Vahl*	Not Threatened	Endemic			✓	✓							
Dicotyledonous Trees & Shrubs	HEBSVS	*Veronica stricta var. stricta* (koromiko)	*Benth.*	Not Threatened	Endemic		✓	✓							✓	✓
Dicotyledonous Herbs other than Composites	VICSAT	*Vicia sativa* (vetch)	*L.*		Exotic			✓								
Dicotyledonous Herbs other than Composites	VINMAJ	*Vinca major* (periwinkle)	*L.*		Exotic					✓						
Ferns	PHYDIV	*Zealandia pustulata subsp. pustulata* (hounds' tongue)	*(G.Forst.) Testo et A.R.Field*	Not Threatened	Native	✓								✓		✓

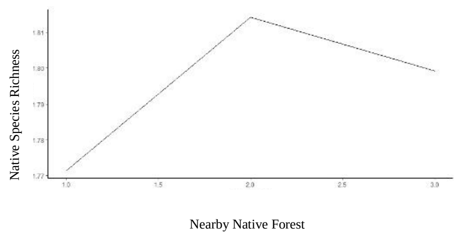
Appendix Six: Scatterplot matrix of RECCE, forest health, and soil variables.

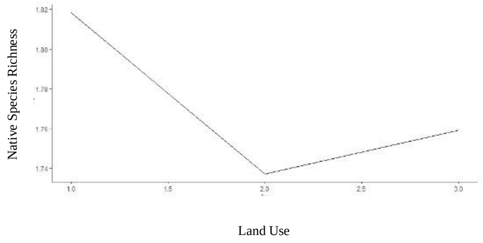


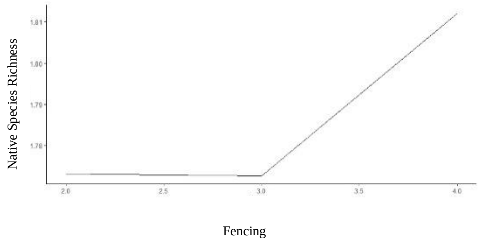
Appendix Seven: Partial dependence plots for the relationships between native woody species richness and the explanatory variables not deemed most important.

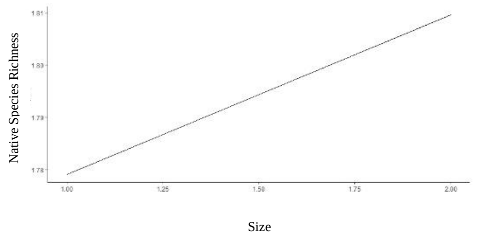


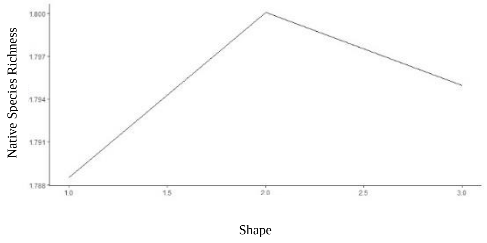


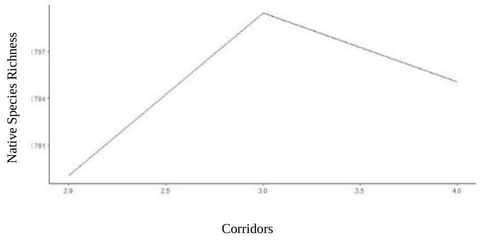


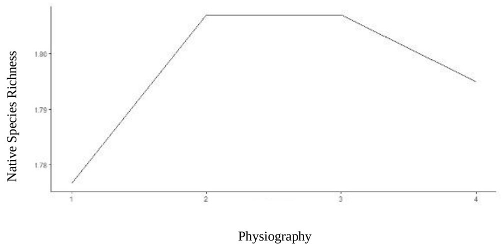


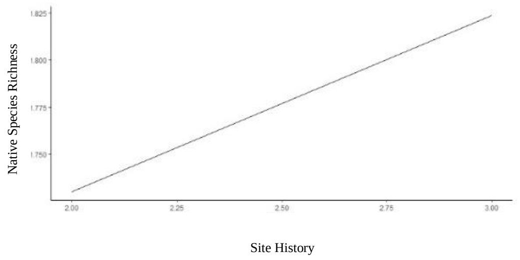




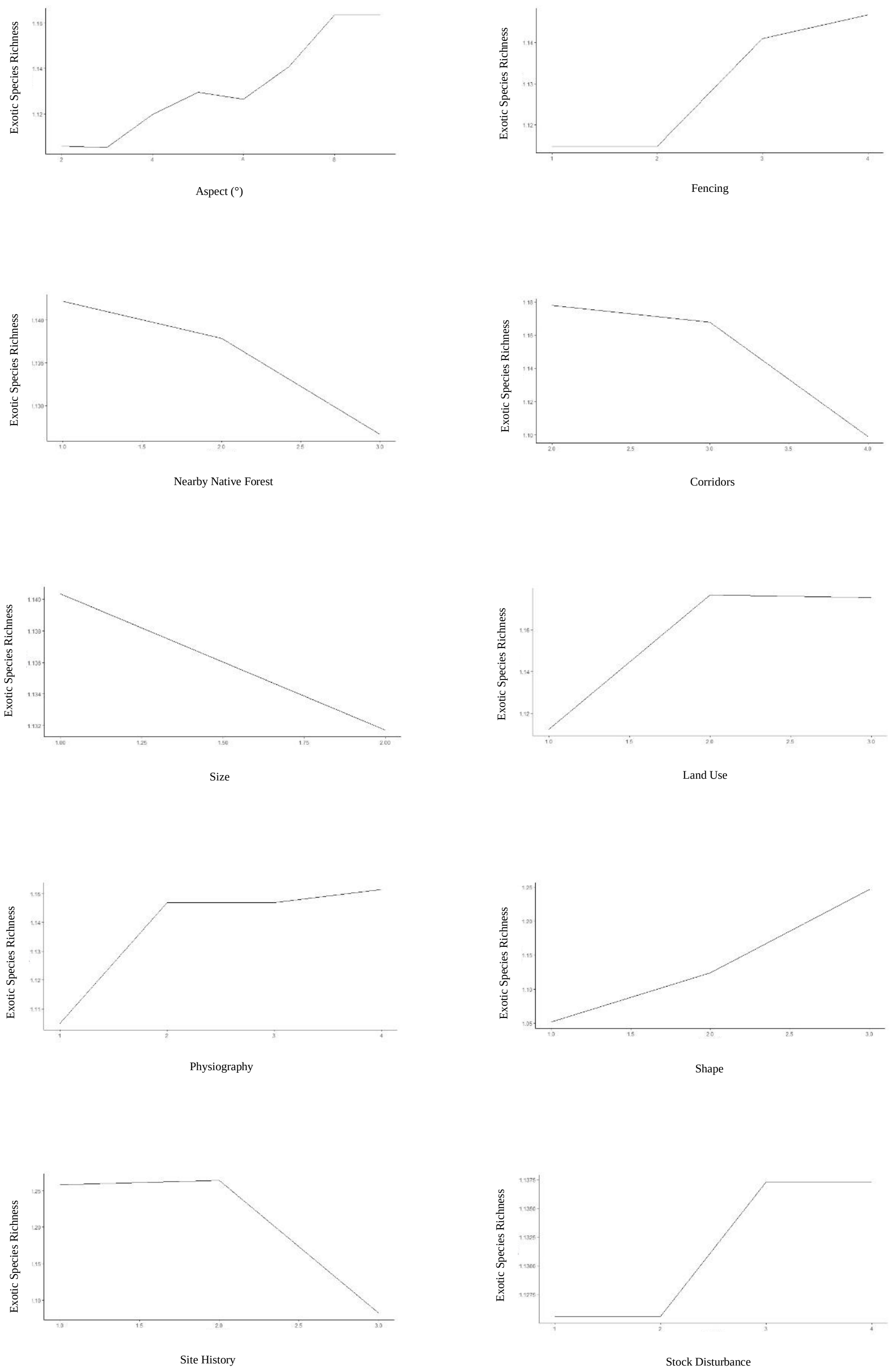




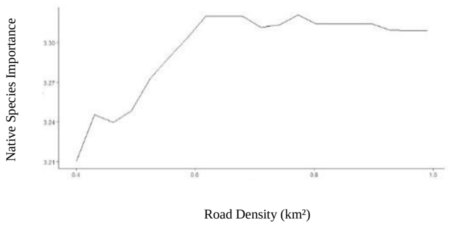


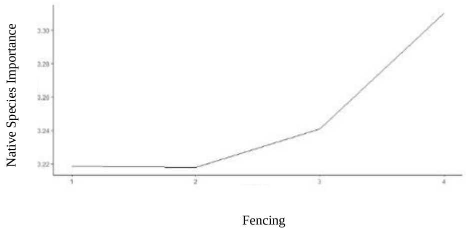


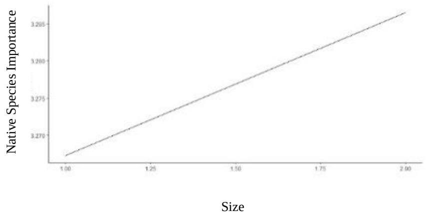
Appendix Seven (continued): Partial dependence plots for the relationships between exotic woody species richness and the explanatory variables not deemed most important.

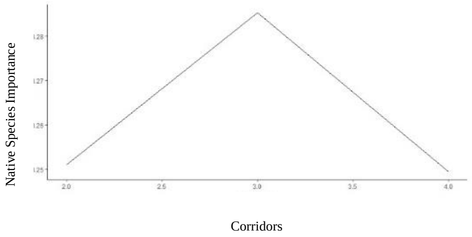


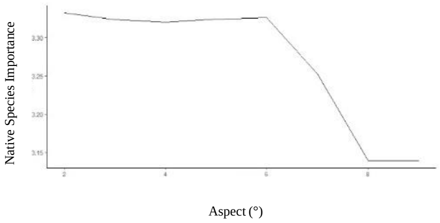
Appendix Seven (continued): Partial dependence plots for the relationships between native woody species importance and the explanatory variables not deemed most important.

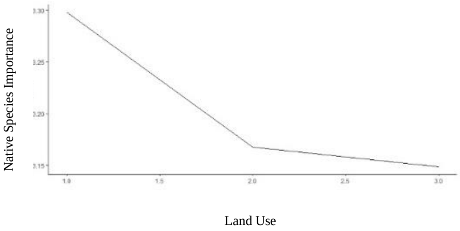


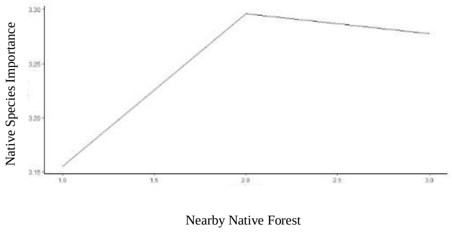


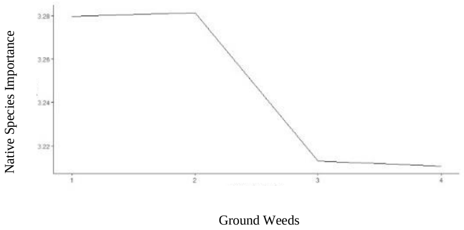


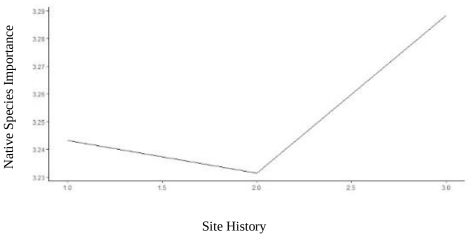


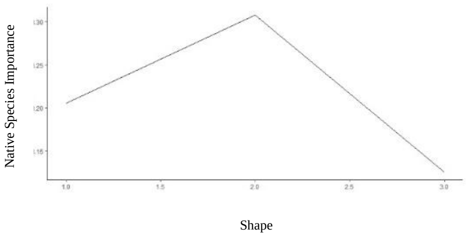


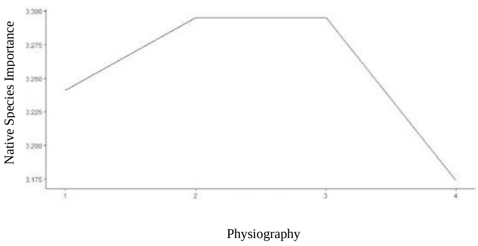


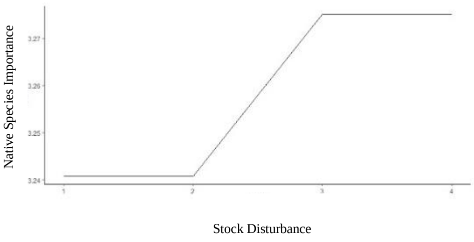




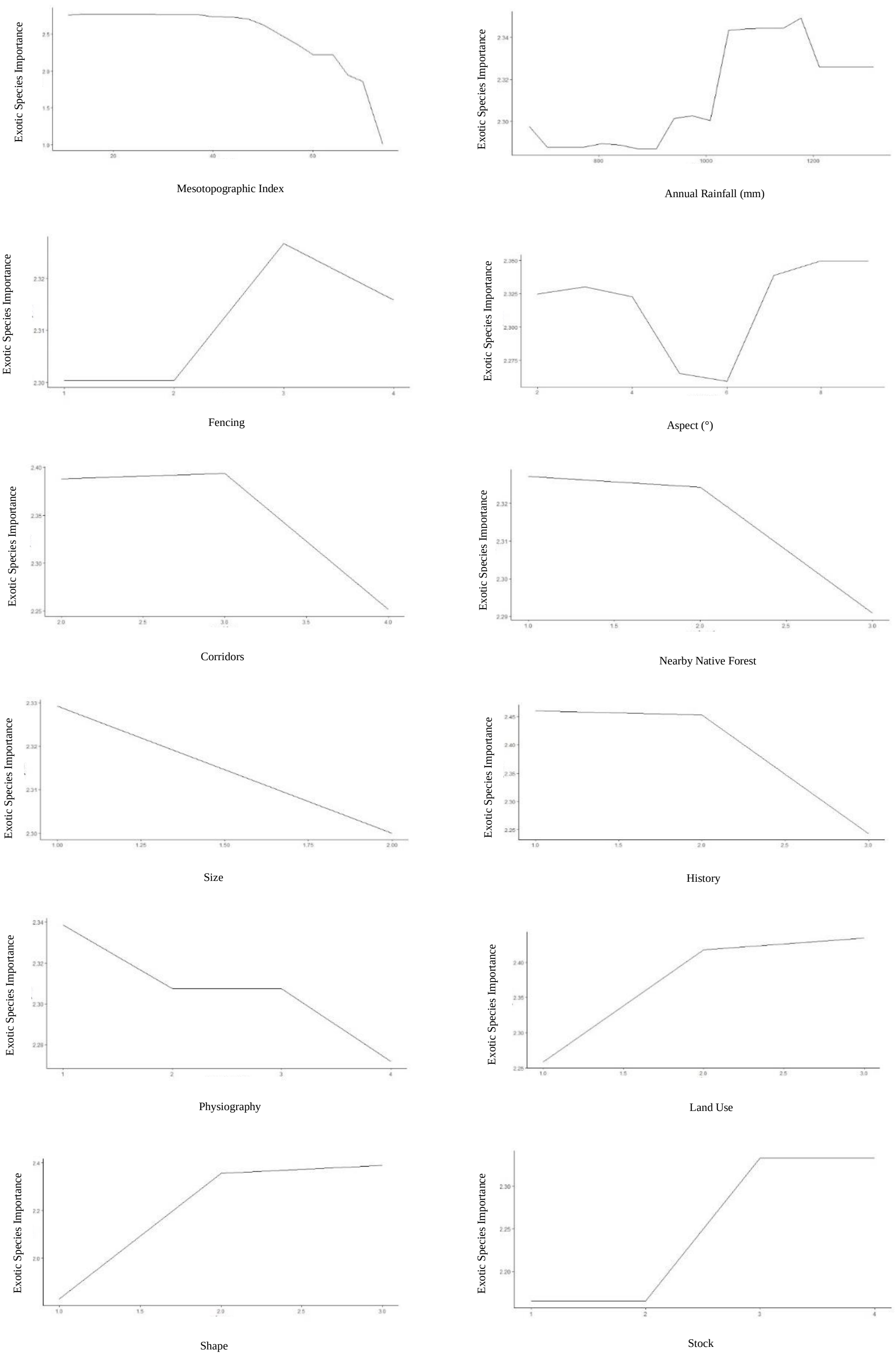




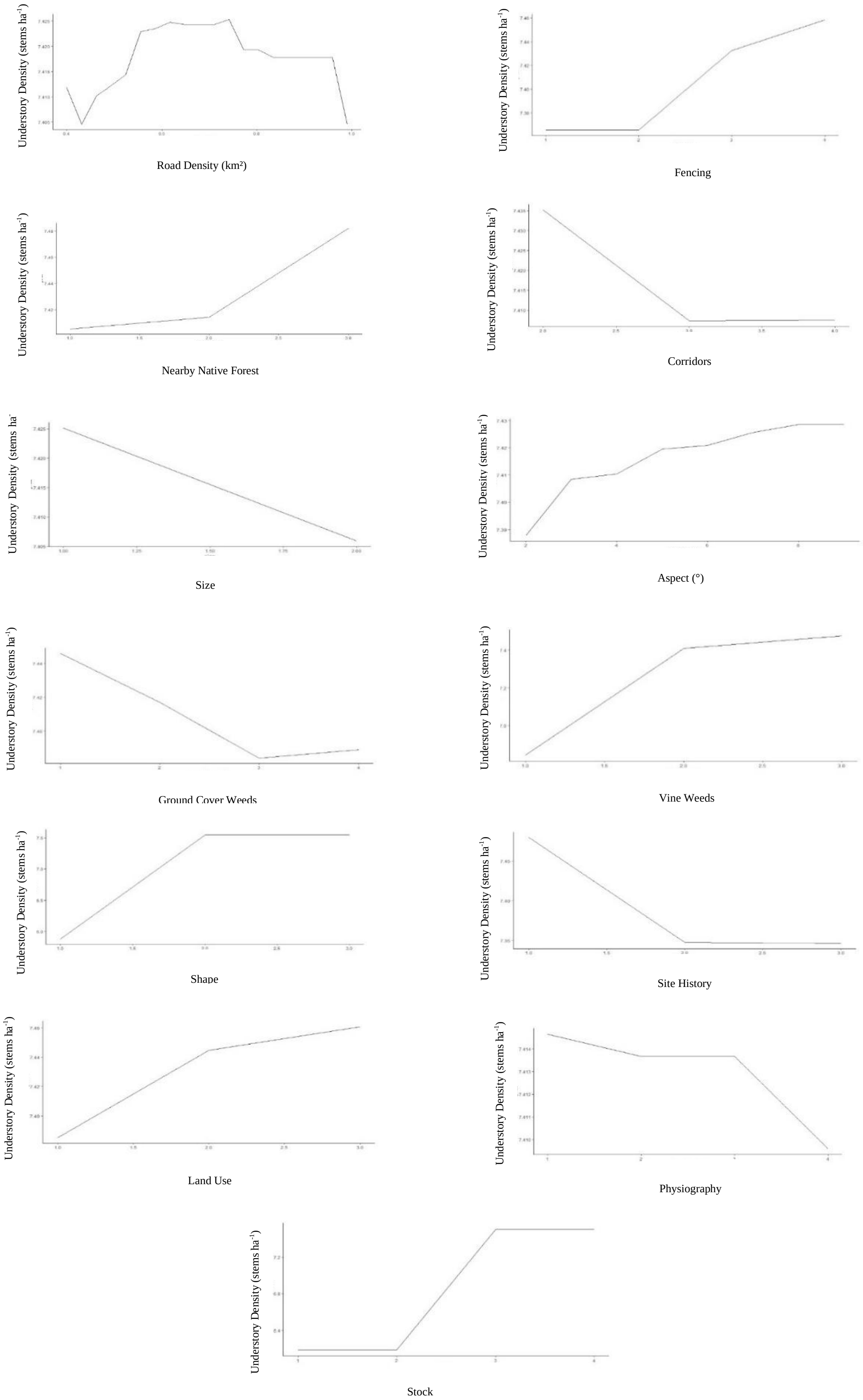




Appendix Seven (continued): Partial dependence plots for the relationships between exotic woody species importance and the explanatory variables not deemed most important.



Appendix Seven (continued): Partial dependence plots for the relationships between understory density and the explanatory variables not deemed most important.



Appendix Seven (continued): Partial dependence plots for the relationships between canopy cover and the explanatory variables not deemed most important.