NZ SCHOOL OF FORESTRY

ABSTRACTS OF POSTGRADUATE THESES AND REPORTS

2006 ONWARDS

CONTENTS

The abstracts presented here are from a range of outputs from postgraduate students of the School. These outputs vary considerably in scope, length and quality.

DOCTOR OF PHILOSOPHY

The PhD is an original piece of research that is examined to the highest contemporary international standard. The research generally takes three or more years and usually there will be publications in refereed journals arising directly from the thesis.

MASTER OF FORESTRY SCIENCE

There are two types of Masters degree. In the first the major output is the thesis, which is a research project of at least one and sometimes up to two years' duration. The thesis is expected to be of a high standard but the scope is often broader, and the extent of analysis and research less than that of the PhD. The second is by papers and report. Because of the requirements for coursework, the report is a smaller piece of work than the thesis and usually takes from a few months up to one year to produce. The report is not lodged in the UC Library database.

MASTER OF SCIENCE (ENVR/BIOL)

As with the MForSc, the MSc(ENVR/BIOL) has two pathways, but in all cases candidates are required to present a thesis. Only those candidates who are directly supervised by academic staff within the School of Forestry at greater than 50% supervision, have their abstracts included within this publication.

MASTER OF GEOGRAPHICAL INFORMATION SCIENCE (MGIS)

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PHD ABSTRACTS

ALZAMORA MALLEA, ROSA M. (2010)
VALUING BREEDING TRAITS FOR APPEARANCE AND STRUCTURAL TIMBER IN RADIATA PINE

The aims of this thesis were; firstly, to obtain economic values for radiate pine traits to produce appearance and structural lumber, and secondly to analyse the selection of efficient logs and profitable trees to substantiate the development of breeding objectives for solid wood quality.

The thesis included three approaches to value wood attributes: hedonic models, partial regressions and stochastic frontiers. Hedonic models generated economic values for pruned and unpruned log traits to produce appearance grades. Values for small end diameter were 0.33, 0.19 and 0.10 US $/mm, and for form 2.6, 1.4 and 0.63 US$ for the first, second and third log respectively. The value of mean internode length was 0.19 US $/cm. Branch size traits were non-significant to explain the log conversion return ($p>0.05$).

The economic value of log traits to product structural lumber with stiffness of 8, 10 and 12 GPa was estimated with a partial regression. The values were 1.1, 29.7, 0.3 and -0.4 NZ$/m^3 for small end diameter (cm), stiffness (GPa), basic density (kg/m^3) and largest branch (mm) respectively. Small end diameter and stiffness explained 73% of the variation of log conversion return. The economic values for structural attributes were also derived from a Cobb Douglas stochastic frontier, resulting in 2.1 NZ$/cm for small end diameter and 15.8 NZ$/GPa for stiffness. The change of values between approaches can be attributed to differences of model formulation. The stochastic frontier used aggregate volume of lumber with stiffness of 8 GPa or higher. The partial regression used the economic value of every lumber product derived from the logs, making it more sensitive to changes in wood quality.

Data envelopment analysis (DEA) used structural traits and their economic values to assess the technical and economic efficiency of logs to produce lumber with stiffness of 8, 10 and 12 GPa. The most efficient logs had 1:4 ratios between stiffness and small end diameter, whereas logs that did not generate structural lumber had ratios closer to 1:8. Trait economic values from the partial regression analysis were used as attribute prices to estimate cost efficiency. Efficiency measures were significantly correlated with stiffness and log conversion return; however, they were non-significantly correlated with small end diameter and log prices. The technical efficiency of logs to produce structural lumber was also determined using a Cobb Douglas stochastic frontier which determined that the most efficient logs were characterized by a 1:5 ratio between stiffness and small end diameter.

Selection of trees for deployment was analysed with a portfolio model, where risk was represented as the mean absolute deviation of tree returns due to the variability of volume, stiffness and resign defects. Under high variability (risk), the model selected structural trees with large stiffness and high return. These results suggest an opportunity for narrowing genetic variability (via clonal or family forestry) to make the returns from radiate pine structural grades lumber less risky.

As variability decreased the portfolio model opted for trees that produced appearance and structural lumber. These trees had a stabilizing effect on their returns, as there were phenotypic tradeoffs between stiffness and volume under optimistic and pessimistic growing scenarios. These results showed the benefits of product diversification at the tree level.

AMARAVATHI, KIRAN KUMAR (2011)
THE ROLE OF CRACK WILLOW IN THE WETLAND WATER BALANCE, MOUTERE REGION, NEW ZEALAND

The Waiwhero wetland (16 ha) is one of the largest wetlands in the Rosedale Hills, 35 km north-west of Nelson, New Zealand. It has an extensive cover of *Salix fragilis L.* (crack willow) and has been hypothesised to be a source of groundwater recharge for the Moutere aquifers, an important local groundwater system. However the wetland could also be a groundwater discharge zone, because of the geological boundary that it straddles. The overall aim of this study was to determine the direction of groundwater flux of the wetland by measuring the water balance, with particular emphasis on the transpiration rates from the crack willow trees.

The average daily transpiration (measurement was for 230 days) of crack willows in the wetland (6.4 mm/day) was to twice the potential evapotranspiration (PET) for grassland (3.9 mm/day). The highest measured willow transpiration rate was 12.4 mm/day and the lowest was 0.8 mm/day. High transpiration from crack willows was due to the horizontal energy fluxes (advective energy), tree physiological characters and high soil water content.

The study established that the wetland is a groundwater discharge zone with, on average for the two summer periods (2008 and 2009), the net groundwater discharge being 4.8 mm/day. The daily water balance results between two major rainfall events showed that the initial discharge source was from the surrounding hills and later stabilized at around 6-14 mm/day. It was believed to be a contribution from the shallow and deep aquifers or a combination of local region inflow and aquifers.

The water balance showed that the main loss of water through the hydrological system of wetland during summer was from the high transpiration of willows (7.7 mm/day). The extent of water savings estimated for the 16 ha wetland through a hypothetical situation of willow removal, and the assumption that it is filled with open water without any canopy cover, was 688 m^3/day. However this water savings rate if applied to a large area of crack willow stands would be quite high. On similar lines it is important to understand the transpiration rates of other wetland tree species in New Zealand. This information would help in preparing regional council plans for the introduction of tree species in the wetland for better management of the water resources and sustainable ecosystem management.

BASCUNAN, ARTURO (2023)
REDUCING UNCERTAINTY IN TREE BREEDING SELECTION, THE CASE OF RADIATA PINE IN NEW ZEALAND

The objective of this thesis was to investigate the uncertainty in the input parameters needed to calculate selection index values for the New Zealand radiata pine breeding program. A novel methodology was developed to determine which input parameters are the most important determinants of selection index value. It was found that age-age correlations related to the objective trait tree volume were the most important parameters but paradoxically there is little information available on these parameters. New estimates are provided for ten of the 20 age- age genetic correlations currently required to compute the radiata pine selection index in New Zealand, using information on phenotypic correlations.

Distributions of the values of economic weights for the five objective traits currently used in the radiata pine breeding programme (tree volume, sweep, branch size, wood density, and wood stiffness) were estimated. These estimates were derived using a bio-economic model that involved a partial regression that was run on 111 quarterly New Zealand domestic log prices series from Sept-1994 to Jun-2020 to provide market variation and hence variation in the value of economic weights.

Robust selection (an application of risk analysis) was implemented using the estimated probability distributions of economic weights, where the selection of economic weights was constrained by correlations between the economic weights. These correlations were calculated from the data produced by the bioeconomic model.

As a result, it was found that the trees selected by robust selection were similar than those selected by deterministic selection. The main reason for this result was the lower-than-expected variability in economic weights obtained by the bio-economic model. This means that the uncertainty in future log prices is not relevant because it does not change the decision of which trees must be selected, across the range of economic weight produced by the range of historic log prices.

BENSON, ANDREW (2020)

THE EFFECTS OF ROOT PRUNING ON THE GROWTH, PHYSIOLOGY AND MONETARY VALUE OF *QUERCUS VIRGINIANA* AND TWO SPECIES OF *ACER*

The urban environment in which we live is ever-changing and subject to continued modification to accommodate population growth and to meet modern engineering standards. Within this ever-changing environment, land disturbance and ground modifications are commonplace, which can place nearby urban trees at risk of root damage or root removal, the effects of which can result in physiological stress, growth retardations, reduced life expectancy and increased mortality.

In many regions of the world, the constraints placed upon urban trees by land modifications has prompted the implementation of a range of statutes, best practice documents and local legislations, to afford protection to urban trees, particularly during construction work and development. These documents often contain specific recommendations for tree protection methods and root care practices, informed by the findings of a small pool of research outputs.

The objectives of this thesis were to test the validity of some of the current best practice recommendations relating to tree protection, root pruning and root care practices. In particular, a novel allometric approach to root pruning methods is proposed. In three experiments exposing trees to different types of root severance treatments, the measured diameters of individually severed roots were used to estimate root cross-sectional area. Combined severed root cross-sectional areas for each tree were divided by the trunk cross-sectional area at a given height (x) above ground level, to produce an allometric Area Ratio; $Ar(x)$.

Experiments were carried out in New Zealand, to investigate the effects of increasing root removal treatments on growth (trunk diameter increase, leaf area and new shoot elongation) and physiology (stomatal conductance and chlorophyll fluorescence) of 100 *Acer palmatum* 'Bloodgood' Thunb and 19 *A. negundo* L. Trenches were established 30 cm from the tree base on one (T1) two (T2), three (T3) or four (T4) sides of the trees, plus control (no trenches).

In Florida, USA, two experiments were undertaken using *Quercus virginiana* Mill. The first, was a test of the current tree protection zone (TPZ) principles. Mature trees (n=18) were exposed to five root pruning treatments consisting of a circular trench around each tree, plus control. Trenches were established with radial offsets from the tree base between 3 and 15 times the trunk diameter in increments of three (3x, 6x, 9x, 12x and 15x), plus control (no trenches). The same morphological and physiological responses as the New Zealand study were investigated, with the inclusion of pre-dawn leaf water potential data.

The second Floridian experiment simulated utility trenching (linear root cutting), again using mature *Q. virginiana* (n=31), with treatments consisting of a ≈ 10 m long liner trench offset from the tree base at either twelve (12x), six (6x) or three (3x) times the trunk diameter plus control (no trenches).

Morphological and physiological data were investigated as response variables in the same way as the first Floridian experiment.

In addition to the physiological and morphological response data, each tree was appraised and given a monetary value prior to and several months after root manipulation using four different tree valuation methods (CTLA trunk formula method 9th Edition (CTLA), the Revised Burnley Method (Burnley), the Helliwell Method (Helliwell), and the Standard Tree Evaluation Method (STEM)). Response data following root removal were expressed as a percentage change in value (Δ value %). The purpose of this investigation was to ascertain whether root removal had any effect on the monetary value of urban trees, and to compare the effectiveness of each of these methods for this purpose.

Results of this work indicated that a tree protection zone radius of 12 times the trunk diameter at breast height (≈1.4 m), was insufficient to protect *Q. virginiana* from short-term physiological stress effects during the summer growing season immediately following root severance. Although it was sufficient to avoid sustained water stress symptoms during the first summer growing season after root removal, as well as negative effects on above-ground growth. No significant negative effects were recorded when roots were severed in circumferential trenches with a radius of 15 times the trunk diameter at 1 m.

Severing roots in utility-type trenching made at a distance from the tree base equivalent to three times the trunk diameter at breast height (3x), resulted in sustained water stress symptoms 14 months following root removal, where other treatments (6x and 12x) showed signs of recovery.

The allometric variable ($Ar_{(x)}$) proved to be a reasonably reliable (R^2) and significant (p value) predictor of both physiological and morphological responses, although varied among species / location. Negative effects on above-ground growth for *A palmatum* 'Bloodgood' and *A. negundo* trees, have the potential to arise when the total combined cross-sectional area of severed roots exceeds 22% and 27% of the trunk cross-sectional area at 1.4 m respectively (assuming radial uniformity of the root and trunk cross sections).

The results revealed a general trend towards greater loss in monetary value (Δ value %) with increasing root removal intensity for all methods for one or more treatment types. Values appraised using the CTLA and Burnley methods showed a greater sensitivity to changes in the amount of root loss, owing to the fine scale resolution within a rigid framework of descriptors in the awarding criteria. STEM and Helliwell were generally insensitive to root removal treatments. Linear mixed model analyses using four independent variables (maximum severed root diameter, % tree protection zone removed, total number of severed roots, and $Ar_{(x)}$ revealed that % tree protection zone removal was the best performing tool for predicting percentage loss in value following root removal.

The research outputs of this work have a practical application to assist practitioners in achieving an optimum standard of tree care during ground alterations. Although trees may behave differently between species and age classes, the tree protection zone principles have not previously been empirically tested. By observing how *Q. virginiana* responded to the circumferential root removal treatments, this thesis provides an empirical platform on which to encourage practitioners to extend tree protection zone radii to 15 times trunk diameter at 1 m, as a minimum, if the physiological effects of water stress are to be avoided in the short-term.

In acknowledgement again that responses may vary between species and location, the observations made when *Q. virginiana* roots were severed in linear trenches, again adds a level of empirical robustness to guidelines and best practice texts relating to trenching offsets. Where the work of others has found that linear root cutting closer than three times trunk diameter at breast height can negatively affect tree stability, the results of this work indicate that severing roots at the same distance (three times trunk diameter), results in sustained water stress symptoms. Those symptoms were alleviated

when the trenches were made at a distance equal to six times the trunk diameter at breast height (equating to 24.10% of a tree protection zone prescribed using a 15:1 ratio of trunk diameter). These findings would indicate that severing roots closer to the tree than a distance equal to six times its trunk diameter is not recommended.

Whilst the results add valuable information to a limited pool of knowledge on the effects of root loss, further research using large numbers of different species exposed to the same or similar types of root removal would be advantageous, and necessary to make more robust and generalisable guidelines to the industry. Particularly as this relates to the findings on tree protection radii, where the investigation was limited by the number of available trees and consequently had a low number of replicates. Furthermore, since all of the investigations carried out in this thesis were constrained by time, the temporal effects of root loss on the investigated species were not thoroughly understood. The findings of the linear root cutting experiment would suggest that there is physiological and morphological recovery in *Q. virginiana* in the 6x and 12x treatments after one year. A similar behaviour would be expected when roots were severed circumferentially, and this understanding would further help inform decisions pertaining to tree protection zone recommendations.

Whilst the $Ar_{(x)}$ variable was a significant predictor of the response variables, the unexplained variance in the models was, in some instances, greater than that which was explained. Furthermore, the relationships in each instance were linear, i.e. no curvature in the response was observed. The absence of curvature and occasionally weak (yet significant) relationships between $Ar_{(x)}$ and response, as well as the variation in response between species, precluded its use as a tool to clearly prescribe a broadly generalisable root pruning 'threshold' at which no further root removal should occur. Although the method is more robust than a fixed diameter threshold when accounting for cumulative root loss, the practicalities of its application in a commercial sense would be onerous and time consuming to a practitioner, and a trunk diameter-defined offset at which root loss should be avoided (i.e. no closer than six times trunk diameter at breast height), remains the most suitable means of accounting for cumulative root loss in a practical way.

BEST, TREVOR (2023)
THE CONSTRUCTION OF OPERATOR WELLBEING IN AOTEAROA NEW ZEALAND'S LOGGING INDUSTRY

The forest industry in Aotearoa New Zealand is pursuing a strategy of increasing the use of mechanised harvesting systems as a way of reducing the number of serious injury and fatal accidents amongst those working on the felling face. While this will reduce exposure to physical hazards, hazards in the psychosocial environment (such as low job control and conflict between work, home and community life) also impact worker behaviour and wellbeing. Yet little is known about the psychosocial risks and coping adaptations in operation within the industry. Given the relationship between stress and risky and dangerous behaviour, it is imperative the industry develops an understanding of how stress operates within the lives of this group of workers to ensure the desired safety outcomes are achieved.

The first objective of this research, therefore, was to explore how machine operators working in the forest industry construct their wellbeing (conceptualised as a spectrum between stress and wellness) within their work life. Stress is a subjective process where the meanings an individual attribute to an event and their ability to cope with that event determines the stress experience. Understanding stress, therefore, means being able to encapsulate the impacts of social and institutional issues such as power, control and ethics and their impact on the perceptions individuals have of their stress experience. As little is known about these phenomena within this context, constructivist grounded theory methods were used to provide a substantive explanation of the processes in operation. Developing this substantive explanation was the second objective of the research.

Twenty-seven operators were recruited from three regions to participate in a semi-structured interview to explore their experiences of stress and wellness. Analysis consisted of three steps – initial coding, intermediate coding and theoretical coding. Within this process, interview text was first dissected into incidents and then organised into concepts with increasing levels of abstraction. That continued iteratively until a core category was identified. This was a category that encapsulated the process that was evident in the concepts and connections that emerged from the analysis. A grounded theory was explicated by conceptualising the narrative inherent in the core category and explained using extant theory.

The data revealed that wellbeing could be explained by the concepts and connections encapsulated in the core category *securing a place in a hierarchical world.* Within this core category, operator wellbeing was an outcome of the adaptation's operators used to secure a sense of place within the various contextual and socio-cultural hierarchies in which their lives unfold. The level of wellbeing the operators experienced was a function of the resources they were able to access from their position of disadvantage within that context. Most of the workplace resources were controlled by the other parties active within the setting, namely the forest owner / manager and contractor. Those resources were deployed in the interests of the controlling actor. While each of the actors were dependent on the others for their social position, the implication was that achieving improvement in wellbeing outcomes (where that was required), would be based on greater recognition of that mutual dependence and a subsequent re-alignment of each actors' interests.

BOCZNIEWICZ, DANIEL (2023)
DEVELOPING FULLY COMPATIBLE TAPER AND VOLUME EQUATIONS FOR ALL STEM COMPONENTS OF *EUCALYPTUS GLOBOIDEA* BLAKELY TREES IN NEW ZEALAND

Background: Individual tree taper and volume equations are essential for forest management. They provide estimates of volume that are incorporated into plot level volume equations and growth and yield models to estimate volumes per hectare in forest crops. Moreover, taper equations allow forest managers to estimate the dimensions of logs that can be cut from stems in their forests when they have measured diameters at breast height outside bark (dbhobs) and heights of trees in inventories. Compatible taper and volume equations have the property that the same individual tree volume can be estimated either from the tree volume equation or by integrating the taper equation. Durable eucalypt species such as *Eucalyptus globoidea* Blakely have especially valuable heartwood, so managers require estimates of the volumes and shapes of heartwood zones within trees. Simple overall wood taper and volume equations would therefore be inadequate.

Methods: 74 *Eucalyptus globoidea* trees were destructively sampled in eight trials throughout New Zealand. Tree ages were 7 to 29 years old, the diameters at breast height (dbhs) were 11 to 67.6 cm, and the heights were 7.2 to 35.4 m. All trees were felled, and lengths and taper diameters outside bark were measured. Discs were cut at irregular intervals along the stems to measure heartwood and sapwood's taper diameters. Heartwood and sapwood components were identified by applying methyl orange dye and quantified using image analysis. In this study, compatibility was extended so that sums of estimated volumes of separate components of stems, bark, sapwood and heartwood would equal overall tree volume estimates. In addition, taper equations were made for outside bark, inside bark and heartwood that were compatible with their respective volume equations. Parameters of five volume equations for the whole stem, whole wood, bark, sapwood, and heartwood were simultaneously estimated. Compatible taper equations for the whole stem, stem wood and heartwood were estimated to be compatible with volume equations, creating a fully compatible system. Different model variants were tested using dbhob and tree height as independent variables (model 1) and heartwood ratio, diameter and height as additional independent variables (models 2A-C, 2Aa-Cc, 3A-K, 3Aa-Gg). Three techniques were used to obtain heartwood-related measurements: the electric resistance tomograph PiCUS TreeTronic scan simulation, increment core simulation and measurements from the

bottom stump parts of felled trees. The goal of model 1 was to create compatibility between all volume and taper equations using primary predictor inputs. The purpose of the rest models was to improve the prediction of the heartwood volume and taper using additional independent variables.

Results: For model 1 with two independent variables (dbh, tree height), root mean squared error (RMSE) of volume models were: heartwood (0.13 m^3), sapwood (0.06 m^3), wood inside bark (0.15 m^3), bark (0.11 m^3), wood including bark (0.14 m^3). RMSE of taper models predicting diameter were: heartwood (2.57 cm), wood inside bark (2.35 cm), and wood including bark (2.47 cm).

For models with three independent variables (dbh, tree height, heartwood ratio), the best RMSE results were obtained from model 2Aa for heartwood volume 0.11 m^3 and model 2A for heartwood taper 2.59 cm. For models with four independent variables (dbh, tree height, heartwood ratio and diameter), the best RMSE results were obtained from model 3H for heartwood volume 0.07 m^3 and heartwood taper 2.14 cm. For models with five independent variables (dbh, tree height, heartwood ratio, heartwood diameter and height), the best RMSE results were obtained from models 3B for heartwood volume 0.07 m^3 and heartwood taper 1.96 cm.

Conclusions: A compatible system of multiple taper and volume equations was created by simultaneously fitting parameters with minimal bias and precision levels of ± 0.06-0.15 m^3 volume equations and ± 2.35 to 2.57 cm for taper equations for a model with individual tree dbhob and height as independent variables. By using the additional independent variables (heartwood ratio, diameter and height), heartwood volume and taper predictions were improved by up to: ± 0.02 m^3 (models with three independent variables), ± 0.06 m^3/ ± 0.43 cm (models with four independent variables), ± 0.06 m^3/ ± 0.61 cm (models with five independent variables). Leave-one-out cross-validation of the fitted models yielded very similar levels of precision and bias to those encountered when fitting models with the entire dataset.

The taper and volume equations were incorporated into an interactive tool to provide volume and taper estimates of durable *Eucalyptus globoidea* trees for forest managers. The interactive tool produces complex taper and volume information for all stem components using the independent variables as model inputs. Connecting all tree stem wood and bark components' taper and volume and ensuring their compatibility is novel in forest mensuration. Moreover, future development and improvements for similar projects are suggested.

BOWN, HORACIO E. (2007)
REPRESENTING NUTRITION OF *PINUS RADIATA* IN PHYSIOLOGICAL HYBRID PRODUCTIVITY MODELS

Hybrid physiological models are being increasingly used to assess productivity, carbon sequestration, water and nutrient use and environmental impacts of management decision. Users include forest managers, politicians, environmental agencies and scientists. However a wider use of these models has been prevented as a result of an incomplete understanding of the mechanisms regulating carbon allocation, nutrient availability in soils and nutrient uptake by trees. On-going innovation in clonal forestry, genetic improvement and vegetation management techniques is also poorly represented in hybrid models.

This thesis examines means to represent nutrition and genotype-nutrition interactions in productivity physiological hybrid models. Nutrient limitations and growth differences between genotypes were hypothesized to operate through key physiological processes: photosynthesis, carbon allocation and nutrient internal cycling. In order to accomplish the aims of the study both greenhouse and field experimentation were carried out.
In a first experiment, responses of photosynthesis (A) to intercellular CO_2 concentration (C_i) were measured in a fast- and a slow-growing clone of *Pinus radiata* D. Don cultivated in a greenhouse in a

factorial combination of nitrogen and phosphorus supply, and analysed using the biochemical model of leaf photosynthesis described by Farquhar *et al*. (1980). There were significant positive linear relationships between the parameters, $V_{cmax,}$ J_{max}, and T_p and both foliar nitrogen (N_a) and phosphorus (P_a) concentration on an area basis. The study showed that the effects of nitrogen and phosphorus supply on photosynthesis were statistically independent and that the photosynthetic behaviour of the two clones was equivalent.

In a similar study, gas exchange and chlorophyll fluorescence were simultaneously measured to determine internal transfer conductance (g_m) based on the "constant *J* method". Transfer conductance may pose significant limitations to photosynthesis which may be differentially affected by nutrition and genotype in *Pinus radiata*. Values of g_m were similar to those of stomatal conductance (g_s) and their ratio (g_m/g_s) was not influenced by nutrient supply or clone being on average (± 1 SE) 1.22 ± 0.04. Relative mesophyll limitations (L_M, 16%) to photosynthesis were marginally greater than those imposed by stomata (L_S, 13%), and together smaller than the relative limitations posed to photosynthesis by biochemical processes (L_B, 71%). The CO_2 concentration in the intercellular air spaces (C_i) was (± 1 SE) 53 ± 3 μmol mol^{-1} lower than in the atmosphere (C_a) while CO_2 concentration in the chloroplasts (C_c) was (± 1 SE) 48 ± 2 μmol mol^{-1} less than C_i. Values of L_S, L_M and L_B and CO_2 diffusion gradients posted by g_s (C_a-C_i) and g_m (C_i-C_c) did not change with nutrient supply or clone.

In a third experiment, one-year old *Pinus radiata* cuttings from four genotypes were cultivated in silica sand with a factorial combination of nitrogen (N_0=1.43 and N_1=7.14 mM) and phosphorus (P_0-0.084 and P_1-0.420 mM) supply for 24 months. N supply was enriched with ^{15}N, $\delta^{15}N$ 0.5115%) provided by the source of N in nutrient solution applied during the second year. Recovery of labelled and unlabelled N was used to estimate N remobilisation. N remobilisation scaled with plant growth, N content and N and P supply. In relative terms, 65% of all stored N was remobilised in the high-nutrient supply regime compared to 42-48% at lower N and P addition rates. Most N remobilisation occurred during spring-summer (77%), coincidently with the largest proportion of needle development (80%), indicating that N remobilisation was driven by sink-strength. Foliage was by far the main source for internal cycling while roots were the main sink (40%). Clones exhibited differences in N remobilisation capacity, but these differences were completely explained by the size of the N pool before remobilisation took place, indicating that N remobilisation performance was similar among clones.

In a fourth study, four clones were cultivated in silica sand with a factorial combination of nitrogen and phosphorus supply for ten months, and patterns of carbon allocation examined using a carbon balance approach. Gross-primary productivity (GPP) scaled mainly with nitrogen but also with phosphorus supply. The fraction of GPP (GPP = ANPP + APR + TBA) allocated to above-ground components (ANPP) increased with N and P supply at the expense of total-below ground C allocation (TBCA) with no apparent effect on the fraction of GPP partitioned to above-ground plant respiration (APR). Carbon use efficiency (NPP:GPP) scaled with nutrient supply, being 0.42 in the low-nutrient supply regime compared to 0.51 in the high-nutrient supply regime, suggesting that in poor fertility environments a larger proportion of the C budget is respired compared to the net productivity. Fast-growing clones allocated about 2-4% more carbon to above-ground components (ANPP) at the expense of carbon allocated below-ground (TBCA) with no effect on carbon respired above-ground (APR), indicating that faster-growing genotype allocate more carbon to leaf area which may compound and increase overall GPP over time.

The field component of this thesis was conducted in a subset of locations where ENSIS (formerly New Zealand Forest Research Institute) had established trials to test the influence of species, soil disturbance and plant nutrition on sustainability indicators. Plots were small in size (3 m x 3 m) with trees spaced at 0.5 m x 0.5 m (40 000 trees ha^{-1}) with nine measurement trees surrounded by a two-row buffer. All sites were planted in winter 2001 and harvested in spring 2005. The aim of this pilot study was to examine patterns of carbon allocation during the fourth year after planting in control and fertilized mini-plots of *Pinus radiata* in five sites with contrasting climate and soil conditions in the

South Island of New Zealand. The study showed that the fraction of gross-primary productivity allocated belowground increased as the soil C:N ratio increased. However, these results should be interpreted with caution due to the unusual nature of the trial and the reduced number of sites studied.

Two existing physiological models were selected for the discussion in this thesis (3-PG, Landsberg and Waring 1997; canopy net carbon exchange model, Whitehead *et al*. 2002). Potential improvements for the nutritional component of 3-PG comprise: accounting for reductions in carbon use efficiency (NPP:GPP) in poor-fertility environments, adding a preliminary fertility modifier (F_N, 0-1) driven by soil C : N ratio and soil N, adding a preliminary relationship between carbon allocation to roots and the soil C : N ratio and representing faster-growing genotypes by increasing their leaf area but not their photosynthetic performance. The canopy net carbon exchange model (NCE) combines the coupled model of leaf photosynthesis – stomatal conductance described by Leuning (1995) with canopy structure and a water balance model to scale carbon assimilation from leaves to canopies. Potential improvements to account for nutrient deficiencies in the leaf model by Leuning (1995), comprise using nutrient ratios to discriminate nitrogen (N_a'P_a < 23 mol mol^{-1}) from deficiencies (N_a/P_a > 23 mol mol^{-1}), adding relationships between photosynthetic model parameters V_{cmax} and J_{max} to P_a, and correcting the estimation of photosynthetic parameters V_{cmax} and J_{max} by accounting for transfer conductance (g_m). The canopy net carbon exchange model may be also modified to account for carbon-use efficiency, carbon allocation to roots and genotype in a similar form to that proposed for 3-PG.

The results previously outlined provide a preliminary framework to represent tree and soil nutrition in physiological hybrid productivity models.

DASH, JONATHAN P. (2020)
ON THE DETECTION AND MONITORING OF INVASIVE EXOTIC CONIFERS IN NEW ZEALAND USING REMOTE SENSING

Conifers are amongst the most economically and culturally valued trees on Earth. They provide significant ecosystem services both within and outside of their natural range. For this reason, many northern hemisphere conifer species have been planted extensively in southern hemisphere countries. The evolutionary history of many conifer species means that they are frequently invasive in indigenous ecosystems. In New Zealand large areas of northern hemisphere conifers have been planted. These areas include commercial plantations managed for timber production and areas established for erosion control, hydrology management, agricultural, and amenity purposes. Many historical introductions were inappropriately located and included conifer species that are now known as invasive. This resulted in exotic trees with vigourous growth, rapid maturity, and abundant seed production occurring in remote and mountainous areas from where they have spread. The land area now invaded by exotic conifers is estimated to total around 2,000,000 ha and is increasing even under current management. The ecological and social impact of this situation is great, and this has led New Zealand government agencies, and other organisations, to undertake substantial control programmes. Without these efforts a much larger area will be invaded leaving a substantial detrimental legacy. Invasive conifer control relies on herbicide application or mechanical removal. These methods are expensive and challenging particularly when conducted across large areas of frequently mountainous terrain. Accurate information on the location of invasive conifers is either not currently available or is inadequate.

Remote sensing surveys potentially offer a useful solution as they can provide valuable information across large areas of challenging terrain and can deliver detailed information about targeted areas. With appropriate research remote sensing methods could provide valuable information to help improve the efficacy and efficiency of invasive conifer control programmes.

There has been substantial research into the remote detection of invasive plants originating from many parts of the world. Space-borne and both piloted and unpiloted airborne platforms have been used. In many instances this has provided useful and practical information for managers and policy makers but, to date, research into remote detection of invasive conifers has been limited in scope, incomplete, or

restricted to a single environment. Furthermore, a comprehensive review of the research literature revealed several gaps that the experimental research contained within this thesis addressed. Two of the research topics used the emerging technology of unpiloted aerial vehicles (UAVs). These flexible and reliable platforms provide a new data source that can provide ultra-high-resolution data over small to medium sized areas. With appropriate method development this represents a new source of critical information on the early stages of invasive conifer spread where detecting small plants is critical. The technology has delivered substantial efficiency compared to conventional ground- based measurements but has ushered in a new sampling challenge where the operator must decide how to deploy the UAV for data collection. This is particularly relevant where efficient re-use of UAV-based models is desirable to save model development and reference data labelling effort. The challenge of monitoring historic trends in invasive conifer spread was also investigated through analysis of the Landsat archive. No previous research had addressed this topic although automated methods developed for other applications had considerable promise. Single-date analysis can only provide information on the current distribution of invasive conifers and so the impacts of historical policy and management activities remain anecdotal without considering the temporal dimension.

Given the knowledge gaps identified in the published literature three broad research questions were developed and addressed through experimentation.

1. Can ultra-high-resolution data be used to detect the presence of invasive exotic conifers prior to the onset of early coning in a highly vulnerable environment?

2. Can UAV-based models of invasive conifer distribution be transferred between sites and does site complexity have a significant effect on model portability?

3. Given the size and availability of the Landsat archive can automated methods be developed that allow tracking of the historical spread and management of invasive conifers?

Three experiments were implemented to address these three research questions. To address research question one a detailed field study was installed in a vulnerable environment with a simplistic grassland non-target vegetation structure. The study site was subject to a first order conifer invasion event spreading from a shelter-belt on agricultural land. Very high-resolution multispectral and laser scanning data was collected over the site using both UAV and conventional piloted aircraft. These data were used to develop statistical models suitable for detecting invasive conifers based on their spectral and structural properties. A large field dataset (ca. 17,000 trees) was also collected and used to validate the accuracy of the remote detection methods. Detection errors were characterised with reference to the size, age, and coning status of trees measured at the study site.

To address research question two a multi-site case study that encompassed an ecological and site complexity gradient of the vulnerable ecosystems within New Zealand was installed. Across all sites UAV-based models of invasive conifer distributions were developed. These were transferred to all other areas of interest (AOI) within the experimental framework. The experimental design meant that the portability of models both within, and between, sites could be tested. The influence of the complexity of both the donor and receiver site on model predictive accuracy after transfer was also explored. In all cases model accuracy was assessed using cross-validation.

To address research question three a methodology was developed based on an implementation of a land cover change tracking algorithm within Google Earth Engine. This technique was applied to a vast and heterogeneous mountainous area of New Zealand's South Island. The algorithm was carefully configured to identify changes in the pixel-level spectral trajectory within the Landsat archive that might be associated with invasive conifer spread or management control. These change segments were treated as base learners in a subsequent random forest attribution model that defined the causal agent of identified changes in the landscape.

The main findings of the research were as follows.

1. Ultra-high-resolution data was extremely useful for the early detection of invasive conifer invasions including small trees. Critically relatively simple statistical methods were suitable for the detection of 99% of all trees found to be coning.
2. UAV-based invasive conifer distribution models were found to be robust to transfer to different AOIs within the same site without a decrease in accuracy. UAV-based invasive conifer distribution models could be transferred to sites with similar or lower complexity than the sites used for model development without a significant decrease in accuracy. However, models transferred to more complex sites could not produce viable results. Invasive conifer models based on spectral data were found to be more robust to transfer than those based on ALS data.
3. The methodology implemented offered a viable means of detecting vegetation changes over time through the Landsat archive. The attribution models developed had moderate accuracy but substantial class confusion remained. Nevertheless, maps of invasive conifer spread and control for the period 2000 - 2019 could be produced and were accurate enough to be useful for assessing the impact of historical management and land use policy within the expansive study area.

This research has shown that through exploiting a range of different platforms remote sensing can provide critical information for the detection and monitoring of invasive conifers across a wide range of vulnerable environments. Through matching the platform and sensor to the desired application practitioners can acquire accurate information that operates from the sub-tree scale up to the regional or national scale. New knowledge on the portability of UAV-based invasive conifer distribution models has been produced with clear findings that will increase sampling efficiency, and offer guidance for practitioners on when models can be reused and when new training and model development data is required. The most comprehensive systematic review on the use of an emerging remote sensing technology (UAVs) for invasive alien plant detection was also produced. This review has highlighted trends in the current research, research gaps, and offered guidance on future development pathways that must be followed to increase the value that can be extracted from these datasets.

DAVIES, NICHOLAS T. (2019)
HIGH THROUGHPUT BREEDING FOR WOOD QUALITY IMPROVEMENT

Eucalypt species are fast-growing and can produce high quality timber for appearance and structural products including Laminated Veneer Lumber (LVL). Their use for solid wood products is hindered by the fact that they can contain large growth-strains, which im- pose substantial processing costs. Growth-strains are associated with log splitting, warp, collapse and brittle-heart. The body of work presented here focused on the possibility of very-early selection at two years of age, of *Eucalyptus bosistoana* trees for growth- strain and other wood properties, including an in-depth assessment of the accuracy of the methodology used.

Chapter 1 gives an introduction on growth-stresses in trees and how this knowledge devel- oped over the last century. Chapter 2 describes a pilot study assessing wood properties at a young age. Growth-strain was assessed by measuring stem openings after splitting along the pith, which resulted in a left-censored dataset. A Bayesian approach to the analysis was used to increase the accuracy of genetic parameter prediction from the left- censored data. Chapter 3 tested the hypothesis that the reason for the left-censored data was tension wood formed early in growth resulting in a reversed stress profile. The testing showed this was not the case, at least under the given experimental conditions. Chapter 4 describes a very-early selection trial (age 2) of 81 *Eucalyptus bosistoana* families with seven measured traits (growth-strain, under-bark diameter, density, stiffness, volumetric shrinkage, height and acoustic velocity), which yielded heritability estimates of 0.23, 0.57, 0.70, 0.77, 0.39, 0.71, and 0.80 respectively. Following this the precision of the split- ting test was investigated. Chapter 5 describes an experimental approach which found that the splitting test could predict surface growth-strains with

a precision of ±1003 micro- strain (Chapter 5). The accuracy of the splitting test was further investigated in Chapter 6 using a classical mechanics model. The effect of differing surface strain fields on the results of both the splitting test and point measurements such as strain-gauges, indicated that the theoretically obtainable maximum accuracy of the splitting test is approximately ±281 micro-strains. This is similar to four evenly spaced strain-gauges. Finally, Chapter 7 reviews very-early selection and provides guidelines for future breeding projects where reduced cycle times are desired.

DONG, VIET ANH (2019)

UNDERSTANDING FACTORS INFLUENCING NON-INDUSTRIAL PRIVATE FOREST OWNERS' DECISIONS IN PLANTING AND HARVESTING TREES: A CASE STUDY IN THAI NGUYEN PROVINCE, VIETNAM

In the last few decades, the forest management system in Vietnam has switched from being centrally-planned and has become market-oriented. Under the current management model, private ownership is recognised and forests and forestland are allocated to non-industrial private forest owners, who are one of the biggest groups of forest owners in the country. After the transformation of the management model, the forest cover of the country shifted from net deforestation to net reforestation. However, the contribution of forestland allocation to this net reforestation is still a topic of debate.

The central argument for developing this research is that the most important aspect of forest management is the understanding of forest owners' behaviour in planting and harvesting trees. This purpose of this research is therefore to improve the understanding of non- industrial private forest owners' decisions in planting and harvesting trees by performing a case study in Thai Nguyen province, Vietnam.

Institutional Analysis Development (IAD) was used as the principal framework to guide the direction of the research. The data for the study was collected through two interview surveys in 2015 and 2017. Logistic and linear mixed-effects models were used to identify factors affecting the forest owners' decisions in planting and harvesting trees. The best subset selection, Ridge regression and Least Absolute Shrinkage and Selection Operator (LASSO) techniques were used to obtain multiple-predictor models and to quantify the importance of individual predictors in the models.

The results of this study indicate that the most important factor affecting the afforestation intensity of the forest owners is the forest owners' perception of their forestland. It was found that the forest owners who owned forestland in order to generate cash income from forestry activities were more likely to plant trees. Conversely, it was found that the forest owners who considered forestland as an investment tended not to plant trees. Additionally, the total number of forestland plots, annual income and awareness of the government subsidy for establishing forests were positively correlated with afforestation intensity. Meanwhile, age, level of education, total cropland area of the forest owners and total number of people in the workforce in the forest owners' family were negatively correlated with afforestation intensity.

The harvest intensity model was developed with respect to *Acacia mangium* because this is the dominant species planted in the province. The best-fit model indicates that tree age and gender of the forest owners were correlated with harvest intensity. Timber price was positively correlated with harvest intensity. The cost of harvesting also plays a role in describing harvest intensity.

The results of this study suggest that the factors affecting the decisions of the forest owners are diverse. Therefore, it is necessary to develop management tools that allows forestry policy makers to (i) understand their policy-targeted audiences, (ii) test the impact of their policies during the policy-design stage, and (iii) receive feedback from their targeted audiences by observing changes in society. The

approach developed in this comprehensive study is applicable for this purpose and is easily generalisable to a wide range of regions or countries.

DUBEY, MANOJ (2010)

IMPROVEMENTS IN STABILITY, DURABILITY AND MECHANICAL PROPERTIES OF RADIATA PINE WOOD AFTER HEAT-TREATMENT IN A VEGETABLE OIL

Radiata pine is a major plantation grown wood in the Southern hemisphere, but has inferior dimensional stability and low durability compared to other commercial species and the improvement of these features is the focus of this thesis.

Specifically this thesis examines the dimensional stability, durability and mechanical properties of radiata pine after heat-treatment (160-210°C) in linseed oil. Changes in colour, micro-structure and chemistry with heat-treatment were studied. To optimise the treatment results, oil heat-treatment of wood was also carried out after thermo-mechanical compression of wood and the effect of the prior thermo-mechanical compression on stability, durability and mechanical properties were examined.

The oil heat-treated wood turned uniformly darker in colour. The hydrophobicity (Water Repellence Efficiency-WRE up to 30%), dimensional stability (Ant-Swelling Efficiency-ASE up to 60%) and fungal resistance (up to 36%) were improved with the extent of the changes mainly depending on treatment temperature. However, the mechanical properties of oil heat-treated wood were reduced compared to the untreated control group. Accelerated UV weathering tests have shown that the oil heat-treated wood retained its colour and dimensional stability better than the untreated wood (the control group).

The cell wall of treated wood was intact and no distinct structural changes were observed even at the most severe treatment (210°C for 6 hrs). The treatment resulted in changes to the wood chemical constituents, mainly the degradation of hemicelluloses which is believed to be principal reason for alterations in wood properties.

A study of the effect of prolong heating on the linseed oil showed an increase in viscosity with heating time which in turn reduced the oil uptake and water repellency of treated wood. However, no significant difference in the colour and dimensional stability of the treated wood was noticed with oil of different heating ages. Oil absorbed by the wood during heat treatment was removed by organic solvent extraction and its contribution to the weight percentage change and moisture related properties were evaluated. The oil uptake percentage, determined by organic solvent extraction, was greater than the weight percentage loss that was deduced to occur during the heat treatment phase, which was attributed to mass losses or thermal degradation of wood constituents. Moisture excluding efficiency decreased after removal of the oil from treated wood, which suggested that the hydrophobicity of treated wood is affected by oil absorption. The influence of the post-treatment cooling period on properties of treated wood was studied separately. Oil uptake increased substantially with the post-treatment cooling time which in turn affected the hydrophobicity of treated wood although this effect was less important to dimensional stability.

The loss of mechanical properties due to heat-treatment was successfully countered by thermo-mechanical compression of wood prior to the oil heat-treatment. The wood was compressed to 39% of its original thickness without any visible surface checks and cracks. Spring back and compression set recovery in densified wood decreased after oil heat-treatment. This combination treatment also resulted in improved fungal resistance compared to untreated wood.

From this research, it is concluded that oil heat-treatment of radiata pine wood can improve its dimensional stability and durability obviating the need to introduce any persistent toxic chemicals. Thermo-mechanical densification of wood prior to oil heat-treatment can countered the loss of

mechanical properties due to heat-treatment. The heating oil can be re-used in subsequent treatments and oil uptake can be minimised by limiting the post-treatment cooling time without any significant effect on the dimensional stability of treated wood.

FERRERAS MORENO, MANUEL (2021)
COMPUTATIONAL ANALYSIS OF MOLECULAR VIBRATIONAL SPECTRA

Spectroscopic measurements are a foundational tool in chemical research that quantify the interaction between electromagnetic radiation and quantum states of matter. The details of experimental spectra are fundamentally determined by the electronic structure of the system under study, which is the ultimate basis of all its chemical properties. The utility of a spectrum lies in being able to extract detailed information about the way in which nuclei and electrons are organized within the system.

Molecular spectroscopy comprises a set of techniques for obtaining information on the electronic and geometric structure of molecules, both isolated and in different environments, providing information of the systems studied under the measurement conditions in which they have been recorded. Among the most widely used spectroscopic techniques we have *ultraviolet-visible (UV-vis) spectroscopy*, which interrogates transitions between electronic states of molecules; *microwave spectroscopy*, which measures the energy required to transition between different rotational quantum states; *nuclear magnetic resonance spectroscopy*, a technique used mainly in the elucidation of molecular structures, that is based on the absorption of electromagnetic radiation (radio frequency waves) by some atomic nuclei under the influence of a magnetic field; and *vibrational spectroscopy*, the focus of this study, which directly provides information on transitions between vibrational energy levels, and indirectly reflects the composition, structure and bonding of a system. The most common vibrational spectroscopic techniques are Infrared (IR) spectroscopy and Raman spectroscopy. An overview of the principles behind both of these techniques is provided in Appendix A.

The vibrational spectrum is a unique and characteristic physical property of a molecule or material. Thus, vibrational spectra can be used as a "molecular fingerprint" in the identification of unknown samples by comparison with reference spectra. Some examples of this can be found in the characterization and identification of polymers[1-3] as well as their structural and surface properties[4,5]. Also, in the field of biological and medical sciences, the uses of vibrational spectroscopy are widespread in the characterization of lipids, nucleic acids, proteins and peptides, in addition to characterizing disease in animal tissues, recognizing plants and differentiating microbial cells, among others.[6-11] However, in recent times, new industrial and environmental applications of vibrational spectroscopy have been introduced. Industrial applications include the characterization of pharmaceutical materials for production processes,[12-14] food quality analysis,[14,15] identification of the different components of paints[16], pulp and paper quality control[17] and even potentially quantifying strain in wood.[18,19] Environmental applications include air, water and soil analysis, as well as measurement of gases and atmospheric compositions, which is crucial for understanding global climate changes and astronomical observations.[20-25]

However, if reference spectra are unavailable, interpretation of vibrational spectra is much harder. In some cases, vibrations arising from specific functional groups can be assigned using heuristic rules,[26] but in general, computational support is required to ensure vibrational spectra can be thoroughly and meaningfully assigned.[27]

Quantum chemical software packages provide access to a range of electronic structure models that can be used to describe how the energy changes as a function of molecular configuration (i.e. construct potential energy surfaces) and consequently solve the nuclear vibrational Schrödinger equation to

predict vibrational spectra. A hierarchy of electronic structure models of different computational cost and accuracy are available, and these may be combined with a range of different models for predicting nuclear vibrational motion, as well, to yield overall predictions of varying accuracy and computational cost. A brief description of all electronic structure and nuclear vibrational models employed in this thesis is provided in the Methods section.

For small molecules, very accurate predictions of vibrational spectra are possible by constructing potential energy surfaces at high levels of *ab initio* theory and using nuclear vibrational models that account for anharmonicity;[28] the propensity of a molecule to spend more time at longer bond lengths to avoid the repulsive forces that are magnified upon bond compression, and also the way that stretching/compressing a molecule in one way makes it harder/easy to stretch/compress it in a different direction.

Because benchmark results can be generated for small molecules, they provide an ideal testing ground for trialling approximate and less computationally intensive schemes for constructing potential energy surfaces and/or solving the nuclear vibrational Schrodinger equation. In the first results chapter of this thesis (Chapter 3), we address the problem of finding more efficient schemes for constructing potential energy surfaces by taking a "two-level" approach – computing the harmonic part of the potential energy surface that describes symmetric vibrations along normal mode coordinates at a high level of *ab initio* theory, while constructing the remainder of the potential energy surface (the anharmonic region) at a lower level of theory.

The remainder of this thesis focusses on using more approximate nuclear vibrational models to interpret experimental observations. First, we study the nature of two novel chloride hydrates trapped in cyclopropenium chloride crystal. These chloride-water clusters are of fundamental importance in understanding a broad range of physicochemical processes in nature, particularly in biological and geological systems.[29-31] The discreteness of these clusters can be assessed by comparing experimental IR spectra to predicted IR spectra obtained from gas phase calculations. If a cluster is discrete, there will not be any specific interactions stabilizing it, so a gas phase model should provide quite accurate predictions. However, in some cases, specific interactions with the surrounding environment may contribute to forming and/or stabilising a particular chloride hydrate structural motif. In such cases, modelling the IR spectrum is more complicated because environmental effects need to be taken into account. In Chapters 4 & 5, we investigate the structure and vibrational spectroscopy of two quite different chloride hydrate clusters that form within subtly different cyclopropenium chloride crystal environments.

For very large systems, applying quantum nuclear vibrational models can become impractical. In these cases, it may be appropriate to use classical physics-based approaches to modelling macromolecular structure and dynamics. In *Molecular Mechanics (MM)*, the energy of the system is then calculated as a function of the nuclear coordinates with the use of *force fields,* in which atoms are simulated as balls, and bonds as springs. To simulate the time-dependent evolution of the system, we can use Molecular Dynamics (MD) simulations. Further details of how force fields are defined and parameterised is provided in the Methods section, along with an explanation of how molecular dynamics simulations work and how key thermodynamic parameters such as temperature, pressure and volume are set and controlled.

Cellulose, the most abundant material in the biosphere,[32] is one such system that is not particularly amenable to quantum nuclear vibrational analysis.[33] The interest in this polymer has grown in the recent years as it has become a potential source of renewable fuel and materials.[34-38] The presence of hydrogen bonds play an important role, not only in the physical properties, solubility, hydroxyl reactivity and crystallinity, but also in the mechanical properties of cellulose.[39,40] The structure and hydrogen bonding patterns within common allotropes of cellulose (Ia and Ib) have been studied

experimentally and confirmed computationally.[41-47] Although some quantum harmonic frequency calculations have been performed,[45] they are not accurate enough to allow experimental IR spectra to be fully understood or assigned. Thermal shifts in IR stretching frequencies have also been observed.[48,49] Paradoxically, these may be easier to understand and explain than the IR frequencies themselves, because thermal effects can be modelled via classical molecular dynamics simulations.[50,51] In the last results chapter (Chapter 6), we address this problem, using a classical molecular dynamics model to explore how changes in temperature affect O- H stretching vibrations and hydrogen bond lengths, and how this is coupled to and driven by changes along other vibrational modes of crystalline cellulose.

FORBES, ADAM S (2015)
NON-HARVEST *PINUS RADIATA* PLANTATIONS FOR FOREST RESTORATION IN NEW ZEALAND

New Zealand has lost *ca*. 71% of its former indigenous forest cover and this has contributed to the profound impacts, and declining trends, reported for the state of New Zealand's indigenous biodiversity. Today *ca*. 7% of the land area is occupied by exotic plantation forest, 90% of which comprises *Pinus radiata* monocultures. Despite its exotic identity, these *Pinus* plantations are known to facilitate the regeneration of shade-tolerant indigenous forest flora. However, above-ground successional development is lost in commercial plantations when clear-fell forest harvest occurs. Over the life time of a plantation forest, for a range of social, economic, or environmental reasons management objectives might change meaning that plantation owners no longer intend to harvest their forest. Here I introduce the concept that "non-harvest" *P. radiata* plantations provide one option for the long-term restoration of indigenous forest cover in New Zealand.

This research addresses three research questions: (1) What are the long-term forest regeneration patterns in New Zealand's non-harvest *P. radiata* plantations? (2) Which ecological processes act to constrain indigenous forest regeneration processes? (3) How can management intervene to address these constraints, and thereby promote indigenous forest regeneration in exotic non-harvest *P. radiata* plantations?

I surveyed a *ca*. ninety-year chronosequence of *P. radiata* plantations to examine patterns in plantation understorey regeneration and determine the main factors influencing forest regeneration. I conducted an experimental canopy gap study within *ca*. 18-year-old *P. radiata* plantation forest to determine the potential for creation of small-scale artificial canopy gaps as a means of accelerating seedling growth rates of mature forest canopy species. I carried out experimental thinning of dense tree fern dominated *P. radiata* plantation understories to determine the potential of understorey thinning interventions as a means of accelerating seedling growth rates of mature forest canopy species. I surveyed a *ca*. 50-year-old podocarp underplanting trial to determine the potential for accelerating and directing forest succession by underplanting non-harvest *Pinus* stands with mature forest canopy species.

The findings of this research illustrate that the long-term structure and composition of *P. radiata* plantation understory regeneration is strongly influenced by both stand age and proximity to indigenous forest seed sources. The reliable natural establishment of large- fruited, bird-dispersed mature forest canopy species requires the sheltered conditions provided by mature stands, proximal seed sources, and seed dispersal vectors. Creation of small-scale canopy gaps provides a means of increasing light transmission to the plantation understorey, and thereby optimising light levels for the growth of mature forest canopy species. Plantation understories comprising dense tree fern stands were found to significantly reduce both transmitted light and seedling growth rates of mature forest canopy species. Underplanting a degraded and ecologically isolated *Pinus* plantation with indigenous conifers accelerated successional development and provided a means of achieving dominance by mature forest canopy species within only 50 years.

This research shows that the sheltered conditions and long-term stability of "non- harvest" *P. radiata* plantations provide one means of restoring indigenous forest communities in New Zealand. This method of forest restoration is particularly relevant for lowland, commercially-productive, landscapes where indigenous forest loss has been greatest and where opportunities to restore indigenous forest are limited. The research also illustrates the important role of indigenous forest remnants as natural seed sources in the landscape, and thus the importance of maintaining indigenous remnants amongst commercially-productive landscapes. This research shows that while constraints on indigenous forest regeneration within *P. radiata* plantations do exist in the form of competition for light and limited indigenous seed dispersal, management interventions to address these limitations are possible and can successfully accelerate and direct indigenous forest regeneration in non-harvest *P. radiata* plantations. Thus, this research establishes that exotic "non-harvest" plantations can provide an important opportunity for the management and conservation of indigenous biodiversity in New Zealand.

GUO, FEI (2019)

MOLECULAR DEFORMATION OF WOOD AND CELLULOSE STUDIED BY NEAR INFRARED AND RAMAN SPECTROSCOPY

Eucalyptus can be an alternative plantation species to radiata pine for New Zealand. One major problem preventing eucalyptus wood from high-value uses is its high growth-stress level, which causes problems in solid wood processing. Current methods to measure growth-strain are destructive and time-consuming. Growth-stress in wood, like mechanical stress, can cause deformation on the molecular level, which can be detected using spectroscopy. The overreaching objective of this thesis was to investigate the possibility of a non-destructive and rapid spectroscopy-based method to measure strain in wood using near infrared (NIR) and Raman spectroscopy. This work first aimed to demonstrate the effect of growth-stress on veneer production (chapter 2). Before exploring the possibility of measuring growth-strain in trees non-destructively using NIR (chapter 5) and Raman (chapter 6) spectroscopy, a fundamental understanding of molecular strain in wood was gained by studying dry (chapter 3) and deuterated (chapter 4) wood using transmission NIR. NIR is sensitive to moisture. The effects of moisture and instrumentation on the band of interest were also examined in chapter 5.

In chapter 2, the suitability of *Eucalyptus globoidea* for veneer and LVL production was investigated in relation to growth-strain levels. Veneer recovery, veneer splitting and wood properties were evaluated and correlated with growth-strain. Veneers with no, or limited, defects can be obtained from *E. globoidea*. Veneer recovery (54.5%) inversely correlated with growth-strain and was highly variable between logs, ranging from 23.6% to 74.5%. There was a moderate positive association between splitting length and growth-strain ($r = 0.73$), but no significant association with wood stiffness. Growth-strain reduced veneer recovery by splitting, and was largely independent of stiffness, suggesting the possibility of finding trees with both low growth-strain and high stiffness, desirable for structural wood products. The considerable variation in growth-strain and stiffness indicated a possibility for genetic improvement. The unfavourable effects of growth-strain highlighted the demand for a rapid and non-destructive method to evaluate growth-strain levels in wood.

Chapter 3 describes experiments aimed at better understanding the effects of molecular deformation of wood and cellulose on NIR spectra. Dry wood and paper samples were stretched to different strain levels using a purpose-built tensile test device fitted into an NIR spectrometer while collecting transmission spectra. Consistent spectral changes caused by mechanical strain, assigned to OH stretching bands, were observed for all sample types. Bands at 6286 ± 5 cm^{-1} and 6470 ± 10 cm^{-1} were tentatively assigned to the OH groups connected with the 2OH···6O and 3OH···5O intramolecular hydrogen bonds of crystalline cellulose Iβ, respectively. Both bands shifted to higher wavenumbers, indicating the elongation of the hydrogen bonds. A linear relationship was found between band shifts and mechanical strain. Band shift rates for the 3OH bond were more than twice that of the 2OH bond,

consistent with bending of the glycosidic bond. Bending tests showed that the band at around 6286 cm^{-1} shifted in opposite direction when under tension or compression.

Chapter 4 summarises the roles of accessible and inaccessible cellulose in the load transfer of wood using deuterium exchange combined with NIR spectroscopy. The spectral changes on NIR spectra caused by mechanical strain could be highlighted by averaging the loading and unloading cycles to compensate for effects of desorption and isotope re-exchange due to environmental fluctuations. After deuteration, the bands affected by mechanical strain at around 6420, 6240 and 4670 cm^{-1}, which had been assigned to hydroxyl groups in cellulose, remained at these positions, suggesting that the inaccessible cellulose fraction was the main load-bearing component in wood. A small band at around 4700 cm^{-1} responding to mechanical strain was only visible in the deuterated spectra, indicating that accessible hydroxyls also contributed to the load transfer. Furthermore, the measurements confirmed previous reports of moisture adsorption of wood under tensile stress.

Chapter 5 investigated the possibility of measuring growth-strain non-destructively using NIR spectroscopy. This requires the measurement of water-saturated samples by reflection NIR. Results showed that abundant free water in rewetted and never-dried green samples overlapped with the band of interest and weakened the structural information on crystalline cellulose in the NIR spectra; reflection NIR spectra were shown to be of lower quality than transmission spectra. Despite the weak signal for rewetted and green samples, the 6286 cm^{-1} band shifted linearly to higher frequencies with the increase in tensile strain, in both transmission and reflection NIR spectra, because of the elongation of hydrogen bonds in cellulose. Further, NIR band-shift rates were lower for never-dried green samples than for those previously dried, suggesting differences in macroscopic and molecular strain. Lastly, growth-strains of 163 green wood samples were measured destructively using strain gauges and correlated to previously collected NIR spectra. No correlation was found, however, between growth-strain of green stems as measured by strain gauges and the NIR spectra in reflection mode. Challenges included excessive signal overlap at high moisture content, lower signal-to-noise ratio of diffuse reflection compared with transmission NIR spectroscopy, and variations in growth- strain.

In Chapter 6, Raman spectroscopy was examined for its potential to measure growth-strain non-destructively, as the spectra are unaffected by water. A partial least squares model built from the Raman spectra could predict tensile strain with a root mean square error of 427.5 με, in a dataset with growth-strain ranging from −135 με to 4780 με. Apart from the widely reported band shift at 1095 c m^{-1} upon mechanical strain, spectral changes at 1420, 1120, 895, 456 c m^{-1} were identified. These bands might be attributed to the molecular deformation of cellulose. The band shift rates during tensile tests were −3.06 and −2.15 cm^{-1}/% for rewetted and green wood, respectively. As for the NIR measurements, the difference in the Raman band shift rates indicated that less macroscopic strain was transferred into molecular strain for green wood than previously dried wood. This indicated irreversible molecular changes in the wood cell walls upon air-drying below fibre saturation point. Further, Raman spectra were collected from the wood surface of 18 green eucalypt stems before measuring growth-strain. A moderate correlation was found between growth-strain measured with strain gauges and the 1095 cm^{-1} band position. Raman spectroscopy could be used to non-destructively estimate growth-strain with moderate accuracy, but was negatively affected by the inhomogeneity of wood, instrumental instability, and fluorescence effects.

GUO, TINGDONG (2019)

THE EFFECT OF RESIDENTIAL PROPERTY REDEVELOPMENT ON URBAN FOREST DYNAMICS IN CHRISTCHURCH, NEW ZEALAND

As a global phenomenon, many cities are undergoing urban renewal to accommodate rapid growth in urban population. However, urban renewal can struggle to balance social, economic, and environmental outcomes, whereby economic outcomes are often primarily considered by developers. This has important implications for urban forests, which have previously been shown to be negatively

affected by development activities. Urban forests serve the purpose of providing ecosystem services and thus are beneficial to human wellbeing. Better understanding the effect of urban renewal on city trees may help improve urban forest outcomes via effective management and policy strategies, thereby maximising ecosystem service provision and human wellbeing. Though the relationship between certain aspects of development and urban forests has received consideration in previous literature, little research has focused on how the complete property redevelopment cycle affects urban forest dynamics over time. This research provides an opportunity to gain a comprehensive understanding of the effect of residential property redevelopment on urban forest dynamics, at a range of spatial scales, in Christchurch, New Zealand following a series of major earthquakes which occurred in 2010 – 2011. One consequence of the earthquakes is the redevelopment of thousands of properties over a relatively short time-frame. The research quantifies changes in canopy cover city-wide, as well as, tree removal, retention, and planting on individual residential properties. Moreover, the research identifies the underlying reasons for these dynamics, by exploring the roles of socio-economic and demographic factors, the spatial relationships between trees and other infrastructure, and finally, the attitudes of residential property owners.

To quantify the effect of property redevelopment on canopy cover change in Christchurch, this research delineated tree canopy cover city-wide in 2011 and again in 2015. An object-based image analysis (OBIA) technique was applied to aerial imagery and LiDAR data acquired at both time steps, in order to estimate city-wide canopy cover for 2011 and 2015. Changes in tree canopy cover between 2011 and 2015 were then spatially quantified. Tree canopy cover change was also calculated for all meshblocks (a relatively fine-scale geographic boundary) in Christchurch. The results show a relatively small magnitude of tree canopy cover loss, city-wide, from 10.8% to 10.3% between 2011 and 2015, but a statistically significant change in mean tree canopy cover across all the meshblocks. Tree canopy cover losses were more likely to occur in meshblocks containing properties that underwent a complete redevelopment cycle, but the loss was insensitive to the density of redevelopment within meshblocks.

To explore property-scale individual tree dynamics, a mixed-methods approach was used, combining questionnaire data and remote sensing analysis. A mail-based questionnaire was delivered to residential properties to collect resident and household data; 450 residential properties (321 redeveloped, 129 non- redeveloped) returned valid questionnaires and were identified as analysis subjects. Subsequently, 2,422 tree removals and 4,544 tree retentions were identified within the 450 properties; this was done by manually delineating individual tree crowns, based on aerial imagery and LiDAR data, and visually comparing the presence or absence of these trees between 2011 and 2015. The tree removal rate on redeveloped properties (44.0%) was over three times greater than on non-redeveloped properties (13.5%) and the average canopy cover loss on redeveloped properties (52.2%) was significantly greater than on non-redeveloped properties (18.8%).

A classification tree (CT) analysis was used to model individual tree dynamics (i.e. tree removal, tree retention) and candidate explanatory variables (i.e. resident and household, economic, land cover, and spatial variables). The results indicate that the model including land cover, spatial, and economic variables had the best predicting ability for individual tree dynamics (accuracy = 73.4%). Relatively small trees were more likely to be removed, while trees with large crowns were more likely to be retained. Trees were most likely to be removed from redeveloped properties with capital values lower than NZ$1,060,000 if they were within 1.4 m of the boundary of a redeveloped building. Conversely, trees were most likely to be retained if they were on a property that was not redeveloped. The analysis suggested that the resident and household factors included as potential explanatory variables did not influence tree removal or retention.

To conduct a further exploration of the relationship between resident attitudes and actions towards trees on redeveloped versus non-redeveloped properties, this research also asked the landowners from the 450 properties that returned mail questionnaires to indicate their attitudes towards tree management (i.e. tree removal, tree retention, and tree planting) on their properties. The results show that residents

from redeveloped properties were more likely to remove and/or plant trees, while residents from non-redeveloped properties were more likely to retain existing trees. A principal component analysis (PCA) was used to explore resident attitudes towards tree management. The results of the PCA show that residents identified ecosystem disservices (e.g. leaf litter, root damage to infrastructure) as common reasons for tree removal; however, they also noted ecosystem services as important reasons for both tree planting and tree retention on their properties. Moreover, the reasons for tree removal and tree planting varied based on whether residents' property had been redeveloped. Most tree removal occurred on redeveloped properties because trees were in conflict with redevelopment, but occurred on non- redeveloped properties because of perceived poor tree health. Residents from redeveloped properties were more likely to plant trees due to being aesthetically pleasing or to replace trees removed during redevelopment.

Overall, this research adds to, and complements, the existing literature on the effects of residential property redevelopment on urban forest dynamics. The findings of this research provide empirical support for developing specific legislation or policies about urban forest management during residential property redevelopment. The results also imply that urban foresters should enhance public education on the ecosystem services provided by urban forests and thus minimise the potential for tree removal when undertaking property redevelopment.

HARRILL, HUNTER (2014)
IMPROVING CABLE LOGGING OPERATIONS FOR NEW ZEALAND'S STEEP TERRAIN FOREST PLANTATIONS

Cable logging will become more important as harvesting shifts to greater annual proportions on steep terrain in New Zealand. The costs of cable logging are considerably higher than that of conventional ground-based methods. Improving cost-effectiveness has been identified as key to ensuring the forestry industry remains cost competitive in the international market. This thesis focuses on ways to better understand and improve cable logging methods by specifically focusing on rigging configurations. The investigation was conducted through a comprehensive literature review, an industry survey to establish current use and preferences, a Delphi survey with experts to establish actual advantages and disadvantages, scale model testing to establish some fundamental knowledge of tension to deflection relationship, and finally a series of targeted case studies to establish both productivity and skyline tension in actual operations. Each of these aspects of the research topic employed different methodology.

The literature review highlighted the most relevant research relating to cable logging world- wide spanning nearly a century. Various research papers, manuals, books and computer software were summarized. While many aspects of cable yarding operations have been investigated, much of it focusing on various aspects of operational efficiency through case studies, there is very limited information with regard to rigging configurations. The survey of 50 cable logging practitioners determined what rigging configurations were commonly used in New Zealand. It includes their perceived advantages and disadvantages for varying levels of deflection, but also for specific scenarios such as pulling away from native forest boundaries and flying logs over a stream. Results showed that there were many conflicting perceptions about rigging configuration options.

Using an expert panel, a Delphi process was used to derive consensus on what advantages were truly unique to each configuration. This allowed the longer lists of perceived advantages from the industry survey to be pared down to a concise list of ad/disadvantages that will be used in the updating of the Best Practice Guidelines for Cable Logging.

To increase our fundamental understanding of tension/payload/deflection relationships, an experiment was conducted in a controlled environment. Using a model yarder in a lab and continuous tension and video recording devices, the dynamic skyline behavior of three similar configurations were tested:

North Bend, South Bend and Block in the Bight. The tensions were compared by use of a two-way analysis of variance, which indicated configuration and choker length were significant variables in some but not all of the dynamic load tests. Results also showed that some configurations performed better than others in minimizing the shock loads due to dropping into full suspension, impact with ground objects, and breakout during bridling.

Finally, a series of eight studies were conducted on targeted logging operations where relevant stand and terrain parameters were related to the continuous skyline tension monitoring, and recording of productivity through time study. The three targeted configurations included (1) North Bend, (2) Standing skyline using a motorized slack-pulling carriage and (3) a live skyline using a motorized grapple carriage.

Results showed that peak and average tensions, as well as amplification factors and the payload to tension relationship, varied between configurations. The study also showed that tensions could be collected to compute measures of payload and tension efficiency, which provided insight into operational performance. The safe working load was exceeded in 53% of all cycles studied and across seven of eight study sites and 14 of 16 spans. Cycle times were significantly different between rigging configurations and that production information could be used to compute measures of labor and energy consumption as well as payload and tension efficiency; which also provide insight into operational performance.

The industry should give serious consideration to the use of tension monitors. Tension monitors have many benefits and have the potential to improve cable logging operations in New Zealand. Monitoring tensions can help one learn new techniques or methods (i.e. rigging configurations), help improve payload analysis software for future planning and help evaluate new technology and machinery.

HARVEY, G. CAMPBELL (2022)

RESIDUAL WOODY BIOMASS IN NEW ZEALAND'S HARVESTED, STEEPLAND PLANTATION FORESTS

The woody residues generated by harvesting plantation forests in New Zealand present significant management challenges, but also opportunities for productive use. Lack of commercially viable demand for the residues results in large quantities left on harvested cutovers and/or stored at landings. The challenges are most acute on steepland sites, typically characterised by aspects such as difficult extraction and longer distance to market. Demand for the residue material is changing; for example as a substitute for fossil fuels. In a market where greenhouse gas emissions are increasingly monetised, woody biomass is becoming regionally important as an energy source for medium-high heat industrial customers.

Forest owners and/or managers' participation in the developing biomass market requires knowledge of the harvest residues; how much is generated, where it is distributed, and what options are available to manage it. This research aimed to close the divide between producers and potential users and has three main components; (1) using in-field survey, set a current benchmark for residual woody biomass in the steepland harvested cutovers, (2) using geospatial technology, survey residue piles that accumulate at landings and (3) a Delphi survey with industry experts to develop consensus where possible on how best to manage the material. For potential biomass consumers, questions of a regional forest industry's ability to supply woody biomass are important, with significant capital investments in plant relying on the quality of that information.

Woody residues on harvested cutovers have seen little investigation over the previous two decades. Mechanisation has resulted in significant changes to harvesting systems during this time, with an unknown effect on residue volumes or distribution. For the first part of the study, using a refined Line Intersect Sampling method based on the US Forest Service Down Woody Materials survey method, a

total of 17 cutovers were measured across six regions of New Zealand, totalling 185 plots. Plot results for volumes of woody residues >25 mm in diameter ranged from 0 to 580 m^3/ha, with a median of 88 m^3/ha. Of the 88 m^3/ha, 7 m^3/ha was older material ('dead'), the remainder fresh from the harvest ('sound'). When considering a minimum piece size that might be feasible to extract from the cutover (>0.8 m in length and >10 cm in Small End Diameter), 30 m^3/ha was of 'sound' quality. Cable-harvested sites carry higher residual woody biomass volumes on the cutover than ground-based harvests (a statistically significant result). Comparing manual versus mechanised felling methods reveals no significant difference in total residue volumes found in the cutover. This study quantifies the opportunity for greater utilisation of large woody residues across New Zealand's steepland plantation cutovers.

Whole tree harvesting in New Zealand's steepland plantations also results in relatively large volumes of residues (needles, branches and stem offcuts) accumulating at the landing. This by-product of the log-making process is typically piled near the landing and represents a more readily available opportunity for utilisation than cutover residues. Measurement of residue piles is uncommon, however. This second part of the study provides a contemporary benchmark for volumes of residue piles and new remote-sensing methodologies for collecting volume information. UAV imagery collected from 16 harvested sites was used to compute digital surface models of landing residue piles. Through manual interpolation of the terrain obscured by the residue piles, the average bulk residue volume found was 0.23 m^3 per tonne of logs harvested, or 170 m^3 per hectare harvested; with results varying from 40 to 350 m^3/ha. Piles were also assessed for depth using the surface models, as depth is proposed as a key indicator of a pile's self-combustion risk. The average maximum pile depth was 2.6 m: the majority of piles achieving accepted best practice in New Zealand harvesting operations (maximum 3 m). The new methodology allows safe and low-cost data capture and could become an increasingly regular part of forest measurement where forest owners need to make informed decisions about the management of the woody biomass resource, as a product or as an environmental hazard.

A further refinement of the photogrammetry method was proposed and tested in a case study of one steepland landing. The refined method enabled an improved render of the terrain surface under the pile by capturing georeferenced data both pre- and post-harvest. Operational benefits from the procedure include being able to accurately inspect pile depth against best practice guidelines and direct pile rehabilitation efforts with more accuracy. Whilst the improved methodology eliminated an estimation procedure, it also required a second visit to the site and more photogrammetry processing, therefore required more resources. The methodology has been demonstrated as a potential tool for operational foresters to support decision making for residue pile management.

Plantation forests in steepland areas have often replaced pastoral farming due to underlying natural and induced soil erosion processes. Under these circumstances conversion to plantation forestry is intended to provide both improved economic returns as well as longer term land stability. Challenges that are inherent to the terrain are transferred with land use change. In addition to adhering to the respective Regional Plans, the forest industry has sought to manage these environmental challenges by implementing Best Management Practices published by the New Zealand Forest Owners Association. Gaining consensus and support for new practice standards can be challenging; although many participants may already be demonstrating suitable standards with the experience gained from exposure to ongoing operations. Focussing on residual woody biomass in remote steepland forests in this third part of the study, a Delphi survey was completed with twenty forest industry experts across New Zealand. The Delphi process was successful in allowing the participants to put forward opinions, unencumbered by affiliations or personal conflict. The outcome improves our understanding of specific practices and knowledge that could inform the advancement of Best Management Practices and how residual woody biomass might be brought to the market (e.g., where it is not currently). The results of the Delphi indicate an intent to participate in the developing biomass market with harvest residues and also a widespread knowledge of practices and processes that lead to woody residues posing risks to operations, the wider environment and communities. Delphi participants identified practices, specific to scenarios near waterways or at the landing, such as retrieving reside piles off

slopes steeper than 15-20°, whether on natural ground or engineered fill which give a measurable target for future operations. There was a strong preference for site-specific management of residues, rather than 'one-size-fits-all' approaches. An example of this philosophy lies in the management of mature crop trees within waterway margins. Leaving standing trees exposes the riparian margin to the risk of windthrow, while removal of the trees risks soil disturbance and unintentional loading of the waterway with felled woody residues. In the Delphi panel's opinion, limiting the number of management options available could result in adverse environmental, or economic outcomes.

Woody harvest residues can provide a new income stream for steepland forest owners and new supply chain participants. Their productive use also promises to drive better environmental outcomes for erodible steepland forests. With improved knowledge of the production of residues in New Zealand plantation forests, inventories and forward projections can be made by forest owners to provide security of supply for new biomass customers investing in biomass-specific equipment. Without supply security, long-term investments in high capital equipment are tenuous. Where the market cannot reach, residue management will continue to innovate to meet the environmental and social expectations of the time. This thesis provides answers and direction for both market situations.

HURST, JENNIFER (2014)
STAND DYNAMICS OF MIXED-*NOTHOFAGUS* FOREST

Sustainable management of mixed-species forests for timber is underpinned by research on forest stand dynamics and quantification of tree recruitment, growth and mortality rates. Different performance among species across light gradients theoretically prevents more shade-tolerant species from excluding shade-intolerant species, driving succession and allowing species coexistence.

This research investigates stand dynamics and performance trade-offs for co- occurring tree species: *Nothofagus fusca* (red beech) and *Nothofagus menziesii* (silver beech), which together dominate extensive areas of New Zealand's indigenous forest. Using permanent plot data, measurements of permanently tagged individuals are used to quantify recruitment, growth and mortality rates for each species, across size classes and life-history stages (i.e. seedlings, trees). First, seedling growth and mortality is examined in relation to microhabitats (e.g., light, substrate type) and contrasted with patterns of seedling abundance. Second, spatially explicit permanent plot data are used to examine tree growth in relation to competition, local disturbance and tree size over a 23-year period. Third, the influence of competition and disturbance on tree mortality and spatial patterns of tree mortality are examined. Fourth, a simulation model for tree population dynamics is parameterised for mixed-*Nothofagus* forest and used to evaluate long term consequences of disturbances (e.g. alternate harvesting regimes) on structure and composition.

Small-scale disturbance favoured each species at different life stages and for different measures of performance (i.e. recruitment, growth or mortality). *N. fusca* seedlings and trees grew fast in high light microhabitats, such as those created by small- scale disturbances, but adult *N. fusca* mortality was elevated near sites of recent disturbance. By contrast, N. menziesii trees grew faster near sites of recent disturbance, which may help this species persist. Consequently, simulation results showed that small-scale disturbance frequency was a major determinant of forest composition and structure, determining whether *N. fusca* or *N. menziesii* is dominant. The simulation model could be developed further and used to inform the sustainable management of mixed-*Nothofagus* forests.

HUSTEDT, SINA (2010)

A RISK ANALYSIS OF NEW ZEALAND'S BIOSECURITY MANAGEMENT SYSTEM: THE SEA CONTAINER PATHWAY

It is widely acknowledged that international trade is a major pathway for the spread of invasive species. International agreements and domestic legislation aim to reach a balance between facilitating trade and providing nations with the right to protect their environmental, public and economic health. This is achieved through the development of standards that prescribe procedures that must be followed before a commodity is imported. Under Section 22 of the Biosecurity Act (1993) Biosecurity New Zealand of the Ministry of Agriculture and Forestry (MAF) develops import health standards for the importation of commodities and sea containers and for the approval and management of transitional facilities.

Under current regulations, before being allowed to enter New Zealand, a sea container must first be accompanied by appropriate documentation for the sea container itself and any contents (this includes cargo manifests, any required treatment certificates for the cargo and cleaning certificates for the sea container itself). Upon arriving in New Zealand the sea container is transported to a transitional facility for inspection and unloaded once biosecurity clearance has been obtained. There are approximately 7,000 transitional facilities (both on and off wharf) throughout New Zealand and inspections are conducted by persons that have obtained accreditation from MAF for inspections (MAF accredited persons).

Based on current importation procedures and other information made available, mathematical models were developed for three sea importation pathways (sea containers, woodpackaging and used vehicles) that involved the inspection of imported units by MAF accredited persons. These models were designed to predict the effectiveness of the current border inspection policies and procedures. Inspection accuracy was found to have the most influential impact on slippage (the rate at which contamination passes through border procedures undetected) along the measured pathways. Under current conditions, an estimated 5.75% of all sea containers, 4.12% of all sea containers containing woodpackaging and 1.63% of all used vehicles that enter New Zealand annually are contaminated in some manner despite having biosecurity clearance. A 3% increase in inspection efficiency reduced slippage to 0.5% of sea containers, 2.16% of woodpackaging and 0.001% of used vehicles entering New Zealand annually.

Given that the accuracy of the inspection was the most influential aspect of the border management procedures, mathematical models were develop to predict the cost of compliance recovered by MAF if all inspections were conducted by MAF inspectors as apposed to MAF accredited persons. Under current regulations the cost of compliance (if MAF inspector conducted inspections of all imported units) was estimated to be $117.36 million for sea containers, $35.16 million for woodpackaging and $5.44 million for used vehicles. Increasing the inspection accuracy to the ideal 100% increased the cost of compliance by 75.36%, 61.96% and 61.92% for sea containers, woodpackaging and used vehicles respectively.

These findings indicate that Government investment in the training of inspectors throughout New Zealand would improve current border detection rates. Under current regulations, the cost incurred by MAF inspectors inspecting all imported units is recoverable. Currently the cost of compliance is approximately 1% of the value of annual imports. These costs are seen by the import sector as part of their daily business and understand that these measures are in place for the long term sustainability of their businesses (Anon. 2005).

ISKANDAR, DUDI (2011)
THE DECISION MAKING PROCESS IN THE ADOPTION OF AGROFORESTRY TECHNOLOGY BY SMALLHOLDER RUBBER FARMERS IN INDONESIA

The contribution of rubber to national economic and social development is important for Indonesia. However, smallholding rubber, the dominant rubber producer, has low productivity. Various new technology programmes have been introduced by the Indonesian government with other agencies to increase the productivity of existing traditional rubber and incomes among smallholder rubber farmers in Indonesia. However, the adoption of new technology was low and the reasons for these were still unclear.

This study explores how smallholder farmers in Indonesia adopt new technology. Rubber Agroforestry System (RAS) introduced mainly by International Centre for Research in Agroforestry (ICRAF) in Jambi and West Kalimantan provinces in Indonesia is used as a case study. A combination of Ethnographic Decision Tree Modelling (EDTM) proposed by Gladwin (1989a) and a logistic regression model were used as the main methodologies to determine the decision criteria of rubber farmers regarding adoption of clonal rubber. The EDTM as qualitative method helped to identify the main reasons, motivations and constraints that influenced a farmer's decision to adopt or not adopt the new technology and also present details about the process of the farmers' decision making. Meanwhile, logit as the quantitative method was useful to identify the significant variables involved in the decision making process.

The results of this study show that the decision making process for adoption of clonal rubber is complex and influenced by various factors. The decision tree models for Jambi and West Kalimantan differed showing the importance of social context and infrastructure. The main reasons for a farmer's decisions to adopt clonal rubber is the expectation that clonal rubber is better in growth and yield and it will increase production per ha and income. The decision to adopt is supported by evidence from demonstration plots, trust in the technology deliverers and availability of incentives. The main constraint in adoption for both areas was limitation of capital as the clonal rubber required more capital to establish. The other constraints are risk and uncertainties including pest and disease problems, the shortage of labour, lack of technical knowledge, lack of access to clonal seedlings, and observation of clonal rubber that has been of low quality or managed inadequately. The decision tree models have been tested and the results show that the models were able to predict the farmers' decision making with good accuracy of 82% and 83%. In addition, the quantitative model shows the significant factors that determine adoption of clonal rubber in Jambi and West Kalimantan are land, incentives and income factors.

The qualitative and quantitative methods contributed to increased robustness of data and give different kinds of valuable data and information to stakeholders and policy makers in Indonesia. In order to encourage rubber farmers in Jambi and West Kalimantan to adopt clonal rubber, this study suggests improving policies to ensure they are aligned with needs of the rubber farmers, improving farmers' access to capital sources such as credit with simpler mechanisms, increasing the number and skills of extension workers, encouraging farmer to farmer learning, empowering farmers and leadership, improving infrastructure including better access to clonal seedlings and improving partnership with NGOs.

IYIOLA, EBENEZER (2022)
WOOD QUALITY OF DURABLE EUCALYPTS

Eucalypts are used globally on a larger scale for pulpwood than for sawn timber. They are known for high growth stresses which have limited its value and productivity as sawn timber. Previous studies have addressed the growth stress problem in some species but not at a large scale, as they are time consuming and costly to measure. The demand for durable wood is increasing, both in domestic and

international markets, and there is a need to grow durable wood for heavy structural applications such as post and poles. Some eucalypts produce naturally durable heartwood.

This thesis focused on the assessment of early screening of three eucalyptus species for properties such as growth, growth strain, checking/collapse, heartwood diameter, extractive content, volumetric shrinkage, acoustic velocity and stiffness. Chapter 1 gives an overview of growth strain, different methods of assessing durability, collapse in wood, acoustic velocity assessment methods, and genetic parameters in a breeding programme.

Chapter 2 investigates the accuracy of growth strain assessments using the 'splitting' and 'quartering' test method as well as other characteristic properties (acoustic velocity, diameter, air- dry density, dynamic MoE and volumetric shrinkage) of 22 families of *E. bosistoana* at age 2 years old.

Positive phenotypic and genetic correlations ($r_p = 0.78$, $r_g = 0.96$) were found between the 'quartering' and the 'splitting' test. In light of the high genetic correlation, there is no need to consider the more time consuming 'quartering' test for assessing growth strain as the genetic change was insignificant.

Relevant properties revealed promising genetic control ($h^2 = 0.63$ for diameter, $h^2 = 0.16$ to 0.33 for growth strain, and $h^2 = 0.83$ for volumetric shrinkage). Significant variability was also observed for diameter (CGV = 23%), growth strain (CGV = 15 to 23%) and volumetric shrinkage (CGV = 18%) indicating that wood quality improvement through genetic selection is feasible. There was a non-significant favourable negative correlation between dynamic MoE and growth strain ($r_g = -0.22$), and a significant favourable correlation between the volumetric shrinkage and growth strain ($r_g = 0.34$) was reported.

Chapter 3 describes the genetic parameters of wood properties in 83 families of 2-year-old *E. quadrangulata* with the following traits measured: diameter, growth strain, acoustic velocity, dynamic MoE, air-dry density and volumetric shrinkage. The growth strain was assessed in the stem using the 'splitting' test method in the green state by sawing along the length via the pith to measure the distortion and the large end diameter. The growth strain varied from 458 to 4742 $\mu\varepsilon$ with average strain of 1784 $\mu\varepsilon$ and a coefficient of phenotypic variation (CPV) of 26%, while volumetric shrinkage ranged from 17.1% to 36.1% with an average of 19.0% and a CPV of 21%. The traits revealed narrow sense heritability estimates that varied from 0.20 to 0.92 with substantial genetic gain. Phenotypic and genetic variability ranging from 5% to 26% and from 4% to 20% was observed for all the wood properties, respectively.

Wood properties, namely diameter, growth strain, checking, acoustic velocity, dynamic MoE, volumetric shrinkage and air-dry density of 2-, 7- and 8-year-old *E. globoidea* grown from seed or as coppice at two sites in New Zealand were assessed in Chapter 4. Noticeable levels of growth strain (means 2406 $\mu\varepsilon$ to 3084 $\mu\varepsilon$) were present. Therefore, growth strain should be considered in a breeding programme for this species.

Growth strain, volumetric shrinkage and air-dry density were higher in the coppice than at the top of seed-grown trees. As the effects of coppice and stem height were confounded in this study further work is needed to confirm if trees from coppice suffer from higher growth strain.

Checking was observed in discs, indicating challenges for drying *E. globoidea* timber. Heartwood was more prone to checking (4.01%) than sapwood (2.14%). Checking was significant and negatively correlated with growth strain ($r_p = -0.19$) but showed significant positive correlation with growth ($r_p = 0.22$) suggesting that bigger trees are more likely to have a checking problem.

Substantial variability was revealed for growth strain (CPV = 19% to 24%) and checking (CPV = 83% to 102%), the traits most likely causing wood quality issues for *E. globoidea*, suggesting possibilities of improvement in a breeding programme if the trait is heritable.

Chapter 5 describes genetic variation in wood properties of mid-rotation age of 141 families of *E. globoidea* by assessing the following traits: heartwood diameter, core length, combined sapwood diameter, heartwood collapse, sapwood collapse, standing tree acoustic velocity and extractive content in the heartwood. Heartwood diameter ranged from 0 to 190 mm with heritability (h^2) of 0.51. Predicted extractive content ranged from −4.4% to 31.7% and had a value for h^2 of 1.16. Collapse was higher in the heartwood than in the sapwood and heartwood collapse revealed genetic control of h^2 = 0.30) while lower heritability was found for sapwood collapse (h^2 = 0.12). Heritability for acoustic velocity was h^2 = 0.36. There was significant positive genetic correlation between the heartwood diameter and the core length (r_g = 0.88), that is, large trees also having the most heartwood. However, a significant negative correlation was revealed between the heartwood diameter and extractive content (r_g = −0.45), indicating that a compromise is required for simultaneous genetic selection to be feasible. Genetic gain, especially for heartwood diameter, growth and extractives, can be realised in this species. However, improving acoustic velocity for this species might be challenging, as low genetic variation (CGV = 6%) was observed.

KEYE, CONSTANZE (2017)

SELECTION AND PERFORMANCE OF ECOSYSTEM ATTRIBUTES FOR ASSESSMENT OF RESTORATION SUCCESS IN BIODIVERSITY OFFSET MODELS

Biodiversity offsets are an international emerging impact assessment tool, attempting to bridge the gap between biodiversity conservation and sustainable economic development. Offsets shall compensate for unavoidable ecological damage after appropriate prevention and mitigation measures have been taken so that there is no net loss and ultimately a net gain for biodiversity near the impact site. Worldwide, ecologists are being challenged in choosing the most appropriate ecosystem attributes for use in biodiversity offset models. Attributes ought to represent the key biodiversity features at a given site, be quantifiable, easy to measure, reliable, and sensitive to management actions. However, biodiversity is complex and not easy to describe or measure, especially in the context of offsetting. Determining which attributes are the most appropriate for this task is currently compromised by the lack of a theoretical framework. To ensure that offsetting does result in genuine biodiversity retention, attribute choice has to be based on a sound scientific basis.

To help establish such a foundation, this thesis first suggests a conceptual framework for attribute selection in forest ecosystems. Then ecosystem attributes commonly applied or suggested for the assessment of restoration success in forests are reviewed and a set that appears to be most suitable for application in biodiversity offsets is identified. Second, the performance of vegetation related attributes in terms of their predictability and information content are tested in a New Zealand restoration project using a chronosequence approach. Third, the surrogacy value of these vegetation measures for other species groups and ecosystem function is assessed. In particular, how well the recovery of aboveground attributes can predict the restoration of belowground attributes is assessed. This is critical, as typically the largest amount of site biodiversity occurs below-ground. Finally, a general set of attributes that will be applicable in most forest types is identified for biodiversity offset models. In addition, further recommendations for attribute selection within offsets models and how to manage uncertainty associated with them are given.

Results of this thesis suggest that: (i) Structural elements such as basal area and mean diameter are the most predictable attributes, providing important information about the successional development of forests. (ii) Compositional measures can be less predictable but provide the highest information content.

Predictability of these measures can be optimised if early to mid-successional stages are used as a restoration target and if restoration includes active management such as planting. (iii) Vegetation measures do not correlate well with the recovery of belowground species groups, but further research is necessary to confirm this. (iv) This research emphasises that the re-creation of old growth forest attributes can take several centuries when starting from early successional stages. It might be also surrounded by a high uncertainty in respect to compositional development; in particular, when passive reestablishment of vegetation is applied as a restoration tool. Therefore, achieving a no net loss of biodiversity as required by biodiversity offsets might, in many cases, be doubtful when offsetting for the loss of old growth forest habitats.

LALIBERTÉ, ETIENNE (2011)

LAND-USE INTENSIFICATION IN GRAZING SYSTEMS: PLANT TRAIT RESPONSES AND FEEDBACKS TO ECOSYSTEM FUNCTIONING AND RESILIENCE

Land-use change is the single most important global driver of changes in biodiversity. Such changes in biodiversity, in turn, are expected to influence the functioning of ecosystems and their resilience to environmental pertur- bations and disturbances. It is widely recognised that the use of functional traits and functional diversity (FD) is best for understanding the causes and functional consequences of changes in biodiversity, but conceptual develop- ment has outpaced empirical applications. This thesis explores these ideas in grazing systems, which are expected to undergo rapid intensification of fertiliser use and grazing pressure to meet the growing global demand for livestock products.

First, a flexible framework for measuring different facets of FD is de- scribed, and a new multidimensional FD index, called functional dispersion (FDis), is presented. Second, two vegetation sampling methods are com- pared with regard to their ability to detect changes in vegetation compo- sition. Third, shifts in plant trait distributions following land-use changes are quantified and compared to null models, and a maximum entropy ap- proach is used to quantify the direction and strength of selection on each trait. Fourth, it is shown that these shifts in trait distributions have cascad- ing effects on primary production, litter decomposition, soil respiration, and ultimately soil carbon sequestration. Finally, data from 18 land-use intensity gradients are used to show that land-use intensification reduces functional redundancy and response diversity, two components of biodiversity that are thought to influence ecosystem resilience to future disturbances.

This study illustrates (i) the importance of considering species functional differences to understand how plant communities react to changes in soil resource availability and grazing pressure, and (ii) how such changes directly, indirectly, and interactively control ecosystem functioning, as well as (iii) increasing the vulnerability of ecosystems to future disturbances.

LI, YANJIE (2018)

USE OF NEAR INFRARED SPECTROSCOPY TO PREDICT WOOD TRAITS IN *EUCALYPTUS* SPECIES

New Zealand is known for radiata pine (*Pinus radiata*) plantations, a pale coloured and non- durable timber. It is used in many agricultural and industrial sector products such as posts and poles. Wood preservatives are used to protect the non-durable timber against decay. One of the most widely used wood preservatives is the inorganic water-based preservative copper chrome arsenate (CCA). Wood preservatives give rise to environmental problems. CCA has been largely banned for most uses in the USA, Europe and Australia. There is a large demand for natural durable timbers in both the domestic market and international market. Naturally durable timbers often come from tropical forests and are frequently supplied from illegal/unsustainable sources. Such timber also has colour and is often used in the furniture industry. According to the NZ Ministry of Primary Industries' annual forestry imports statistics (https://catalogue.data.govt.nz/dataset/annual-forestry-import-statistics), over $50 million of

sawn hardwood timber and $36 million of wooden furniture were imported by New Zealand in 2017 as a result of a lacking suitable domestic resource.

Some eucalyptus species have high natural durability and colour. The natural durability makes them ideal for wide-ranging agricultural and industrial use, particularly for posts and poles. *Eucalyptus bosistoana* has class 1 natural durability and a fast growth rate in New Zealand's climate. *E. bosistoana* can grow up to 30-40 m in height and usually has wood of excellent stiffness, high density and hardness.

The New Zealand Dryland Forests Initiative (NZDFI) was established in 2008 and aims to establish a sustainable naturally durable timber industry in New Zealand. It choose *E. bosistoana* as the main durable species for genetic improvement. NZDFI's durable eucalypts will produce high value naturally durable timber to meet the future demand of durable timber and replace CCA and illegal tropical hardwood.

A successful plantation industry needs to ensure quality (i.e. natural durability of the wood). Due to differences in genetics, environment and tree age, heartwood quantity and natural durability vary significantly within a specie and tree. Breeding can be an efficient way to reduce variability.

The primary objectives of this research were:

1) Develop a method to quickly assess heartwood traits for inclusion in a large scale breeding programme.
2) Assess genetic control over heartwood traits in *E. bosistoana*.

To achieve these objectives, this thesis also investigated:

a) The distribution of extractives within a tree.
b) Optimisation of the sampling technique.
c) The possibility to apply the technique to other durable eucalypts species in the breeding programme.

Chapter 1: General Introduction and literature review

A literature review highlighted that to obtain high quality for naturally durable wood, it is necessary and possible to ensure consistency through a breeding programme. Traditional methods to assess heartwood are time- and cost-consuming and need to be replaced to allow inclusion of heartwood traits in a tree breeding programme. Near infrared (NIR) spectroscopy has been successfully used to analyse heartwood.

Chapter 2: Effects of variable selection and processing of NIR and ATR-IR spectra on prediction of extractives content in *Eucalyptus bosistoana* heartwood

The use of quick attenuated total reflectance infrared (ATR-IR) spectroscopy and NIR spectroscopy to predict extractives content (EC) in the heartwood of *E. bosistoana* with partial least squares regression (PLSR) models was studied. Different spectra pre-processing methods and variable selection were tested for calibration optimisation. While variable selection substantially improved the NIR-PLSR models, only small effects were observed for spectra pre-processing methods and ATR-IR-PLSR models. Both, the NIR-PLSR and ATR- IR-PLSR models yielded reliably EC results with high R^2 and low root mean square error (RMSE). NIR based models performed better (RMSE 0.9%) than ATR-IR based models (RMSE 1.6%). Analysis showed that the models were based on IR signals assigned to chemical structures known from eucalyptus heartwood extracts. Combined with PLSR and

variable selection, both, ATR-IR and the NIR spectroscopy, can be used to quickly predict EC in *E. bosistoana*, a measure needed in tree breeding and quality control of for durable timber.

Chapter 3: Predicting extractives content of *Eucalyptus bosistoan*a F. Muell. heartwood from stem cores by near infrared spectroscopy

Time and resource are the restricting factors for the wider use of chemical information of wood in tree breeding programmes. NIR spectroscopy offers an advantage over wet-chemical analysis in these aspects, this work describes the development of a NIR-based assessment of EC in the heartwood of *E. bosistoana*, which does not require milling and conditioning of the samples. This was achieved by applying signal processing algorithms (external parameter orthogonalisation (EPO) and significance multivariate correlation (sMC)) to spectra obtained from solid wood cores, which were able to correct for moisture content, grain direction and sample form. The accuracy of EC predictions was further improved by variable selection, resulting in a root mean square error of 1.27%. Considering the range of EC in *E. bosistoana* heartwood of 1.3 to 15.0%, the developed NIR calibration has the potential to be used in an *E. bosistoana* breeding programme or to assess the special variation in EC throughout a stem.

Chapter 4: Application of Near Infrared spectroscopy to heartwood of three durable eucalypts for quantification of extractives and species identification

This chapter describes the use of NIR spectroscopy to quickly determine the EC in the natural durable heartwood of the three eucalypts, *Eucalyptus bosistoana*, *E. globoidea* and *E. argophloia*. PLSR prediction models combined with variable selection considering all species predicted the EC with a residual mean square error (RMSE) of 0.90%, a better result than achieved for smaller datasets from single species. Considering the EC range of 0.34 to 18.85%, this method can be used to select durable breeds, an otherwise time and resource consuming property to measure. Key signals in the NIR spectra for the PLSR models were shared between the species and related to common chemical structures reported from eucalyptus heartwood extracts. Furthermore, it was possible to determine the species from NIR spectra with 100% accuracy, indicating that NIR spectroscopy can be used as a non-destructive method to segregate timber form mixed-species forest plantations.

Chapter 5: Distribution of extractives within trees

The radial and vertical of EC distributions in roots and tree stems were studied. In older trees, the inner heartwood showed a lower EC than the outer part of heartwood. Roots contained heartwood. The middle section of roots had the largest heartwood area and highest EC. In stems of older trees, EC was highest at medium height. Young tree stems and roots did not show a marked radial profile of EC in heartwood.

Chapter 6: Genetic variation in heartwood properties and growth traits of Eucalyptus bosistoana

Forty-one *E. bosistoana* families were evaluated for the production of heartwood quantity and quality in two sites. High estimated heritabilities of heartwood diameter (HWD) were found in both sites (h = 0.66 and 0.71). The estimated heritabilities of EC were lower with 0.16 and 0.25. Weak genetic correlations between HWD and EC were found in one site, but highly negative (-0.86) genetic correlations were observed in the other. The G E interaction had no significant influence on growth traits but a small level influence on EC. Five families were selected for tree breeding as they produced both, large HWD and high EC, in both sites. The data suggested that genetic breeding selection could improve the heartwood quantity and quality of *E. bosistoana* plantations.

LIN, HUIMIN (2018)

RISK AND IMPACT OF INSECT HERBIVORES ON THE DEVELOPMENT OF DRYLAND *EUCALYPTUS* FORESTRY IN NEW ZEALAND

Eucalyptus plantations in New Zealand are occupied by a number of exotic insect defoliators and have increasing risks of new pest incursions. Pest outbreaks causing significant defoliation can reduce tree growth and productivity. Integrated pest management (IPM) strategy is useful to reduce potential risk of insect outbreaks and minimise pesticide use that has negative impacts on the environment. However, IPM in forestry plantations in New Zealand is still in its infancy. An industry centred on the production of naturally durable wood products is being developed in dryland areas in New Zealand. One of the priority species in the emergent industry is *Eucalyptus bosistoana,* which is drought tolerant and can produce highly durable heartwood. For durable species, including *E. bosistoana* to be considered as a commercially valuable option for planting in the future, we need to understand the risk and impact of currently present insect defoliators on these species.

Understanding the population dynamics of key insect defoliators is essential to predict their outbreak potential. Hence, insect surveys were conducted for *Paropsis charybdis*, *Opodiphthera eucalypti, Strepsicrates macropetana* and *Phylacteophaga froggatti* over two growing seasons in a dryland *E. bosistoana* site. Additionally, an insect development assay was conducted in the laboratory to attain base temperatures and degree-day requirements (DD) of life stages of *P. charybdis* (the most important eucalypt insect pest in New Zealand) to construct a DD model to simulate its phenology. Results showed that the observation of one generation of *P. charybdis* was different from previous studies, likely due to the drought conditions at the site. One to two generations were observed for *O. eucalypti*, and multiple overlapping generations were observed for *S. macropetana* and *Ph. froggatti*. The model was most capable of predicting voltinism of *P. charybdis* under the scenario assuming longer DD requirement of median egg laying age and hibernation start by 20 March, or a scenario with assumptions of shorter DD requirement of median egg laying age, hibernation start by 20 March and later over- winter adult emergence date (late September). Prediction of appearance of life stages was not highly accurate, but models that assumed shorter DD requirement for the median egg laying age tended to be the most accurate.

To assess the impact of defoliation on the growth of young *E. bosistoana* in dryland area, a trial simulating different defoliation severity (moderate and severe defoliation) and timing (spring and late summer, and spring plus late summer) effects on the growth of *E. bosistoana* was conducted. Only spring moderate defoliation did not significantly reduce tree growth, while other defoliation treatments significantly reduced either diameter or height growth. Severity of defoliation had a negative relationship with tree growth, but there was no significant difference observed between moderate and severe defoliation treatments. Late summer defoliation had a larger impact than spring defoliation, and this was exacerbated by defoliation severity. Repeated defoliation had greater negative impact on tree growth relative to single defoliation events. These results imply that spring moderate defoliation may not require pest control.

With the objective to identify families of *E. bosistoana* that have higher/lower resistance or tolerance to insect defoliation, and the most suitable method for this purpose, tree health assessments were conducted on 14 *E. bosistoana* families and 1 *E. globoidea* family using four assessment methods (based on defoliation levels and pest loads) over two growing seasons in an *E. bosistoana* site. Significant variation in insect susceptibility and tolerance was found between *E. bosistoana* families to the examined pest species except *O. eucalypti*. Southern provenance families were found to be more insect tolerant. The single *E. globoidea* family and Family 125 (Bungonia provanence) of *E. bosistoana* were found to be relatively fast growing and resistant to examined pests. These families should be maintained in the breeding programme.

To assess the between species variation in susceptibility to *Paropsisterna variicollis*, tree heath assessments were also conducted on 11 durable eucalypt species at three dryland sites in the Hawke's Bay region in the North Island. Significant between species variation in defoliation and pest loads of *Pst. variicollis* was observed. The most susceptible species tested were *E. tricarpa* and *E. bosistoana*, while the least susceptible species were *E. macrorhyncha*.

Implications of the thesis cover three aspects of IPM, including pest monitoring, defining control action thresholds and tree improvement (selective breeding) to reduce insect outbreaks. The findings from this thesis can be applied more broadly to the sustainable IPM of the developing New Zealand durable eucalypt industry and the wider plantation forestry industry.

LOZA-BALBUENA, ISABEL (2009)
POTENTIAL OF THE NEW ZEALAND FOREST SECTOR TO MITIGATE CLIMATE CHANGE

New Zealand is both an Annex I Party to the UNFCCC, and an Annex B country of the Kyoto Protocol. By ratifying the latter, NZ has committed to reduce greenhouse gas emission to 1990 levels. The country should take domestic actions and can also use any of the Kyoto Protocol flexible mechanisms. Afforestation and reforestation on low carbon density land has been recognised as a carbon sink and hence a possible mitigation option for climate change. The current situation for New Zealand is that at last over the first commitment period (2008-2012) the country is in deficit, because emissions have continued to grow over the 1990 level, there is an increase in the deforestation rate and lower rates of new planting.

The objective of this study is to analyse the potential of the New Zealand forest sector as an integrated system to mitigate climate change. It also analyses the impact of different mechanisms on potential area of new land planting, management of stands, and the supply, allocation, and demand of wood, and wood products.

The New Zealand forest industry carbon balance (i.e. net atmospheric exchange minus emissions) is modelled for different national estate scenarios, log allocation of harvested volume and residues used for bioenergy. The net present value of these scenarios is estimated and the economic viability assessed. The level of incentives needed to increase the returns to an economically viable level is estimated in term of carbon unit value ($/tC). Moreover the land use economics at a project level (land market value vs land expectation value) is assessed. Incentives needed in monetary terms and carbon value are also estimated. The implications of discounting carbon benefits are discussed.

It was found that the carbon balance of the whole industry should be analysed for policy development on climate change mitigation options. New planting, longer rotation ages, avoiding deforestation, and allocating additional harvested volume to sawmills showed positive impact to the atmosphere. New planting appeared to be not economically viable, thus incentives are needed. It is acknowledged that, there are emissions from the sector that were not included, and that data and models used need further research to improve the accuracy of the results. Moreover, assumptions on the economic issue and an analysis of simultaneous implementation of more than one mitigation option would also improve the results.

MAGALHÃES CORDEIRO TEIXEIRA, ANA (2022)
POST-FIRE ECOLOGICAL RESTORATION AND LANDSCAPE MANAGEMENT ON THE PORT HILLS, SOUTH ISLAND, NEW ZEALAND

Wildfires are becoming more frequent in ecosystems that evolved with limited exposure to fire (non-fire-prone). For example, the non-fire-prone native forests in New Zealand are under increasing fire

pressure, as fire events have been occurring more frequently in recent decades and are predicted to continue increasing as a consequence of climate change. In non-fire-prone ecosystems, fires are usually catastrophic, causing severe vegetation damage and presenting major challenges for restoration as the flora is poorly fire adapted. The aim of this research was to understand the post- fire responses of the native woody vegetation after one of the most catastrophic fires in New Zealand's recent history, the 2017 Port Hills wildfire, and to provide restoration and landscape management strategies focused on reducing the negative impacts of wildfires.

In order to clarify the context in which the 2017 fire took place and to identify the vegetation types affected by the fire, historical changes in land cover over the last four decades were explored by comparing historical aerial photography with pre- and post-fire orthophotography. Then, aiming to assess the post-fire responses of the vegetation, specifically the capacity of species to resprout, plots were established and monitored across the burnt patches of native forest. In addition, the resprouting analysis was expanded for the whole country through a review of the available literature. Finally, given the increased demand for restoration triggered by this fire event and the need to understand the main factors influencing seedling performance, restoration plantings were established and monitored across the burnt landscape.

The results show that the landscape switched from grassy- to woody-dominated over the last four decades, with extensive pasturelands converted into Pinus radiata forests. The resprouting investigation demonstrated that a few New Zealand native species are capable of resprouting after fire, and that the pre-fire vegetation composition and abundance of species are important predictors of resprouting patterns at the community level post-fire. The restoration experiment showed that seedling performance is species specific, and influenced by the predominant vegetation types pre- fire, weed control treatment post-fire and the initial height of seedlings at planting.

In general, changes in land cover, such as the increase in *P. radiata* plantations and reduced grazing intensity, probably exacerbated the effects of the 2017 wildfire. Recommendations are, therefore, made for management actions to focus on reducing the impacts of future wildfires, for example through the establishment of fuel breaks and green firebreaks across the most flammable vegetation types. Ultimately, by interpreting and integrating all the results, a novel approach that incorporates resprouting into restoration planning is proposed for regions increasingly susceptible to future wildfire events. By planting higher proportions of species capable of resprouting, it may be possible to engineer restored native forests to be more fire resilient and more resistant to invasion by fire- adapted exotic species.

MANN, LESLIE (2023)
QUANTIFYING VARIATION IN PAROPSINE DEFOLIATION WITHIN *EUCALYPTUS*

This thesis developed various methods to quantify and better understand paropsine (Coleoptera: Chrysomelidae) defoliation within *Eucalyptus*, with the overarching goal of reducing herbivore damage in plantation forests. To date, paropsine preferences and impacts on *Eucalyptus* in New Zealand remain poorly understood with only a few published studies (Lin et al., 2017a; Radics et al., 2018; Withers et al., 2017). Furthermore, defoliation was previously measured with visual ground-based assessment; as a consequence, quantifying defoliation is semi-subjective. Research needs to be undertaken to fill these knowledge gaps. This thesis expands on the work of Lin (2017) and includes *E. bosistoana* families and other *Eucalyptus* species identified as priority species by the New Zealand Dryland Forest Initiative (NZDFI). This thesis is composed of five chapters, which seek to improve our knowledge of *Eucalyptus* tolerance and resistance to paropsine defoliation. The first chapter is a review of previous literature, followed by four separate, but interconnected chapters detailing experimental results, which are summarised in a final concluding chapter.

In chapter one, my literature review identifies knowledge gaps, especially with regard to *Eucalyptus* tolerance and resistance (Lin (2017a) already reviewed differences in *Eucalyptus* species resistance in the North Island) to paropsine beetles in the South Island, what drives paropsine beetle preferences, and the way that defoliation is currently assessed in the field. These gaps led me to develop four main research questions, each of which was explored by one of the four subsequent chapters. My research questions were:

1. Are there *Eucalyptus* species, *Eucalyptus bosistoana* families, clones or even provenances that are more resistant or tolerant to paropsine defoliation?
2. Are there *Eucalyptus* species more tolerant to controlled artificial defoliation at different water deficit?
3. Is there a relationship between *Eucalyptus* foliar chemistry and paropsine defoliation?
4. Can remote sensing be used to reliably quantify *Eucalyptus* paropsine defoliation?

In chapter two, seven *Eucalyptus* species from two subgenera (Symphyomyrtus subg.: *E. bosistoana, E. camaldulensis*, *E. tricarpa*, *E. quadrangulata,* and *E. cladocalyx;* Eucalyptus subg.: *E. globoidea*
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and *E. macrorhyncha*), 74 *Eucalyptus bosistoana* families and 132 *Eucalyptus bosistoana* genotypes (clones) were measured in the Marlborough region between December 2019 and March 2021 to investigate variation in their resistance and tolerance to paropsine defoliation. Resistance was measured with the Crown Damage Index (CDI) and tolerance was measured with growth (height gain, DBH gain and new stem length) over time. Compared to the Symphyomyrtus subgenus, the Eucalyptus subgenus was generally more resistant to paropsine defoliation, with the exception of *E. cladocalyx*. *Eucalyptus cladocalyx*, *E. macrorhyncha* and *E. globoidea* were the most resistant to paropsine defoliation. *Eucalyptus bosistoana's* most resistant family and genotype were family 805 and genotype 839a. *Eucalyptus quadrangulata*, *E. bosistoana*, *E. tricarpa* and *E. camaldulensis* were all potentially tolerant regarding the new stem growth, whereas *E. cladocalyx*, *E. macrorhyncha* and *E. globoidea* were the most tolerant regarding the height and DBH growth. The *E. bosistoana* family 835 and genotype 24a were potentially tolerant.

In chapter three, two *Eucalyptus* species (*E. bosistoana* and *E. globoidea*) were placed in a greenhouse for 101 days to test defoliation and water tolerance in a more controlled environment. Three artificial defoliation severity levels, two water levels and two defoliation frequency levels were applied. Tree growth (height and diameter gain), dry biomass (total, leaf, stem, root) as well as leaf carbon and nitrogen content were measured. Both species were negatively affected by water stress, meaning that planting these species in drylands will likely exacerbate the negative impact of paropsines. Nevertheless, *E. globoidea* was more resistant to water deficit and defoliation than *E. bosistoana*. Low levels of defoliation stimulated *E. bosistoana* biomass (overcompensation), but high levels of defoliation negatively impacted this species. *E. globoidea* may generate taller trees as a mechanism to tolerate defoliation, whereas *E. bosistoana* may produce trees with denser overall biomass (stem in particular) and narrower trunk. Compared to trees that had only been defoliated once, trees that had been defoliated twice grew less. This demonstrated that both species exhibit some elements of tolerance to defoliation, but *E. globoidea* is more tolerant than *E. bosistoana*.

In chapter four, leaves from seven *Eucalyptus* species from two subgenera (Symphyomyrtus subg.: *E. bosistoana, E. camaldulensis*, *E. tricarpa*, *E. quadrangulata,* and *E. cladocalyx;* Eucalyptus subg.: *E. globoidea* and *E. macrorhyncha*) were collected in a trial from the Marlborough region to study the iv

potential relationship between foliar chemistry and paropsine defoliation. The leaves were then oven-dried, ground, extracted with ethanol and analysed with a High Performance Liquid Chromatography (HPLC). The *Eucalyptus* subgenus Symphyomyrtus and Eucalyptus foliar compound diversity were distinct. These preliminary experimental results suggest a relationship between foliar chemicals and paropsine defoliation. Defoliated species had higher foliar compound concentration and richness than

non-defoliated species, except for *E. camaldulensis*, which displayed low foliar compound concentration and richness despite being significantly defoliated. Two compounds specific to *E. cladocalyx* may be paropsine repellent.

In chapter five, six *Eucalyptus* species from two subgenera (Symphyomyrtus subg.: *E. bosistoana, E. camaldulensis*, *E. tricarpa*, *E. quadrangulata,* and *E. cladocalyx;* Eucalyptus subg.: *E. globoidea*) were measured in a trial from the Canterbury region with three LiDAR sensors to assess the potential of this technology to accurately detect defoliation. LiDAR data were compared to Crown Damage Index (CDI) field measurements to assess its prediction accuracy. The 5 % accuracy difference among the three LiDAR sensors under evaluation indicated that each could be useful for predicting paropsine defoliation and show good promise for further experiments. The most effective LiDAR metrics for predicting paropsine defoliation on *Eucalyptus* trees were itot, zimean, imax, imean, and isd, with zkurt, zpcum2 to zpcum9, p1th to p3th, pzabovemean, pzabove2, and ipcumzq10 to 70 being less useful. All of these metrics are related to either tree height or foliage density (canopy cover).

My results contributed to a better understanding of tolerance and resistance to paropsine beetle within *Eucalyptus*. This contributes to limiting the effect of paropsine on the *Eucalyptus* forest industry. These findings are a valuable starting point to deeper exploration and guiding future *Eucalyptus* breeding in terms of paropsine herbivory.

MARTANA, KADIM (2014)

MODELLING SOCIO-ECONOMIC IMPACTS OF REDUCING EMISSIONS FROM DEFORESTATION AND FOREST DEGRADATION-BASED POLICY: A CASE STUDY OF INDONESIA

The Government of Indonesia is committed to cut its emissions by 26% by 2020. In forestry sector, this is done through reducing emissions from deforestation and forest degradation (REDD) program. Following up the commitment, several pilot activities of the REDD Program in Indonesia including the Berau Forest Carbon Program (BFCP) which is located in the Berau District East Kalimantan Indonesia are carried out. The program set measures to reduce emissions, particularly in the forestry sector. One of the identified activity is the implementation of reduced-impact logging in the logging sector, which is complemented by other approaches.

This main research aims to investigate the economy-wide impact of implementing RIL on the Berau Economy. For the purpose, a dynamic recursive CGE model for the Berau District East Kalimantan Province Indonesia was constructed, and was used to simulate a policy to implement reduced-impact logging (RIL). To provide input for the Berau CGE model, surveyed of relevant experts' opinion method was utilised to obtain and confirm the impact of implementing RIL on the logging costs. The surveyed experts opinion was alsom employed to obtain estimate of the incentive require for maintaining RIL application within the logging sector of the District. Aggregate surveyed opinion revealed that implementing RIL will the logging production cost to increase, and incentives are required to compensate the cost incurred due to application of RIL.

In general impact of the RIL policy is negative on the Berau economy suggested by the loss in gross domestic products, and other macro-economic variables. Providing compensation, which is simulated as a logging output-based subsidy, improves the Berau economy, although to only a lesser degree. Worker household (particularly agricultural worker) type is the most negatively affected.

The RIL policy causes a significant negative impact on the logging output which further leads to declining output of forest-based and pulp & paper industries. The RIL implementation, however, simulates production increase in some other agricultural activities (notably in oil palm plantation). Furthermore, results simulations with the logging output-based subsidy suggest that magnitude of

economic impacts is reduced than what would otherwise occur in the scenario of implementing RIL only (no subsidy is provided).

The RIL policy seems to give signal of 'unexpected' emissions leakage indicated by increases in output of some agricultural-based activities such as oil plan plantation, other estate crops, and food crops. Increase in emission is also expected to occur outside the Berau District as indicated by the increase in the District's imports.

MEIFORTH, JANE J. (2020)
NEW ZEALAND KAURI TREES – IDENTIFICATION AND CANOPY STRESS ANALYSIS WITH OPTICAL REMOTE SENSING AND LIDAR DATA

The endemic New Zealand kauri trees (*Agathis australis* (D.Don) Lindl.) are a key species in New Zealand's northern indigenous forests. As one of the largest and longest-lived trees in the world, mature kauri are a tourist attraction and have high cultural significance for local Māori. However, the trees are threatened by the deadly kauri dieback disease (*Phytophthora agathidicida* (PA)). Over the last decade, PA has been detected throughout most of the kauri distribution area. PA is a soil-borne pathogen that enters the trees via the root system and causes collar rot, thereby blocking the transport of water and nutrients to the canopy, eventually killing the tree.

This thesis aims to develop methods based on remote sensing to automatically identify kauri trees and detect stress symptoms in their canopy. It is important to note that canopy stress symptoms are not proof of an infection. The reference data used here include 3165 precisely located crowns from three study sites in the Waitakere Ranges west of Auckland. They cover a representative range of both kauri and associated tree species in different forest ecotypes and stand situations. The selection of kauri crowns includes a range of phenological varieties, such as colour variants, growth stages and stress symptom levels.

The structure of this thesis follows three research questions, which form the basis of three scientific papers. The first paper aims to identify kauri trees with optical remote sensing. A distinct spectral pattern of kauri crowns could be discovered with the use of an airborne AISA Fenix hyperspectral image in the far near-infrared part of the spectrum. The paper presents a method to distinguish kauri with no to medium symptoms from dead and dying tree crowns and other canopy species with no to medium symptoms. High user's and producer's accuracies of 94.6% and 94.8% for the class "kauri" were achieved in a Random Forest classification using five spectral indices on five wavelengths (670–1209 nm). The kauri spectra showed a high separability to the spectra of 21 other canopy species. However, the distinction between dead and dying trees and other tree species turned out to be more difficult. A minimum crown diameter of 3 m was defined for the 1 m pixel resolution to minimize the effect of mixed pixels. The overall accuracy (OA) for the three target classes could be improved from 91.7% to 93.8% by combining "kauri" and "dead/dying" trees into one class, separately classifying low and high forest stands and a binning to 10 nm bandwidths.

The second paper focuses on an analysis of reflectance patterns for different stress levels and growth stages in kauri crowns. The analysis was again based on hyperspectral images and 1258 manually edited reference crowns of "kauri" and "dead/dying" trees. The field assessment for stress symptoms was complemented with an evaluation of visible canopy symptoms in Red-Green-Blue (RGB) aerial images. An image guideline for stress assessment based on aerial images was developed. A Normalised Difference Vegetation Index (NDVI) in the near-infrared/red spectral range and indices with bands in the near-infrared and red-edge were identified as the most important band combinations to describe the full range of stress responses. However, pigment-sensitive indices with bands in the green and red spectral ranges are more important for describing first stress symptoms and stress responses in smaller trees with denser foliage. Five indices on six bands in the visible to near-infrared region (450–970 nm)

achieved a correlation of 0.93 with a Random Forest regression for the description of five stress symptom levels from non-symptomatic to dead. A stratified approach with individual models for pre-segmented low and high forest stands improved the overall performance. Additional bands in the far near-infrared region improved the root mean square error (RMSE) slightly from 0.43 to 0.42 but not the correlation.

In the third paper, the use of WorldView-2 satellite data (8 multispectral bands, 1.8 m pixel resolution pan-sharpened to 0.45 m) in combination with LiDAR data was tested for the stress detection with 1089 manually edited reference crowns of kauri and dead and dying trees. Five basic levels of canopy stress symptoms, from non-symptomatic to dead, were further refined for the first symptom stages based on field observations and aerial images. The minimum crown diameter for the use of WorldView-2 attributes for stress detection was defined as 4 m to avoid mixed pixels and to detect dying top branches in smaller crowns. Attributes from only the WorldView-2 image resulted in a correlation of 0.89 (RMSE 0.48, mean absolute error (MAE) 0.34) in a Random Forest regression for crowns larger than 4 m in diameter. This result can be improved to a correlation of 0.92 (RMSE 0.43, MAE 0.31) with additional LIDAR attributes, including intensity values. The selection of attributes confirms the findings from the second study, with an NDVI on near-infrared and red bands as the most important spectral index for the full range of stress symptoms. It also confirms a higher importance of pigment-sensitive indices with green, red and red-edge bands for the detection of first stress symptoms. These initial symptoms are more related to changes in the foliage than the crown architecture.

The results of this thesis present a methodical basis for kauri identification and stress detection using remote sensing data. The methods presented here require further testing and refinement with reference data in other forest areas and should be applied in the full processing chain with automatic crown-segmentation. However, when this has been done, remote sensing methods have considerable potential for automated monitoring of canopy stress symptoms in kauri trees.

MISHRA, GAYATRI (2019)

HEARTWOOD FORMATION AND THE CHEMICAL BASIS OF NATURAL DURABILITY IN *EUCALYPTOS BOSISTOANA*

The New Zealand Dryland Forests Initiative (NZDFI), aims to establish a sustainable natural durable timber industry in New Zealand. The natural durability of heartwood is highly variable within a species and lower at the centre of a tree. Therefore, it is critical to ascertain that trees meet international standards for durability to ensure a viable industry based on plantation grown naturally durable Eucalyptus. A strategy to ensure that wood from future plantings meet industry requirement is to select superior genotypes in a breeding programme. Several *Eucalyptus* species have been planted by NZDFI, but the primary focus is on *E. bosistoana* as it is a class 1 durable timber.

Little is known about the heartwood formation in young trees. It is possible that the young trees do not have true heartwood, but an extended transition zone, the zone between sapwood and heartwood where parenchyma cells remain alive synthesising heartwood extractives. Therefore, the wood quality research of NZDFI needs to ensure that the young trees have formed true heartwood. Understanding heartwood formation is critical for the success of a plantation forest industry aiming to produce ground-durable timber. The objective of chapter-2 was to identify conventional and confocal microscopy methods, which allow the observation of cell organelles and the chemical composition in *E. bosistoana* parenchyma cells before and after heartwood formation. Nuclei, microtubules and peroxisomes in parenchyma cells of 2-year-old *E. bosistoana* stems were visualised by confocal microscopy combined with optimised immunolabelling protocols. Iodine/potassium iodide stained starch (amyloplasts), while amido black stained proteins in sapwood. Fluorescence emission spectra confirmed the presence of chloroplasts in xylem parenchyma of 2-year-old *E. bosistoana*. Fluorescence emission spectral (lambda) scans showed differences between parenchyma and fibre cells as well as sapwood and

heartwood. The physiological changes between sapwood and heartwood visualised in parenchyma cells helped the understanding of heartwood formation in young *E. bosistoana* trees.

As part of an *E. bosistoana* breeding programme, the hypothesis of prolonged transition from sapwood to heartwood in young *E. bosistoana* trees, resulting in a wide transition zone has been tested in chapter-3. This needs to be considered when assessing trees for heartwood quantity and quality. Heartwood formation was investigated in radial profiles in cores from bark to bark of 6-year- old trees with conventional and confocal microscopy, and with a range of different staining techniques that visualised the physiological changes taking place in the parenchyma cells. Immunolabelling with antibodies against histone proteins and α-tubulin, histochemical staining using iodine/potassium iodide and fluorescence emission spectral scanning, demonstrated that in heartwood nuclei, microtubules, reserve materials (starch) and vacuoles were absent. The observations revealed that 6-year-old *E. bosistoana* trees contained heartwood. The loss of water conductivity by tyloses and the death of the parenchyma cells occurred in close proximity resulting in a transition zone of ~1 cm.

A key feature of heartwood is the formation of extractives that impart natural durability, a sought after wood property. The durability between trees is highly variable. Apart from the quantity of heartwood extractives in the wood, the chemical composition of the extracts varies. Therefore, the objective of NZDFI is to select young *E. bosistoana* trees with the most potent extracts for next generation durability improvement.

Chapter-4 describes the development of an antifungal assay to determine the bioactivity of *E. bosistoana* heartwood extracts against a white rot (*Trametes versicolor*) and a brown rot (*Coniophora cerebella*). The most suitable procedure was to spread dimethyl sulfoxide (DMSO) solutions of extract onto solidified agar, inoculate with fungi and calculate the growth rate (cm/h) by fitting a linear regression for the diameter of fungi against time. Controls were needed to normalise the fungal growth, i.e. calculating a relative growth rate, to account for the variation in growth conditions between different runs.

Chapter-5 describes the variability in bioactivity and chemical composition of *E. bosistoana* heartwood extracts between individual trees grown on two different sites (Lawson and Craven Road). Statistical methods combining the results of the fungal assays and the quantitative gas chromatography (GC) of the extracts allowed the investigation of bioactive compounds. The bioactivity of extracts was assessed against white rot (*Trametes versicolor*) and brown rot (*Coniophora cerebella*). Ethanol extracts from *E. bosistoana* heartwood were less effective on the white rot than against the brown rot. Variability in the bioactivity of extracts against the two fungi was observed between the trees. A small site effect in the bioactivity was found for the white rot but not the brown rot. Bioactivity of the extracts against the white rot was not correlated to that against the brown rot. The absence of such a relationship indicated that the two fungi were affected by different heartwood compounds. Thirty two compounds were quantified in *E. bosistoana* ethanol extracts by GC, of which six (benzoic acid, hexadecanoic acid, 1,5-dihdroxy-12-methoxy-3,3- dimethyl-3,4-dihydro-1H-anthra[2,3-c] pyran-6,11-dione, octadecanoic acid, polyphenol and beta- sitosterol) were identified. Significant variability in eight compounds (out of the 32) was found between the two sites. Multivariate (PLSR) analysis identified compounds at retention times 10.2 and 11.5 min (hexadecanoic acid) to be most related to the bioactivity of the E. bosistoana heartwood extracts against white rot and brown rot.

Breeding programmes benefit from early assessment, enabling short breeding cycles. While trees only form heartwood when several years old, wounds can be induced at a young age. As wound reaction has some similarities to heartwood formation the objective of chapter-6 was to investigate if the wound reaction can be used as a proxy to assess trees early in a breeding programme for heartwood features. 1.6-year-old individuals from 27 *E. bosistoana* families with known heartwood diameter and extractive content were wounded and the axial wound reaction was correlated to the known heartwood features. No correlation between wound reaction and heartwood features in *E. bosistoana* families was found. Wound reaction was under weak genetic control. Therefore, it seems to be not possible to assess

heartwood formation early in a breeding programme by measuring the axial wound response in 1.6-year-old *E. bosistoana* trees.

Furthermore, two families with small and large wound reaction were selected to characterise physiological and chemical variations in woundwood, heartwood and sapwood by microscopy and gas chromatography. Microscopic observations revealed the absence of starch and that vessels were occluded with tyloses in woundwood and heartwood. Morphological features were not discernible by eye between the families with large and small wound reaction. Gas chromatography revealed variation in the chemical composition of woundwood, heartwood and sapwood extracts.

MORENO CHAN, JULIAN (2007)

MOISTURE CONTENT IN RADIATA PINE WOOD: IMPLICATIONS FOR WOOD QUALITY AND WATER-STRESS RESPONSE

This thesis studied the influence of moisture content on the dynamic estimation of stiffness in wood of *Pinus radiata* D. Don. This is an important non-destructive measure for estimation of stiffness in standing trees, logs and lumber. Moisture content affects both acoustic velocity and density in the fundamental equation of dynamic MOE (DMOE = $V^2\rho$, where V = acoustic velocity and ρ = density). Investigation included measurements with boards in the laboratory considering moisture contents below and above FSP as well as temperatures below and above 0°C. This also included field measurements of trees in contrasting climate sites and over different seasons including a long drought. Methods for measuring green density and moisture content and the patterns of variation of these parameters were also investigated. A secondary component of this thesis explored the wood quality and some mechanisms of tree response to water stress in two contrasting sites in terms of rainfall and water deficits in a region of Australia.

The large increases in DMOE for frozen wood above the FSP (4.5 to 6 GPa) will limit the use of DMOE for grading logs in regions with freezing winters. Results from the experiment remeasuring young trees and the upper range of moisture content and temperatures above 0°C from the experiment with boards showed small to moderate variation in DMOE (0.1 to 1 GPa) which calls for further investigation on analytical procedures for adjustment of DMOE. Such procedures should consider that variations in acoustic velocity and density with changes in moisture content are not proportional and that there are counteracting effects between the two parameters. It remains to be investigated whether the typical variation (under normal climate conditions) in sapwood green density observed in our experiments has some implications for the use of DMOE. On the other hand, it is anticipated that the large differences along the stem and among stands in whole-section green density may bias DMOE measurements in logs for resource assessment. This also needs to be investigated. A comparison between acoustic velocity alone and DMOE for resource assessment under different scenarios is recommended.

The study in two contrasting climate sites (high-altitude vs. warm-dry) in the Hume region of Forests NSW, Australia, including young (10-11 years) and mature trees (34-36 years) of radiata pine showed distinctive short and long-term responses of trees to cope with the water-limiting environment. In response to long-term water deficits the warm-dry site developed heartwood and thus reduced sapwood earlier and at faster rates than the high-altitude site. The onset of heartwood formation seemed to be triggered by some site threshold for water use as broadly indicated by the sapwood area/ha. The warm-dry site also showed increased short-term responses to water stress and these were interpreted as seasonal mechanisms of the trees to cope with the limiting environment. The trees compensated for the lower available moisture and higher transpiration rates by lowering their saturation and disrupting water conduction at some points (cavitation). The inverse trends of cavitation spots and cavitation bands with height in the stem suggested the trees have different strategies to sacrifice conducting xylem

depending on the position on the stem. Finally, it is suggested that saturation tended to fall to critical 'safe' levels as a result of water stress and this varied depending on age, site, and position in the stem.

Significant decreases in DMOE and basic density were observed for the warm-dry site and were attributed to lower proportions of latewood due to lower rainfall for that site during the period of latewood formation. These showed no obvious association with any of the long-term water-stress traits (sapwood percentage and number of heartwood rings).

MORGENROTH, JUSTIN A. (2011)

THE EFFECT OF POROUS CONCRETE PAVING ON UNDERLYING SOIL CONDITIONS AND GROWTH OF *PLATANUS ORIENTALIS*

Urbanisation is characterised by mass migration of people to urban areas and conversion of land from rural to urban land uses. Changes in population dynamics have led to half the world's population living in urban areas; in developed countries, urban dwellers account for three-quarters of the total population. Though populations have shifted from rural to urban areas, people continue to reply on their environment, and trees in particular, for tangible and intangible benefits alike. A great deal of factual and anecdotal knowledge supports the role of trees for ecological, social and economic well-being. In spite of this, during urbanisation, previously vegetated land is converted to housing, roads, or utility corridors, all of which are necessary to support growing populations.

This thesis investigates tree growth in these modified urban landscapes, in particular, the effects of pavements on urban trees. Pavements are truly pervasive, covering more than half of all land in highly developed urban areas. Their durability and strength are of great importance to transportation, but large-scale soil sealing is not without consequence. Pavements affect the hydrologic cycle, soil and air temperature, and nutrient cycling. Because of their effect on the surrounding environment, pavements inherently affect remnant or planted trees. They are believed to negatively affect tree growth and survival, thereby compromising the ecological, social, and economic benefits otherwise derived from the urban forest.

In recent times, porous pavements have been increasingly installed in favour of impervious pavements. Porous pavements are perceived to be an environmentally-sound alternative to standard impervious pavements. This thesis begins by reviewing the literature concerning porous pavements' effect on underlying soil and urban vegetation, thus illustrating the scarcity of empirical data describing the effect of porous pavement on tree growth. A greater understanding of porous pavement's impact on the surrounding environment is needed, if its installation is to continue.

With this aim in mind, this thesis describes an experiment in Christchurch, New Zealand, which monitored the impacts of porous and impervious pavement on underlying soil conditions, and subsequent tree growth. The experiment comprised 50 *Platanus orientalis* trees planted in an augmented factorial design, which consisted of controls and four treatments. Trees were split evenly among plots, such that ten replicates existed per treatment. The pavement treatments measured 2.3m by 2.3m, and were based on the combination of pavement type (2 levels: porous, impervious) and pavement profile design (2 levels: +/- subbase compaction and gravel base). The resulting four treatments were impervious concrete pavement (IP), impervious concrete pavement with compacted subbase and gravel base (IP+), porous concrete pavement (PP), and porous concrete pavement with compacted subbase and gravel base (PP+). From December 2007 to March 2009, data were collected to determine the effect of these treatments on soil moisture, aeration, pH, and nutrient concentration. Final tree height, stem diameter, shoot and root biomass, and root distribution were also measured at the conclusion of the experiment.

Results of this experiment indicated that the effects of pavement porosity on soil moisture and aeration were dynamic, varying with season and soil depth. Increased soil moisture beneath porous pavements

resulted from rapid infiltration following precipitation. This decreased the duration of plant stress resulting from drought. Relative to bare soil, paved plots had consistently greater soil moisture, likely because pavements reduced evaporation. The inclusion of a gravel base in the profile design limited capillary upflow, which resulted in lower soil moisture under pavements designed with a gravel base. Soil aeration was significantly lower beneath pavements relative to unpaved plots. This is likely related to greater soil moisture beneath pavements. Finally, soil pH increased beneath pavements, in particular beneath porous pavements.

Though all growth parameters increased for trees surrounded by porous, rather than impervious pavement, this occurred only in the absence of a compacted subgrade and gravel base. Evidently, the impact of the compacted subgrade superseded the impact of pavement porosity. Furthermore, root growth was relatively shallow beneath pavements, likely due to favourable soil moisture directly beneath pavements.

This research highlights (i) the dramatic effect of pavements on underlying soil conditions; (ii) that pavements do not inherently limit tree growth; (iii) that porous pavements can conditionally improve tree growth; and (iv) that soil compaction limits potential benefits resulting from porous pavements.

MURPHY, BRENDAN D. (2008)
BIOLOGICAL CONTROL OF *PAROPSIS CHARYBDIS* STÅL (COLEOPTERA: CHRYSOMELIDAE) AND THE PAROPSINE THREAT TO *EUCALYPTUS* IN NEW ZEALAND

Ineffective biological control of the *Eucalyptus* pest *paropsis charybdis* Stål (Coleoptera: Chrysomelidae: Paropsini) in cold areas of New Zealand was believed to be caused by climatic mismatch of the egg parasitoid *Enoggera nassaui* Girault (Hymenoptera: Pteromalidae). Two Tasmanian strains of the parasitoid were introduced to test climate-matching theory in 2000, with approximately 7000 wasps released. Establishment of the Florentine Valley strain was detected in 2002 using the Mitochondrial (mtDNA) gene Cytochrome Oxidase I (COI) as a strain specific marker. The hyperparasitoid *Baeoanusia albifunicle* Girault (Hymenoptera: Encyrtidae) and primary parasitoid *Neopolycystus insectifurax* Girault (Hymenoptera: Pteromalidae) were detected for the first time in New Zealand.

As paropsines have proven highly invasive internationally, a risk assessment of the paropsine threat to New Zealand was undertaken by evaluating the host range of *E. nassaui* and a reproductive assessment of 23 paropsine species in the genera *Dicranosterna* Motschulsky, *Chrysophtharta* Weise, *Paropsis* Olivier, *Paropsisterna* Motchulsky and *Trachymela* Weise. *Enoggera nassaui* proved polyphagous, but bioassay results proved that *Paropsis* species were significantly more susceptible to the egg parasitoid than *Chrysophtharta* species. Resistance within *Chrysophtharta* was attributed to spine-like chorion modifications. A COI derived *Chrysophtharta* phylogeny divided the genus into two distinct groupings, which was supported by chorion morphology.

Paropsine reproductive output was tested for key parameters indicating pest potential. Pest specie displayed fecundity exceeding 600 eggs at an oviposition rate of 10 eggs per day^{-1}. Several non-pest species were identified as potential pests based on these parameters. The *Chrysophtharta* phylogeny suggested a moderate relationship between genetic relatedness and reproductive output. The *Acacia* defoliating paropsine *Dicranosterna semipunctata* (Chapuis) was evaluated for its susceptibility to *E. nassaui* and reproductive output. Egg parasitism occurring in bioassay did not translate into biological suppression following a specifically targeted release of *E. nassaui*, and the fecundity and oviposition rates fell below the thresholds predicted for a pest paropsine species.

Despite establishment of Tasmanian *E. nassaui*, hyperparisitism has now rendered this control agent ineffective in New Zealand. *Neopolycustus insectifurax* offers the best hope for future biological control of paropsine species in New Zealand.

NGUYEN, VIET XUAN (2019)
MODELLING PRESENT AND FUTURE ABOVEGROUND BIOMASS OF EVERGREEN BROADLEAF FORESTS IN VIETNAM

Forest reforestation and degradation have both occurred over the past five decades in Vietnam. To cope with this problem, the Vietnamese government has established plans and set up strategies to reduce deforestation and forest degradation. It also launched national support for the conservation and sustainable management of forests, as well as enhancement of forest carbon stocks in developing countries (REDD+) programs. A limited number of studies have attempted to establish a database of aboveground biomass of evergreen broadleaf forests in Vietnam, as well as growth models such as height versus diameter at breast height (H-D) models, basal area (G) increment models, and above ground biomass (AGB) increment models. In addition, the information describing the relationships between environmental indicators and tree species distributions was also insufficient, leading to potential failure of reforestation and rehabilitation projects.

This study examined the correlation between environmental indicators and tree species distributions. It also sought to develop H-D models based on the outcomes of grouping tree species into different groups, and model the relationship between G and AGB increments with other environment factors and stand characteristics.

The study utilized data collected from Forest Inventory and Planning Institution (FIPI) and validation data from Vietnamese Academy of Forest Sciences (VAFS). It then employed ordination analysis to analyse the correlation between tree species groups and environmental factors. In addition, previous H-D functions applied in past research on tropical forests were used to develop H-D models for this particular study. Validation procedures were used to compare selected H-D models with other H-D models applied in the same forest types. Lastly, a decision tree approach was adopted to select the climatic, soil, and stand variables that were most likely to be useful for the development of G and AGB increment models.

The findings were that there was a correlation between solar radiation, depth to bedrock, clay content, temperature and rainfall with tree species distributions. Nine selected H-D models for nine respective tree species groups were less biased and more precise compared to two given H-D models in a validation procedure. Finally, both G increment models and AGB increment models were developed, in which these climatic, soil, and stand variables were directly added. The study was intended to contribute valuable data and relevant models for the benefit of forest managers and administrators who could use the results to effectively carry out the process of reforestation, REDD+ projects, and national forest inventories programs at minimal cost in timely and efficient manners.

OBI, OKEY FRANCIS (2018)
USING ADVANCED ANALYSIS TECHNIQUES TO BENCHMARK FOREST HARVESTING SYSTEMS: A STUDY OF THE NEW ZEALAND FOREST INDUSTRY

The concept of benchmarking is applied to businesses and industries for the continuous measurement and improvement of production systems and organizational performance. This makes it important to continuously measure and improve the operational performance in order for any industry to maintain its local and global competitiveness in the ever-changing global business environment. Data analysis techniques has continued to develop allowing a greater level of in-depth analysis of operational data, an example being data envelopment analysis (DEA), a frontier analysis method established in non-parametric framework.

New Zealand has a large forest industry with about 1.7 million net stocked plantation forest area, 30.7 million m^3 of harvested timber and $5.47 billion in value of export forest products. The New Zealand

forest harvesting sector has an existing benchmarking system containing cost and productivity data with over 1000 unique entries on contracted forest harvesting operations in New Zealand from 2009-2015. This thesis shows that advanced operations techniques can be used to analyse the forest harvesting sector by measuring the relative harvesting efficiency of independent logging contractors; identifying external factors that influence the technical efficiency of forest harvesting operations; and including the operating environment factors in the evaluation process of harvesting operations performance. DEA, a non-parametric frontier benchmarking technique is applied in the analyses.

Using DEA on the existing benchmarking database, the relative operational efficiency of independent logging contractors was estimated. Five inputs, which accounted for about 77% variation in the harvesting productivity (output), were used to develop the DEA production models. Output-orientation under the assumption of constant and variable returns to scale were used to estimate the relative aggregate, pure technical and scale efficiencies, and the measure of excessive use of inputs by the contractors. Optimal input usage and output targets were estimated under variable returns to scale for the inefficient contractors to move to the efficient frontier. The results indicate that the majority of logging contractors operated at or near scale efficient level while the main source of inefficiency in the industry is both technical and managerial. Analysis shows that if all inefficient contractors operate at the optimal input and output levels, and were provided with stand and terrain conditions that best suited their operations, on average, system productivity could increase by 45% from 28.7 to 52.2 tons/SMH. The DEA suggests that investment in technology and human capital could improve the overall efficiency of the logging industry.

Although inputs usage are key to the productivity of harvesting operations, factors external to the managerial control of contractors could influence their performance. A two-stage approach that incorporates DEA and regression analysis was used to determine the influence of external factors on the technical efficiency of harvesting operations based on the New Zealand benchmarking dataset. The external factors considered include the size of operation, forest terrain, log sorts, piece size and the forest region. The results indicate that the size of operation, forest terrain, log sorts and piece size, all significantly ($p < 0.01$) influence the technical efficiency of forest harvesting operations. The effect of forest region on the technical efficiency however, was not significant ($p > 0.01$). The result shows that the ability of a harvesting crew to utilize its inputs to achieve desired output level is not only influenced by discretionary factors but also by the operating environment.

Using a forest company-specific database, a multi-step DEA procedure is applied to 67 forest harvesting contractors to estimate their managerial efficiency while taking into account the influence of the operating environment. The performance of the contractors is evaluated using seven inputs, one output and three operating environment factors. The result shows a significant difference between the mean managerial efficiency of the crews before and after controlling for the influence of the operating environment, the latter being higher by 12%. This study provides evidence that without accounting for the influence of the operating environment, the resulting DEA efficiency estimates will be biased; overestimating the performance of crews in favourable environment and underestimating that of those in more difficult environment.

OLIVERA FARIAS, ALEJANDRO (2016)
EXPLORING OPPORTUNITIES FOR THE INTEGRATION OF GNSS WITH FOREST HARVESTER DATA TO IMPROVE FOREST MANAGEMENT

Worldwide approximately 3 billion m^3 of wood is harvested and removed from forests annually. Forest plantations play an important role in forest harvesting providing 46% of the total industrial roundwood produced in the world, while they account for only 7% of the world's forested area. Modern harvesting systems are mechanised for productivity, costs, and safety reasons. Due to the advances and availability of both computing and sensor technologies, mechanised machinery is a platform for

integration of these technologies with electronic control systems capable of monitoring machine functions, estimating measurements, and recording data.

One of the most popular mechanized harvesting systems is Cut-To-Length (CTL). The CTL system typically consists of two types of machines, a harvester, which fells and processes the trees into logs in the stand, and a forwarder that extracts the logs. CTL machines were developed in Scandinavia and are now used worldwide. They are the preferred technology for harvesting fast growing forest plantations in some South American countries such as Uruguay.

Harvesters are equipped with a system called StanForD that provides a mechanism to automatically record data from forest harvesters in a series of file formats. When harvesters are equipped with a Global Navigation Satellite System (GNSS) receiver, these data include a locational reference and a time stamp. GNSS-enabled data provide site-specific information that is a valuable input for both stand level forest management and harvesting operation assessment. The objective of this thesis is to demonstrate the usefulness of GNSS-enabled StanForD files as a tool for evaluating variables affecting harvesting operations and the forest management process. To achieve the objective two independent studies were carried out. Chapter 2 explores opportunities to manage harvesting operations. The goal of this study was to demonstrate the effectiveness of using the geospatial and time information contained in StanForD files to model harvester productivity. A harvester dataset obtained from Uruguay comprised over 63,000 cycles of felled and processed stems (stm files) and 1440 shift hours (drf files). With two thirds of this cycle time data, a mixed effects model was fitted to evaluate harvester productivity as a function of stem diameter at breast height (DBH), species, shift (day/night), slope, and operator. A slope surface derived from a digital terrain model was overlaid with GNSS stem records. The reserved third of the data was used to validate the model. DBH was the most influential variable in harvester productivity, showing a positive correlation and a R^2 value of 0.73 in the validation model. Operator and species also had significant effects. There was no significant slope effect, whereby the study area only had flat and mildly sloping terrain. Shift did not have a significant effect, indicating there was no drop in night shift productivity. The model developed constitutes the first published harvester productivity model in South America based on data automatically collected by harvesters.

Chapter 3 and 4 explore opportunities to provide feedback to improve the forest management process using the site-specific harvester data. Stand productivity of fast-growing forest plantation varies across short distances depending on site and forest characteristics. As plantation forest silviculture is typically resource intensive in establishment, forest management would benefit from a site-specific approach. A tool to characterize such stand productivity variations are yield maps and a cost effective source of data is automatically collected by harvesters. To create such maps we need to understand the effect of geospatial accuracy of tree location recorded by the harvester.

The objective of Chapter 3 is to improve our understanding of spatial resolution for studying variations in volume and stocking across forested stands, and establish guidance for actual spatial resolution that would allow the development of fit-for-purpose forest yield maps from harvester data. This study investigated data sets from seven stands: two had very accurate tree location, and five were harvester data files that have inaccuracy associated with both the GNSS recording under forest canopy and the physical dislocation of the GNSS relative to the harvested tree location. The GNSS unit is on the cabin of the machine, but the tree is felled using a boom and could be up to 12 meters from the cabin. A spatial resolution for studying variations in stand productivity and stocking across stands was established to allow the development of forest yield maps from harvester data. By assessing the variability across a range of cell sizes, it was concluded that a cell size between 40 and 60 m is suitable to use as a reference for calculating volume per hectare and stocking. Based on the outputs of Chapter 3, the objective of Chapter 4 was to develop models to map stand productivity from GNSS enabled harvester data. This chapter first explores several models using the same two stands with accurate tree location used in Chapter 3. It assesses their accuracy, then applies the models to the harvester data stands, and finally compares the results of the models to determine the most suitable models. The

assessment of the models includes the comparison of productivity maps created from inventory plots. Chapter 5 is a synthesis of the findings, contributions, limitations of the studies, and views on future research needs resulting from this work.

PAGET, MARK F. (2014)
GENETIC EVALUATION OF POTATO

A series of studies are presented on the genetic evaluation of cultivated potato (*Solanum tuberosum* L.) to improve the accuracy and efficiency of selection at various stages of a breeding programme. The central theme was the use of correlated data, such as relationship information and spatial and across-trial correlations, within a linear mixed modelling framework to enhance the evaluation of candidate genotypes and to improve the genetic response to selection. Analyses focused on several social and economically-important traits for the enhancement of the nutritional value, disease resistance and yield of potato tubers.

At the formative stages of a breeding scheme, devising a breeding strategy requires an improved understanding of the genetic control of target traits for selection. To guide a strategy that aims to enhance the micronutrient content of potato tubers (biofortification), univariate and multivariate Bayesian models were developed to estimate genetic parameters for micronutrient tuber content from a breeding population generated from crosses between Andean landrace cultivars. The importance of the additive genetic components and extent of the narrow-sense heritability estimates indicated that genotypic 'individual' recurrent selection based on empirical breeding values rather than family-based selection is likely to be the most effective strategy in this breeding population. The magnitude of genetic correlations also indicated that simultaneous increases in important tuber minerals, iron and zinc, could be achieved.

Optimising selection efficiency is an important ambition of plant breeding programmes. Reducing the level of candidate replication in field trials may, under certain circumstances, contribute to this aim. Empirical field data and computer simulations inferred that improved rates of genetic gain with p-rep (partially replicated) testing could be obtained compared with testing in fully replicated trials at the early selection stages, particularly when testing over two locations. P-rep testing was able to increase the intensity of selection and the distribution of candidate entries across locations to account for G×E effects was possible at an earlier stage than is currently practised. On the basis of these results, it was recommended that the full replication of trials (at the first opportunity, when enough planting material is available) at a single location in the early stages of selection should be replaced with the partial replication of selection candidates that are distributed over two locations.

Genetic evaluation aims to identify genotypes with high empirical breeding values (EBVs) for selection as parents. Using mixed models, spatial parameters to target greater control of localised field heterogeneity were estimated and variance models to account for across-trial genetic heterogeneity were tested for the evaluation of soil-borne powdery scab disease and tuber yield traits at the early stages of a selection programme. When spatial effects improved model fit, spatial correlations for rows and columns were mostly small for powdery scab, and often small and negative for marketable and total tuber yield suggesting the presence of interplot competition in some years for tuber yield traits. For the evaluation of powdery scab, genetic variance structures were tested using data from 12 years of long- term potato breeding METs (multi-environment trials). A simple homogeneous correlation model for the genetic effects was preferred over a more complex factor analytic (FA) model. Similarly, for the MET evaluation of tuber yield at the early stages, there was little benefit in using more complex FA models, with simple correlation structures generally the most favourable models fitted. The use of less complex models will be more straightforward for routine implementation of potato genetic evaluations in breeding programmes.

Evaluations for (marketable) tuber yield were extended to multi-location MET data to characterise

both genotypes and environments, allowing a re-evaluation of New Zealand MET selection strategies aimed at broad adaptation. Using a factor analytic mixed model, results indicated that the programme's two main trial locations in the North and the South Islands optimised differentiation between genotypes in terms of G×E effects. There was reasonable performance stability of genotypes across test locations and evidence was presented for some, but limited, genetic progress of cultivars and advanced clonal selections for tuber marketable yield in New Zealand over recent years.

The models and selection strategies investigated and developed in this thesis will allow an improved and more systematic application of genetic evaluations in potato selection schemes. This will provide the basis for well informed decisions to be made on selection candidates for the genetic improvement of potato in breeding programmes.

PEARSE, GRANT D. (2017)
ESTIMATING LEAF AREA INDEX FROM AIRBORNE LASER SCANNING IN *PINUS RADIATA* FORESTS

Leaf area index (LAI) quantifies the amount of leaf surface area per unit ground area. LAI in forest ecosystems regulates the upper limit of possible light interception, atmospheric gas exchange, and primary production. These properties make LAI one of the most important ecophysiological variables with a wide range of potential applications. In the context of forests managed for production, knowledge of LAI offers the potential to align management activities with fundamental biophysical properties. For example, LAI offers the potential to precisely target and monitor management activities such as fertilizer application or disease control. Despite the potential benefits knowledge of LAI offers, usage is seldom seen outside of research applications. A key reason for this is the difficulty in obtaining LAI measurements over large areas, with field based optical methods largely constrained to use under uniform, diffuse sky conditions. Remote sensing of LAI offers one potential solution to obtain large-scale estimates of LAI. However, promising spectral-based approaches have been shown to have limited usefulness for forests with high LAI such as intensively managed coniferous plantations. Airborne laser scanning (ALS) data (lidar) offers enhanced ability to estimate LAI in a range of forest types with a high degree of accuracy, but the optimum methods for estimating LAI from lidar are not well established.

This thesis aims to develop and demonstrate a method for estimating LAI from lidar in New Zealand's intensively managed *Pinus radiata* D. Don forests. To accomplish this, two distinct areas of research are addressed. First, this thesis addresses the need for acquiring a large number of LAI field measurements covering a range of stand conditions in order to calibrate ALS-LAI models. This was accomplished by validating the use of the newly developed LAI-2200C (LI-COR Biosciences Inc., Lincoln, NE, USA). This instrument allows measurement of LAI under clear sky conditions through the application of a model to correct for the impact of scattered light on gap fraction estimates. This thesis presents the first *in situ* comparison of LAI measurements acquired under diffuse and clear sky conditions in a coniferous forest. These results were obtained by repeatedly measuring LAI in plots of pure *P. radiata* in New Zealand. In addition, the thesis presents the first assessment of the importance of acquiring accurate needle spectra to parameterize the scattering correction model. These values were acquired using newly developed methods that allow accurate spectra to be acquired from needle-leaved species via spectroradiometer. The thesis also addresses the stability of needle optical properties with respect to position in the canopy, abaxial and adaxial measurements, and variability between individual trees.

The second part of this thesis used a large number of LAI measurements made possible by the new instrumentation to address key questions on the topic of estimating LAI from lidar.

To date, most ALS-LAI research has been divided between establishing empirical or physical links between lidar metrics for estimating LAI, and few studies have compared these approaches. In

addition, factors known to impact ALS-LAI estimation such as the choice of plot parameters have gone relatively unexplored, as has the use of new statistical learning approaches. This thesis attempts to offer the first simultaneous assessment of the optimum combination of lidar metrics, plot parameters, and modelling approaches for estimating LAI from ALS lidar data in *P. radiata* forests.

Results from the instrument validation suggest that the scattering correction model performs well in coniferous forests. Overall, clear sky LAI measurements were higher on average than diffuse sky measurements. However, there was evidence that this difference resulted from a reduction in erroneous readings obtained from the largest outer sensor ring under diffuse sky conditions. Traditionally, data from this part of the instrument have been error-prone and there was some evidence that clear sky LAI measurements offer increased accuracy by reducing scattering induced error across the range of zenith angles observed by the instrument. The method used to obtain spectroradiometer measurements from needle-leaved specimens was well suited to collecting accurate needle reflectance and transmittance for use in the scattering correction model. Use of these values improved agreement between clear and diffuse sky LAI measurements and reduced the magnitude of the largest differences at the extremes of the range. The results demonstrated that *P. radiata* spectra did not differ significantly with canopy position and were reasonably stable between trees. Measured *P. radiata* needle spectra are presented as part of this thesis and values are suggested for future users of the LAI-2200C scattering correction model in this forest type. Overall, use of measured spectra in combination with masking of outer ring data allowed LAI to be measured under both clear and diffuse sky conditions; however, clear sky conditions offered considerable reductions in the maximum potential measurement error resulting from changes in sky condition over time and between sensor locations.

Results presented in the second part of this thesis demonstrate that LAI can be accurately estimated from lidar data in *P. radiata* forests. A key finding from this work was that use of standard approaches developed for use in other forest types produced some of the worst models of all those trialled, indicating that successful ALS-LAI estimation in *P. radiata* depends on careful selection of lidar metrics, plot parameters, and modelling approach. Specifically, results showed that (1) metrics that form a proxy for gap fraction by computing the radio of returns above and below a chosen height threshold (ratio metrics) were key predictors of LAI; (2) choice of height threshold for ratio metrics strongly impacted model performance and *P. radiata* appeared to require higher thresholds than other forest typces; (3) the concept of a variable height threshold was beneficial in accommodating differences in tree height across plots and led to improved estimates of LAI; (4) a larger fixed plot radius generally improved model performance; (5) use of a variable plot radius linked to instrument view distance was better than any fixed radius trialled; (6) metrics linking lidar penetration to the Beer-Lambert law were only marginally less accurate than empirical models and showed strong predictive ability. This approach may offer a means of estimating LAI without calibration by inverting the Poisson model using gap fraction from lidar and an empirical projection coefficient. Finally, the research found a high level of correlation present between lidar metrics, strongly emphasizing the need for modelling approaches robust to these effects. Regularised regression via the elastic net was found to be a useful method for providing both variable and model selection in high-dimensional space while accounting for the presence of high correlation between metrics. Results from models produced by the random forests algorithm were similar to results from elastic net but provided some useful insights into variable importance.

PHIRI, DARIUS (2020)
MONITORING LAND COVER DYNAMICS FOR ZAMBIA USING REMOTE SENSING: 1972-2016

Global land cover change is characterised by the expansion of agricultural and urban areas, which results in forest loss, especially in sub-Saharan African countries such as Zambia. This topic has received increasing research attention due to the close relationship between land cover and land use, food security and climate change. The Zambian landscape has high rates of land cover change associated with deforestation, forest degradation and urbanisation. With these changes, managing

natural resources in Zambia requires reliable information with which to make informed decisions during land use planning. However, existing land cover information for Zambia is limited in its spatial and temporal scales. The availability of remotely sensed data with an open access policy and a long historical record, such as Landsat satellite imagery, offers opportunities for monitoring long-term land cover change over large areas.

This thesis aims to provide an understanding of the different aspects of remotely sensed land cover monitoring, including image pre-processing, land cover classification, land cover change and factors associated with land cover change in Zambia. This research was conducted at a national scale over a period of four decades (1972–2016). The current study started with a detailed literature review on the development of the methods of Landsat land cover classification, which was followed by testing machine-learning classifiers and pre-processing methods on pansharpened and non-pansharpened Landsat Operational Land Imager (OLI-8) images. Classification of nine land cover types (primary forest, secondary forest, plantation forest, wetlands, cropland, irrigated crops, grassland, waterbodies and settlements) was conducted for six time steps (1972, 1984, 1990, 2000, 2008, and 2016), which were chosen by considering past economic and political events in Zambia. Post-classification analysis was then applied in order to understand changes in land cover. Finally, the factors contributing to land cover change were assessed using a classification tree (CT) approach.

The literature review (Chapter 2) showed that Landsat land cover classification methods have developed from manual delineation to advanced computer-based classification methods. These developments have occurred due to the advancements in computer science (e.g. machine- learning and artificial intelligence) and improvements in remotely sensed data acquisition. To attain high land cover classification accuracies, Landsat images require the selection of an effective classification method and the application of pre-processing methods. The combination of object-based image analysis (OBIA) and machine-learning classifiers, such as random forests (RF), has become more common than the pixel-based approach.

The assessment of pre-processing methods (Chapter 3) on two provinces of Zambia (Copperbelt and Central), which were covered by four Landsat OLI-8 images, indicated that applying both atmospheric and topographic correction improved classification accuracy. The results showed that non-pre-processed images reached a classification accuracy of 68% for pansharpened and 66% for standard Landsat OLI-8 images. Classification accuracy improved to 93% (pansharpened) and 86% (standard) when combined moderate-resolution atmospheric transmission (MODTRAN) and cosine topographic correction pre-processing were applied. The results showed that image corrections are more important when applied on multiple scenes, especially for time series studies. The results also identified that the RF classifier outperformed the other classifiers by attaining an overall accuracy of 96%. These results informed the choice of pre-processing and classification analyses to use for the subsequent land cover analysis.

A nationwide land cover classification analysis was then undertaken for each of the six time steps (Chapter 4). Overall accuracies ranging from 79% to 86% were attained, with more recent time steps, captured by Landsat OLI-8 imagery, having the highest accuracy. The variation in classification accuracies was mainly attributed to the differences in spatial, spectral and radiometric resolutions of the satellite images available for each time step. This chapter also showed that 62.74% of the Zambian landscape experienced change. Primary forest declined from 48% to 16% between 1972 and 2016, while secondary forest increased from 16% to 39% during the same period. The results also showed that forests have been recovering by 0.03% to 1.3% yr^{-1} (53,000–242, 000 ha yr^{-1}); however, these rates are lower than deforestation rates (−0.54% to −3.05% yr^{-1}: 83,000–453,000 ha yr^{-1}). Annual rates of change varied by land cover, with irrigated crops having the largest increase (+3.19% yr^{-1}) and primary forest having the greatest decrease (−2.48% yr^{-1}). Area of settlements, cropland and grasslands increased, while wetlands declined. Due to increased forest fragmentation, forest connectivity declined by 22%.

The CT models for analysing the factors contributing to land cover change (Chapter 5) were produced with overall accuracies ranging from 70% to 86%. CTs are statistical approaches used to partition categorical data (response variables) into mutually exclusive subgroups using a set of explanatory variables. Here, the response variables included a binary scenario (change/no change) and changes from individual land covers. The explanatory variables were the different factors considered to be associated with the land cover changes. The major factors associated with the binary scenario (change or no change to 1972 land cover) were percentage of cultivated area, crop yield, and distance to waterbodies. Forest losses were mainly associated with crop yield, area under cultivation, population density and distance to roads and railways. An important insight from this chapter was the influence of protected areas (e.g. national forests) on forest reversion and recovery.

Due to the national extent and long temporal record of land cover change, the findings from this thesis are important for land use planning in Zambia. This research not only documents deforestation and forest degradation occurring throughout Zambia over the past four decades, but also highlights the importance of increasing the extent of protected areas in order to support forest reversion and recovery. Since forests are an important component of climate change mitigation initiatives, these results will provide baseline information for international climate change mitigation initiatives such as reducing emissions from deforestation and forest degradation (REDD+).

PINJUV, GUY L. (2006)
HYBRID FOREST MODELLING OF *PINUS RADIATA* D. DON IN CANTERBURY, NEW ZEALAND

During this study two models were developed to predict growth of *Pinus radiata* D. Don plantations in Canterbury, New Zealand. The first, CanSPBL(1.2), is a model for whole rotations of stands owned by Selwyn Plantation Limited in Canterbury. The second model, CanSPBL(water) is a hybrid growth model for the Selwyn estate in Canterbury that incorporates an index of root zone water balance over the simulation period. An existing stand growth and yield model CanSPBL was examined using a validation dataset of PSP measurements that were not used in model fitting. Projection bias was shown for mean top height, basal area per hectare, and residual stand stocking particularly for stand at elevations exceeding 450 metres.

The new model, CanSPBL(1.2) showed an increase in precision of 4-46% over CanSPBL(1.0) at a stand level. The components of the stand model include man top height, basal area per hectare, stems per hectare, and diameter distribution. The mortality model was made in conjunction with managers at CanSPBL to exclude catastrophic mortality events from model projections. Data used for model fitting was filtered using a mortality index based on the -3/2 power law. An examination of this model with an independent dataset showed little apparent bias.

The new model, CanSPBL(water) was developed to include an index of water balance over the simulation period. Water balance estimates were made using a sub model for root zone water balance included in the hybrid physiological model 3-PG (Landsberg and Waring, 1997). The new model showed an increase in precision of 1-4% over CanSPBL(1.2) at a stand level (with the exception of the model for maximum diameter which showed a decrease in precision of 0.78%) using climatic inputs that included yearly variation. However the model showed increases of precision from 0.5 to 8% (with the exception of maximum diameter again, showing a decrease in precision of 0.13%) using long term monthly average climatic inputs. The components of the stand model also include mean top height, basal area per hectare, stems per hectare, and diameter distribution. The mortality model was also fitted with a data set filtered using a mortality severity index based on the -3/2 power law to exclude catastrophic mortality events. An examination of this model with an independent dataset sowed little apparent bias.

Two models to predict a one sided canopy leaf area index (LAI) of radiata pine stands in the Canterbury Plains of New Zealand were also developed. The models were fitted using non-linear least squares regression of LAI estimates against stem measurements and stand characteristics. LAI estimates were

derived from digital analysis of fisheye lens photography. The models were kept simple to avoid computational circularity for physiological modelling applications.

This study included an objective comparison and validation of a range of model types. The models CANTY (Goulding, 1995), CanSPBL(1.2 (Pinjuv, 2005), CanSPBL-water (Pinjuv, 2005), and 3-PG (Landsberg and Waring, 1997) were compared and validated with the main criteria for comparison being each model's ability to match actual historical measurements of forest growth in an independent data set. Overall, the models CanSPBL(water), and CanSPBL(1.2) showed a slightly worse fit in predictions of stocking than did the model CANTY. The hybrid model 3-PG showed a better fit for the prediction of basal area than the statistically based model CANTY, but showed a worse fit for the prediction of final stocking than all other models. In terms of distribution of residuals, CanSPBL(1.2) had overall the lowest skewness, kurtosis, and all model parameters tested significant for normality. E-PG performed the worst on average, in terms of the distribution of residuals, and all models tested positively for the normality of residual distribution.

PONT, DAVID (2016)

ASSESSMENT OF INDIVIDUAL TREES USING AERIAL LASER SCANNING IN NEW ZEALAND RADIATA PINE FORESTS

Forest managers aim to maximise the productivity, profitability, health, and sustainability of New Zealand's plantation forests. There is an increasing need for high quality information about forest stands to support effective management. This is exemplified in the concept of precision forestry, which maps variation at a fine scale to allow targeted management, and in the concept of tree-level phenotyping, which quantifies the genetic and environmental drivers of tree growth. Remotely sensed data, in particular airborne laser scanning (ALS), was identified as having strong potential to provide tree level information to assist in attaining the goals of phenotyping and precision forestry. Tree-based, rather than area-based, analyses of ALS were identified as being essential to separate and quantify genetic and environmental factors on individual tree growth, and therefore critical to the development of novel phenotyping methods supporting precision forestry. The aim of this study was therefore to develop methods to characterise individual trees using remotely sensed airborne laser scanning data.

The research was focussed on evaluating the utility of ALS data to estimate key operationally relevant tree attributes for New Zealand plantation-grown radiata pine. Review of the literature identified three key research questions within which to frame the study. The first research question addressed the need to obtain accurate estimates of tree size, form, wood quality and disease attributes from ALS. A set of 36 individual tree crown metrics were derived from ALS data and evaluated for their correlations with ground measurements of the attributes. The second research question was aimed at evaluating the utility of tree-level ALS data in the analysis of genetic and environmental variance components and the estimation of genetic parameters, including genetic gains. The third research question evaluated the effects of ALS pulse density on estimates obtained from tree-level analyses of ALS data.

Strong correlations were established between morphological crown metrics and tree size attributes (r=0.90, 0.82, and 0.84 for H, DBH and V respectively), but not for tree form and wood quality attributes. A moderate correlation (r=0.50) with the level of Dothistroma infection was attributed to the effect of the disease on tree growth, indicating potential for disease phenotyping using remote sensing. Accurate estimates of variance components and genetic parameters were obtained from ALS for tree size attributes, but not for tree form, wood quality and disease attributes. For H, DBH, and V crown-based versus ground-based estimates of narrow sense heritabilities were within 5.0%, 19.5% and 23.9%, and estimates of genetic gains (96 tree selection level) were within 19%, 25%, and 25% respectively. Manually corrected tree segmentations were found to provide negligible improvements to correlations and estimates of genetic parameters, supporting the operational use of automated methods. Exponential reductions in tree detection accuracy, correlations, and estimates of genetic parameters were observed with reducing pulse density. A minimum pulse density of 6 $Pu.m^2$ was recommended for tree-based analysis of ALS in New Zealand radiata pine stands, and results indicated

exponential increases in pulse density will be required to significantly improve estimates.

This study has successfully addressed the research questions and produced important findings regarding tree-based analysis of remotely sensed ALS data. Morphological crown metrics have been derived, representing allometric relationships, which are therefore are expected to have general utility in estimating tree size attributes. Novel features of this research included: the wide range of operationally relevant tree attributes including tree size, form, wood quality and disease; quantification of genetic and environmental factors from ALS; comparison of the effects of automated and manually corrected tree delineations; and the quantification of the effects of pulse density on tree-based analyses. This research provides significant findings in support of the use of remotely sensed ALS data for phenotyping trees in genetics and research trials, and the development precision forestry methods, nationally and internationally.

RACHID CASNATI, CECILIA (2016)
HYBRID MENSURATIONAL-PHYSIOLOGICAL MODELS FOR *PINUS TAEDA* AND *EUCALYPTUS GRANDIS* IN URUGUAY

There is a consensus that prediction systems should be complex enough to predict yield, and the effect of various combinations of forest management practices on the functioning of interactive natural systems, but at the same time maintain a low level of detail in order to have low implementation costs and facilitate their use. For this reason hybrid mensurational-physiological models have gained importance and attention, and it is expected that their adoption will increase in the near future. This study aimed to explore the potential advantages of a hybrid mensurational– physiological model compared to models currently used in forest plantation management, and provide a better understanding of their capability to improve precision and explanation maintaining a certain level of simplicity as required for forest management. This work also aimed to provide updated tools for managing *Pinus taeda* and *Eucalyptus grandis* in Uruguay.

In Chapter 2, taper and volume equations were adjusted as those are essential to estimate individual volume and wood products. Emphasis was on testing compatible taper equations, since no models of this type have been developed to date for any species in Uruguay. However, variable exponent equations gave the best performance for predicting diameter at any height with the lowest prediction errors.

In Chapters 3 to 5, three systems of stand level equations comprising dominant height, basal area, maximum diameter, standard deviation of diameters, and mortality were developed using differential equations through three approaches:

i. Traditional time-based models using sigmoidal difference equations that restricted independent variables to age and parameters as functions of variables for region (base approach).

ii. Augmented time-based models that had parameters as linear functions of water holding capacity and physiographical variables such as elevation, aspect and slope.

iii. Hybrid physiological-mensurational models based on cumulative light sums since time of planting, with potential radiation-use calculated by modifiers accounting for influences of temperature, vapour pressure deficit (VPD), and water balance. These modified light sums replaced time in sigmoidal growth and yield difference equations.

Water holding capacity was the most significant among the surrogate variables tested in the mensurational models for both species (Chapter 3), whereas elevation was seldom significant. Sine and cosine of aspect weighted by the slope, and slope were usually included but to a greater extent to

one species than the other. Gains in accuracy of the augmented approach were small compared to the base equations.

When adjusting hybrid growth models (Chapter 4), combinations of radiation modifiers were selected that yielded accurate results. It was important to determine whether or not the gains in accuracy were sufficiently high to justify dropping the least representative modifiers and lose flexibility. Differences in global radiation across terrain corresponding to a variety of slopes orientations were tested to see whether or not they significantly affected growth. Radiation-use modifiers related to water balance and vapour pressure deficit (VPD) produced the highest gains in precision; however the complete formulation (including also temperature) was preferred in order to maximize the model utility. Accounting for aspect and slope when computing radiation flux did not improve precision in any of the state variables for either species.

For fitting hybrid mortality models (Chapter 5), it was hypothesised that the light-use efficiency approach could better explain the process leading to mortality because it accounts for predisposing site characteristics, recurring perturbations, and aggregation of stress. Extended periods of low water stress and short periods of high water stress were specifically tested as predictors of the probability of mortality. Results suggested that increase in stress did not influence the probability of mortality for *Pinus taeda*. However, stress helped explain the probability of mortality for *Eucalyptus grandis* with a negative effect: the accumulation of mild water stress tended to decrease the probability of mortality.

For *P. taeda*, resource availability increased growth and decreased the probability of mortality and mortality rate, but for *E. grandis,* higher levels of resources increased growth, probability of mortality, and mortality rate. It was hypothesized that the eucalypt species is more sensitive to factors other than water, given a potentially higher tolerance to drought episodes and resilience compared to the pine species.

A comparison of the three contrasting systems in terms of precision and bias as well as their capacity to reflect growth rates changes when site conditions vary was conducted. The comparison was extended to explore possible gains in diameter structure estimates. Results showed that precision tended to increase with higher levels of information; however explanatory variables included in the components of each approach and precision gains varied with species. Any of the three systems of equations can be applied for managing forests in Uruguay, especially for projecting diameter distributions, since the three approaches provided diameter distributions of similar accuracy. Nonetheless models based on the hybrid approach were more precise, especially for *E. grandis* (with precision gains between 9 and 14% among state variables). Biases of the predicted variables were similar between approaches, but consistently less for estimating mortality in long intervals in the hybrid formulation. Along with precision, this approach offered higher utility.

RAJAPAKSHA SHILPAGE, CHAMIRA (2022)
SEASONAL, GENETIC AND ECONOMIC ANALYSIS OF *EUCALYPTUS BOSISTOANA* ESSENTIAL OIL

The New Zealand Dryland Forest Initiative (NZDFI) is working to establish naturally durable eucalyptus plantations in New Zealand. The prioritized species is *Eucalyptus bosistoana*. A central focus is to identify high performing genetic material in a network of breeding trials. Although, heartwood is the main envisaged product, leaves could be used to produce essential oil as a by-product of these plantations. Essential oil quality is mainly determined by oil chemistry. The phytochemical composition of foliage can also have an effect on browsing damage and consequently tree health and profitability of such plantations.

Chapter 1 gives an introduction in the history, chemistry, production and global market of eucalyptus essential oils. A review of NZDFI's durable eucalyptus species indicated that *E. bosistoana* could be a species suitable for essential oil production.

The development of an appropriate method for oil analysis is described in chapter 2. Of the three extractive methods tested, namely accelerated solvent extraction (ASE), hydro-distillation and microwave solvent extraction (MSE), MSE was selected for this work due to its convenience. Ten major compounds (1,8-cineole, limonene, α-terpineol, α-pinene, aromadendrene, β-myrcene, caryophyllene, trans-pinocarveol, ocimene, linalool) were identified in the GC chromatograms of the eucalyptus oils. Chemical analyses of NZDFI's species *E. argophloia*, *E. globoidea*, *E. tricarpa, E. quadrangulata* and *E. sideroxylon* and New Zealand's commercially grown *E. nitens* confirmed that *E. bosistoana* has the highest oil yield (15.8 μL/g) and 1,8-cineole percentage (62%). The data also suggested the essential oil of *E. bosistoana* is different to that of the closely related *E. argophloia*.

Chapter 3 investigates the seasonal variation of essential oil composition in mature and immature *E. bosistoana* leaves. Leaf oil was monitored for 2 years. The highest oil yield (average 16.7 μL/g) and percentage of 1,8-cineole (average 67.1%) were obtained from the leaves collected during summer while they were lowest during winter. Mature leaves contained a significantly higher ($p \leq 0.01$) proportion of 1,8-cineole in (60.9%) than immature leaves (44.6%). Total oil yield ranged from 3.0 to 27.0 μL/g (fresh) in mature leaves and from 5.0 to 26.7 μL/g (fresh) in immature leaves. Oil quality and quantity were comparable to literature reports.

Genetic control of oil traits was investigated in chapter 4. Mature leaves of 8 year old *E. bosistoana* were collected from 1901 trees representing 85 families from one breeding trial. 20 Compounds were quantified in these samples. Data on tree height and insect defoliation (health scores) were also available for 72 families in this trial. Heritability estimates (h^2) of the quantified essential oil compounds ranged from 0.06 to 1.14, with the most abundant compounds 1,8-cineole, aromadendrene and unidentified compound 8 showing the highest h^2 of 0.78, 1.14 and 0.59, respectively. Total oil content had moderate 0.25 heritability.

The negative correlation between total oil content and 1,8-cineol concentration at the phenotypic and genetic level (r_p = -0.44 and r_g = -0.70, respectively) implied that families with a higher quality oil have less oil in the leaves. 1,8-cineole was genetically strongly negatively correlated with myrcene (r_g = -0.74), α-pinene (r_g = -0.71), linalool (r_g = -0.90), aromadendrene (r_g = -0.94), trans-pinocarveol (r_g = -0.75) and unknown compounds 3 (r_g = -0.91), 6 (r_g = - 0.83), 8 (r_g = -0.88) and 9 (r_g = -0.75). 19 Families had breeding values consistent with the standard commercial oil quality requirement of over 60% 1,8-cineole. The results show that planting stock could be selected from the *E. bosistoana* breeding programme which would aid essential oil production, as it is done for other eucalyptus species, i.e. *E. polybractea*.

Oil traits did not correlate with tree height or insect defoliation and these traits were also not heritability in this assessment. However, the small number of individuals (n = 3) assessed for those two traits was likely contributing to this results. Additional work is needed to investigate the correlation of those traits with oil characteristics.

Chapter 5 considers economic aspects of essential oil production from New Zealand grown *E. bosistoana*. Leaf biomass was estimated using published allometric equations for other eucalypt species and validated with available *E. bosistoana* data. This indicated *E. bosistoana* leaf biomass could be comparable to that of *E. globulus*. A sensitivity analysis indicated that biomass, genetics, seasonal variation and fluctuations in oil prices were equally important on the viability of an essential oil operation. Potential small- (400 t fresh leaf/year) and large-scale (2000 t fresh leaf/year) oil production would be supported by NZDFI's envisaged planting programme of 5,000 ha regional catchments. Small-scale oil production could be initiated using the leaves from thinning operations, and expand into a large-operation over time when trees will be harvested. Lastly, based on the operational costs of a domestic small-scale essential oil producer, oil value from *E. bosistoana* would exceed the cost of production.

RAZAVY TOOSI, EHSAN (2011)
SOLUBLE ORGANIC MATTER, ITS BIODEGRADATION, DYNAMICS AND ABIOTIC PRODUCTION

Soluble organic matter represent less than 1% of total soil organic matter (SOM) - but it contributes to many terrestrial ecosystem processes, due to its high mobility and reactivity in soil. Although it has been suggested that soluble organic matter (OM) may serve as an early indicator of soil quality changes as a result of shifts in land-use and management practices, only a few studies have addressed the dynamics of soluble OM in relation to land-use and specifically soil depth.

This study focuses on two aspects of soluble OM. In the first part, I hypothesized that extractable OM obtained by aqueous solutions is a continuum of substances that depending on the extraction method can be separated into two operationally different fractions. The size and properties of these fractions may consistently differ among different land uses and at different soil depths. The objective of this part of the study was then to assess dynamics (size and properties, biodegradability and seasonality) of water extractable organic matter (WEOM) and salt extractable organic matter (SEOM) in a sequence of human dominated land-uses at topsoil and subsoil.

At the second part of the study, I tested the regulatory gate hypothesis –abiotic solubilization of OM- as a primary controlling factor in soluble OM production. The objective of this study was to evaluate the impact of the microbial activity on the net production of dissolved organic matter (DOM) from the native SOM in the presence of added DOM and plant residue.

For the first part of the experiment, the soil samples were collected from four land-uses under bog pine (*Halocarpus bidwillii)* woodland, tussock grassland (*Festuca novae-zelandiae and Heiracium pilosella),* cropland (*Medicago sativa)* and plantation forest (*Pinus nigra).* The selected land uses were located in the Mackenzie Basin, Canterbury, New Zealand and occurring on the same soils, topography and experienced similar climates. Soil samples were obtained from topsoil (0-20 cm) and subsoil (60-80 cm) at the end of each season (November, February, May and August) during 2007-2008. The sampled soils were adjusted to the same water status prior to extraction. While WEOM was obtained during a mild extraction procedure and using 0.01M CaCl2, SEOM was extracted with 0.5M K_2SO_4 at high temperature (75°C for 90 min). Both extracts were filtered through a 0.45 μm filter size.

In the first part of the study, I assessed the biodegradation dynamics of WEOM and SEOM (spring samples), using a double-exponential decay model. The WEOM and SEOM were inoculated and incubated at 22°C for 90d under aerobic conditions. Subsamples were removed on days 1, 3, 7, 12, 16, 30, 42, 60, 75, and 90, filtered (0.22 μm), and analyzed for organic C and N content, UV absorption, and 13C natural abundance ($\delta^{13}C$).

The results of the biodegradation experiment indicated a similar pattern for both C and N of SEOM and WEOM as that of previously shown for soil DOM. However, C and N mineralization rate were considerably larger in the WEOM than SEOM. The parameters of the double-exponential model suggested that regardless of the land-use and soil depth, both the WEOM and SEOM can be modeled in two biological pools, with a largely similar "fast decomposable" but different "slowly decomposable" pools. However, since the extraction was not sequentially followed, a very small portion of the SEOM was comprised of the WEOM and given the greater observed biodegradability of the WEOM, the overall biodegradable portion of the SEOM would be lower than the observed. Despite a greater biodegradability of the organic N than C of both WEOM and SEOM; mainly due to a longer HL of the slowly biodegradable pool of C; the C/N ratio of the samples did not change very much during the biodegradation. This led us to conclude that the biodegradation of soluble OM may occur as a function of N availability.

Parallel to C and N loss, a considerable increase in $SUVA_{254}$ of SEOM, and particularly WEOM occurred during the incubation period. The greater increase in the proportion of aromatic compounds

(assessed by SUVA) in the WEOM than SEOM, implied consumption of simple compounds (vs. very humified) during decomposition and further supported the observed faster biodegradation rate of the WEOM. The data indicated a relatively strong correlation (R2=0.66 and 0.74 for the WEOM and SEOM, respectively) between the amount of biodegraded C and the increase in $SUVA_{254}$. This suggested that $SUVA_{254}$ can be used as a simple, low-cost but reliable approach for describing the biodegradability of soluble OM, as previously suggested by others.

At the end of the bioassay, the ^{13}C natural abundance of the WEOM was significantly depleted, and showed a clear relationship with the proportion of the biodegraded C. This confirmed the previously suggested preferential biodegradation of simple organic constituents (^{13}C enriched), resulting in the accumulation of more depleted ^{13}C compounds (often recalcitrant compounds). Moreover, the results of the $\delta^{13}C$ technique revealed that the relatively greater ^{13}C enrichment of the WEOM obtained from subsoil, seems to be due to the presence of root exudates (often highly ^{13}C enriched). In contrast, a proportionally greater ^{13}C depletion observed in the SEOM particularly at subsoil samples, suggests that there is a close relationship between the SEOM and the typically ^{13}C depleted humified SOM.

The results of the biodegradation model (half-life of both C and N), in addition to dynamics of $SUVA_{254}$ and $\delta^{13}C$ of the WEOM and SEOM were very comparable between top and subsoil samples. This implied that the potential biodegradability of soluble OM under laboratory conditions does not necessary reflect the reported lower in situ biodegradability at soil depth, in agreement with recent evidence suggested by others. Instead, this may be largely due to the lack of optimum conditions (oxygen, nutrients, and moisture) for the decomposer community at soil depth.

Although there was a tendency for a generally greater biodegradability of the samples from the soils under the crop land (both WEOC and SEOC), along with relatively greater increase in SUVA, there was not a consistent trend of the effect of land use on the biodegradation of either WEOM or SEOM. The lower C/N ratio of the soils under the crop land seemed to be related with the observed proportionally greater biodegradability of these soils.

During the second part of the study, I assessed seasonal variations of the size and properties of the previously defined WEOM and SEOM, collected from top-and subsoil from the land-uses. I observed that 10-year after conversion of the degraded tussock grassland to cropland or plantation, the total C stock of topsoil (0-20 cm) when above- and below-ground plant biomass is excluded; has remained unchanged. This was attributed to the limited biomass production of the region, more likely as a result of low productivity of the soil, but also harsh climatic conditions. Not only soil depth, but land-use affected both C concentration and C/N ratio of soil organic matter (SOM), with the greatest C concentration of soils under grassland and plantation in topsoil and subsoil, respectively. Despite the WEOM, the size of SEOM was largely unaffected by land-use and soil depth; instead, the properties of SEOM was more consistent with the effect of soil depth. Given the observed large temporal and spatial variability of the WEOM, the study suggests that the SEOM more consistently reflects the influence of land use and soil depth. No consistent effect of seasonality was observed in terms of size or properties of the SOM and the WEOM and SEOM. Overall comparison of the size and properties of the WEOM and SEOM indicated that OM extraction efficiency may vary largely, depending on extraction conditions. Using more concentrated salt solutions consistently yielded greater amount of OM (N, and especially C) release from soil with properties resembling more those of total soil OM (more humified) compared to the WEOM. The SEOM was also less variable by time and space.

The last part of the study was aimed to assess biotic *vs.* non-biotic solubilization of OM in the presence of added plant residue. Given the need to recognize the source of the solubilized OM during the experiment, I used enriched (^{13}C) plant residue as the source of fresh OM. The above-ground part of ryegrass was added to soil either as plant residue or residue extract (extracted with CaCl2 followed by 0.45µm filtration) -termed DOM. These two forms of added OM (residue/DOM) were conceived to represent two levels of bioavailability for the decomposer community for further assessing possible biotic solubilization of OM. Two soils similar in their OM content and other properties, but different

in mineralogy were selected for the experiment. Soils were incubated for 90d under sterilized *vs.* non-sterile conditions and leached regularly with a dilute aqueous solution (0.05M $CaCl_2$). Plant residue was added to soil (1:100, residue: soil, w/w) prior to the start of the incubation, but DOM was frequently applied to the soils along with each leaching experiment.

The greater C and N concentration in the leachates of both sterilized residue- amended and DOM-amended soils compared to that of living soils, indicated a high microbial activity, as determined by CO_2 loss, in the living soils. However, the proportion of the solubilized C (determined by ^{13}C) from sterilized soils was largely comparable to that of living soils. This supports the recently suggested "regulatory gate" hypothesis, stating that solubilisation of OM largely occurs independent of the size or community structure of microorganisms. In addition, I observed that even with the presence of adequate amount of added fresh OM (ryegrass residue), about 70% of the solubilized C consistently originated from the humified soil OM, highlighting the role of native soil OM as the source of soluble OM in soil. In addition, in the DOM- amended soils, there was strong evidence, indicating that in the sterilized soils, the added DOM was exchanged with the humified soil OM as observed by an increase in SUVA, and humification index (HI) of the leached OM. Although the results of the study did not show a considerable difference in the solubilisation rate of added OM as a function of biological activity (either in the residue- or DOM-amended soils), there was clear evidence that the presence of microbial activity has resulted in further decomposition of the solubilised OM through biological transformations.

Together, the results suggested that the proposed fractionation method can be used to separate two operationally defined pools of soluble OM with consistent differences in their size (C and N), properties ($\delta^{13}C$, $SUVA_{254}$, and C/N ratio) and biodegradability across the land-uses and soil depth. The second part of the study supported the primary role of abiotic factors on the production of soluble OM from native soil OM. Although the abiotic mechanisms involved in the solubilization remain to be addressed by future studies. Cons and pros of the methods with some suggestions for further works have been mentioned in the last chapter.

RIVAS PALMA, ROSA M. (2008)
ENVIRONMENTAL AND SOCIAL VALUES FROM PLANTATION FORESTS: A STUDY IN NEW ZEALAND WITH FOCUS ON THE HAWKE'S BAY REGION

Plantation forests ecosystem functions provide a range of indirect benefits known as forest services. There is lack of knowledge and estimation of the value of forest services. The main aim of the research was to investigate the environmental and social value of plantation forests in New Zealand.

Each step of the research was built up on the perspectives of the stakeholder groups identified. A stakeholder analysis revealed that the most relevant stakeholder group was *Adjacent neighbours*. Through a postal survey forest managers and stakeholders indicated they considered as most relevant *Erosion control* and *Water regulation* (quality and quantity) *Employment, Increased living standard*, and *Recreation*. These services became the focus for the rest of the study.

Through focus groups, the most relevant stakeholder groups, identified and ranked positive and negative aspects in forestry, and selected attributes describing the forest services. These were: *Amount of sediment in water* (water quality), *Algae in water* (water quality), *Percentage of land stabilisation* (erosion control), and *Level of water flow* (water quantity). The attributes for the attitudinal questions were classified as *Community, Employment,* and *Recreation.*

The environmental value of plantation forests was estimated through choice modelling. The valuation survey was carried out only in Hawke's Bay. The payment vehicle used was increased regional council rates with the objective of monitoring environmental qualify of soil and water. Several models were estimated by adding interactions between variables. Model 15b was selected as it provided best model

fit and integrated respondents' demographic and attitudinal characteristics. The results of the model indicated that respondents who had university studies and positive attitude towards plantation forest community values were more willing to pay for improved levels of land stabilisation. The implicit prices estimated indicated that the wider community in Hawke's Bay have a greater appreciation for water quality (lower levels of algae and sediments). The responses to the attitudinal questions indicated that most respondents had positive attitudes towards the community and practical uses of plantations and employment-related values, particularly older respondents.

The environmental and social values identified were linked with forest operations in order to analyse the impact they have. Land preparation and planting, road construction, and harvesting are the forest operations that have a greater impact on the levels of sediment in water.

RODENBERG BALLWEG, JULIE (2013)
TESTING THE AFFORESTATION RESERVATION PRICE OF SMALL FOREST LANDOWNERS IN NEW ZEALAND

The estimation of afforestation reservation prices for small landowners in New Zealand has not been the subject of much research despite its importance in predicting future land use. Reservation prices for planting represent the minimum payment a landowner must receive before converting land from agriculture to forest. A survey of 728 landowners from every region of New Zealand who own between 20 and 200 hectares of forest as well as other unplanted land used for agriculture were surveyed about forestland, forest land owner demographics, ownership objectives, silviculture and reservation prices.

In this study, reservation price strategies were investigated by offering hypothetical annual and one-time payments for converting land from agriculture to forestry. From this survey, the average one-time payment a landowner would be willing to accept to convert a hectare of land from agriculture to forestry was $3,554 and the average annual payment to convert a hectare of land was $360. The key factors influencing the reservation price were; whether or not the landowner lived on the property, if one of the ownership objectives was income from carbon, the primary agricultural enterprise and total household income. An implied discount rate was calculated for each landowner and excluding those who would not accept any payment the average after-tax discount rate was 9.7%.

Small landowners indicated that their primary reason for owning plantation forest was income from timber with very few landowners using their forest land for recreation. The median farm size was 400 hectares and the median forest plantation was 37 hectares. Planting of radiata pine peaked in 1994 and 1995 with more radiata pine planted in 1994 than in all the years from 2000-2009. Most landowners are performing some type of silviculture in their forests. Ninety percent of landowners are pruning in the current rotation while only 61% plan to prune in the future. Only 26% of landowners have engaged in any commercial harvesting in the past ten years but as their current rotation matures 71% plan to replant on the same site. A majority of respondents thought the situation for forest landowners was getting better.

Understanding the reservation price strategies of landowners is important for predicting future land use patterns and recognizing how close landowners are to converting land. The ownership objectives of landowners and the replanting decisions they make are critical for future timber supply. The results of this study can assist in the development of forest establishment incentive programmes. Better information about landowner characteristics will result in enhanced decision-making for the timber industry and the government in New Zealand.

RODRIGUES, ANNA P (2015)

ECOLOGICAL THRESHOLDS AS CONSTRAINTS TO THE GROWTH AND SURVIVAL OF WOODY TREE SPECIES IN DEGRADED GRASSLAND IN THE SOUTH ISLAND'S DRYLAND ZONE

The native dryland zone in New Zealand's South Island has been drastically altered by burning, grazing, and other anthropogenic activities since human first arrived some 700 years ago. Only 30% of its original native vegetation remains, with <2% of it legally protected. Preserving what is left of the remaining natural ecosystems is urgent, and ecological restoration can be an important part of the solution to increase the area by reclaiming some of the degraded landscape within the dryland zone. However, reintroducing native plants as seedlings is mostly ineffective if disturbances have pushed ecological processes over certain thresholds that now represent barriers to ecological succession and restoration. These ecological thresholds can be the exposure of seedlings/saplings to direct sunlight and strong winds, water stress, soil compaction, herbivory, or competition between the native and exotic species for resources, among others.

The objective of the research described in this thesis was to identify management interventions that might allow restoration to overcome key ecological thresholds preventing the establishment of native woody vegetation. The research was undertaken at five study sites in Northern Canterbury and the Mackenzie Basin. A combination of ground cover manipulation and shading trial, together with irrigation and grazing exclusion, were used to investigate the options to overcome these thresholds for the establishment and growth of native woody tree species. The results showed that the native seedlings had higher probability of survival and growth rates in the shaded treatments, likely due to increased soil moisture and soil aeration. Removal of exotic grasses, irrigation, and fencing also increased native seedling establishment; however, the best results were detected when these treatments were combined with shade. Therefore, ecological restoration of degraded dryland areas on former agricultural/pastoral lands can be achieved if the effects of direct solar radiation on soil aeration, soil moisture, and microclimate are reduced through the creation of shelter for planted native seedlings. Additionally, exotic plant species must be removed, or at least reduced in density, and herbivores excluded in order for restoration efforts to be more successful.

ROSCHAK, CHRISTIAN (2018)

STRUCTURE AND DYNAMICS OF LOWLAND PODOCARP-BROADLEAVED FOREST IN THE CENTRAL NORTH ISLAND, NEW ZEALAND – THE EFFECTS OF DIFFERENT SILVICULTURAL REGIMES ON STAND STRUCTURE AND TREE SPECIES COMPOSITION

Podocarp-broadleaved forests and their alliances form one of the largest forest groups in New Zealand and cover an area of approximately 2.9 million hectares. Their vast exploitation and deterioration in the past 150 years called for sustainable forest management as an imperative need. As a consequence, commercial harvesting of these forests is restricted to private land only and is strictly controlled by the Ministry of Primary Industries under the Forests Act 1949 as amended in 1993. The Act demands sustainable management of podocarp-broadleaved forest in a form of selective harvesting of podocarps that is limited to single trees or small groups. But there is concern that selective harvesting of podocarps in this forest type is not sustainable due to the complex structure of those forests.

This thesis explores the regeneration dynamics in an old-growth podocarp-broadleaved forest in the Central North Island and how past harvesting has altered its structure. Tree core analysis is an important tool to obtain information on tree age and growth. As *Beilschmiedia tawa* is the dominant tree species in this forest and as little is known about the suitability of tree cores of this species in age and increment studies, their prospects and limitations are elaborated first. The second study examines the structure of the old-growth podocarp-broadleaved forest and the natural processes that drive recruitment success and failure. In the third study, the impact of different sizes of harvesting gaps on

tree species regeneration and subsequent growth is investigated. The final chapter evaluates the harvesting prescriptions in the Forests Act on the basis of key findings of the above studies.

The results demonstrate that false and missing rings are common features in *B. tawa* tree cores but that individual errors in the form of overestimation and underestimation of calculated increments cancel each other out on a stand basis, making stand level predictions reliable. They further illustrate that the scarcity of large-scale disturbances in old-growth podocarp-broadleaved forest is responsible for a regeneration gap of the podocarps *Dacrydium cupressinum*, *Dacrycarpus dacrydioides*, *Prumnopitys ferruginea*, *Prumnopitys taxifolia* and *Podocarpus totara* but that harvesting can improve their growth conditions significantly if the gaps created are large enough. This is, however, not in accordance with the low-impact harvesting prescriptions in the Forests Act, while the results presented here show that selective harvesting of emergent podocarps is not sustainable and accelerates the decline of those species in this forest type.

SALEKIN, SERAJIS (2019)
HYBRID GROWTH MODELS FOR *EUCALYPTUS GLOBOIDEA* AND *E. BOSISTOANA*: EXPLAINING WITHIN AND BETWEEN SITE VARIABILITY

Plantation forests play a major role in satisfying many forestry needs such as demand for wood and different ecosystem services, which are projected to increase in the future. In New Zealand, the plantation forestry industry is dominated by *Pinus radiata,* which comprise approximately 90% of the net stocked area. Diversification of the New Zealand plantation forest estate by introducing new species is prudent, especially in arid parts of the country where *Pinus radiata* growth cannot achieve its full potential. Several *Eucalyptus* species are potential alternatives to *Pinus radiata*. However, there is currently very little information on their growth dynamics.

Forest growth and yield models are used to understand the growth dynamics of forest trees and are generally mensurational models for mature stands created from inventory data that span several years. Growth models of plantation trees at juvenile ages can generate information useful for plantation establishment, but such models are rarely created. Although mensurational growth and yield models project and create useful information to help management decisions, they provide little understanding of ecophysiological tree growth process. However, ecophysiological process information is important, especially in young plantations. This information can be created through process-based models, but these models are data intensive. Therefore, combining the two modelling approaches through hybridisation can give access to both mensurational and process- based modelling information, without violating basic growth and yield modelling assumptions.

Most existing growth and yield models are developed at stand level or individual tree-level, and productivity of the site is assumed to be homogenous due to silvicultural management and site preparation practices. However, in most sites growth is not homogenous throughout, especially juvenile plantation growth. Therefore, it is important to explore the factors affecting plantation growth within stands.

This doctoral thesis investigates and develops models that include within and between stand factors for juvenile *Eucalyptus bosistoana* and *Eucalyptus globoidea* by using a hybrid ecophysiological modelling approach. The study further tests and compares different hybridisation approaches. It concludes with a preliminary mature-stand mensurational growth and yield model for *E. globoidea*, developed from sparse available data by use of algebraic difference approach (ADA) equations.

The availability of high-resolution digital elevation models (DEMs) is inadequate for rural New Zealand, including the unproductive ex-pastoral lands where this study is sited. However, it is important to have high-resolution DEMs for hybrid ecophysiological study of growth and yield. Filed surveys conducted with global positioning system (GPS) receivers, can be an efficient, useful and

simple method for creating high-resolution DEMs. This study reports on an optimisation procedure for producing DEMs by comparing three non-geostatistical interpolation procedures carried out with field collected GNSS data. Results show that the ANUDEM interpolation algorithm produced DEMs with the highest accuracy. The study also reports that data density influences final DEM resolution.

Within-stand height growth and survival proportion models indicate that topographic, wind exposure, morphometric protection, position index, and distance from ridge top significantly influenced juvenile height growth and survival proportion. These topographic indices were also found to be significant for between-site juvenile height growth and survival proportion, along with temperature. Overall, each of the final models had high precision and minimal bias, therefore they can predict juvenile tree height yield and survival proportion well.

Potentially useable light sum equations (PULSE) with augmented topographic indices were better than PULSE alone, or traditional hybridisation approaches, for explaining between-site growth. In addition to height growth and survival predictions, these hybrid models offer many other uses, including generating useful ecophysiological information, and they offer an improved understanding of tree growth processes.

Finally, the preliminary mensurational growth and yield models for *E. globoidea* were developed to project growth over time with high precision and minimal error. These models create useful growth dynamics information for forest managers, as well as suggesting future research avenues for growing *Eucalyptus* in New Zealand.

SCHORI, JENNIFER (2020) PHD IN BIOLOGY

IMPROVING THE SUCCESS OF INSECT CONSERVATION TRANSLOCATIONS: A CASE STUDY OF THE NATIONALLY ENDANGERED ROBUST GRASSHOPPER (*BRACHASPIS ROBUSTUS* BIGELOW)

The current rates of species loss and decline are so extraordinary that the Earth is speculated to be on the cusp of entering a sixth mass extinction, with the majority of species lost expected to be insects. Insects make up approximately 70 % of all species on Earth and are proportionally the most under-represented class of animal in conservation biology. An important tool for substantially reducing the risk of extinction for critically threatened species is conservation translocation, which is defined by the International Union for Conservation of Nature as "the intentional movement and release of a living organism where the primary objective is a conservation benefit". However, there has been limited applications of translocation as a conservation tool for insects, and only 52 % of terrestrial insect translocations are reported as successful at establishing a persistent population. This thesis develops applied conservation management strategies to improve translocation success for insects using New Zealand's Nationally Endangered robust grasshopper, *Brachaspis robustus* Bigelow (Orthoptera: Acrididae), as a case study.

Brachaspis robustus is a large bodied, flightless, highly visually cryptic and non-stridulating grasshopper. It is a braided river specialist endemic to the Mackenzie Basin, an inter-montane dryland region in the centre of New Zealand's South Island. Currently all wild populations of *B. robustus* that are monitored by the New Zealand Department of Conservation show trends of decline. Despite being one of New Zealand's most threatened grasshopper species, little research has been directed toward maximising conservation outcomes for *B. robustus*.

The first objective of this research was to understand the life history of *B. robustus*. Grasshoppers were tracked from egg to adulthood in captivity in the field and in the laboratory. The life cycle of *B. robustus* was observed to be ~27 months in the field. Females laid on average 1.3 egg pods in the wild, but up to 8 in the laboratory. Egg pods contained between 17 and 35 eggs, and the eggs go through an obligate diapause which is almost certainly broken by cold winter temperatures below 0 °C.

Survivorship was low in the laboratory and in the field, despite no predation pressure from key predators including birds and mammals. Understanding the life history of *B. robustus* has facilitated the interpretation of trends detected during population monitoring, informed the development of captive rearing for release protocols, and provided an opportunity to simulate expected outcomes of future translocations.

The second research objective was to understand the habitat requirements of *B. robustus*. Using miniaturised radio transmitters, the movements of adult female grasshoppers occupying a linear gravel road were compared to those occupying a more natural open braided river habitat. Dense vegetation was found to be unfavourable habitat, indicating that management of vegetation will be important for maintaining habitat quality. No difference in home-range size was found between the two sites indicating that the area of habitat required to support an adult female is likely to be > 300 m^2. This has applications for managing remaining habitat (e.g. area over which management of weed and mammalian predators should be implemented), creating artificial habitat, and selecting potential receiving habitats for conservation translocations.

The third research objective of the current study was to evaluate the threat introduced mammalian predators pose to the persistence of *B. robustus*. The outcome of an experimental translocation where individuals were released into predator reduced and non-predator reduced areas was monitored. In addition, long-term trends were analysed of three populations of another declining dryland grasshopper species, *Sigaus minutus*, that are present in areas where mammalian predators are controlled at different levels of intensity. It was concluded that mammalian predators are likely to pose a substantial threat to *B. robustus,* and that high intensity mammalian predator control across the full suite of predators should be prioritised to improve conservation management and translocation success.

The fourth research object was to develop effective monitoring techniques for *B. robustus*. First, an intensive removal sampling study conducted over a single active season (November to March) was used to rapidly quantify seasonal and demographic variation in visual detectability of *B. robustus*. Juvenile instars were found to dominate population composition in all months except December (adults = 69 %) and males represented > 50 % of monthly captures. Adult females were 2-3 times larger than adult males, and 79 % of those captured were found during the first search of an area, compared to only 52 % of adult males. The odds of detecting an individual were found to increase by 6 % per 1 mm of body length. Second, by conducting experimental monitoring for three consecutive seasons, both population density and population distribution monitoring protocols were developed for *B. robustus.* The recommended population density monitoring protocol used adult female counts as an index of population size to maximise visual detectability and ensure data is biologically meaningful. November and early December was found to be the most appropriate time to conduct monitoring, and > 20 transect replicates with > 4 survey replicates each were required to detect a significant change in adult female population size with power > 0.8. Occupancy modelling was investigated as a distribution monitoring protocol for *B. robustus* by estimating the probability of detection (p_g) in a natural open riverbed compared to a gravel road habitat. Detection of grasshopper presence was found to be high (p_g > 0.6) when using a 100 m x 1 m transect in both habitat types under optimal (no cloud) conditions in February, and a minimum of 3 visits per season was required to have confidence in trend detection. Implementing the population monitoring protocol presented here will be important for measuring the outcome of any future translocations of *B. robustus*. This research has contributed knowledge that has substantially advanced the understanding of a Nationally Endangered insect. It has provided evidence-based conservation management recommendations that contribute toward the development of conservation translocation as a successful and valuable tool for preventing future insect extinctions.

SHADBOLT, ANTONY (2014)
SMALL MAMMALS OF THE PLANTED FOREST ZONE OF SARAWAK, EAST MALAYSIA; AN ASSESSMENT OF DISPERSAL ABILITY AND RESPONSE TO HABITAT FRAGMENTATION

In recent years a push to establish pulpwood plantation forestry in Sarawak, East Malaysia with *Acacia mangium* has been identified as a means to relieve pressure on the State's diminishing natural forest resource whilst providing 1) economic wealth for a developing economy 2) community development, and 3) biodiversity conservation outside the protected area network. In a specially designated 504,000 hectare Planted Forest Zone (PFZ) a range of broad-scale landscape planning initiatives have been implemented in an attempt to conserve a representative sample of biodiversity across the plantation landscape. The effects of forest modification and fragmentation have been widely reported in the literature for mammals, and in this study, non-volant small mammals were fitted with tracking spools and/or radio collars and released into small forest remnants outside of their home ranges to measure response to unfamiliar habitats, forest edges and various scales of habitat fragmentation during simulated dispersal events.

Medium sized patches exhibited the greatest species diversity and abundance, whereas the largest forest areas hosted the largest population of brown spiny rat (*Maxomys rajah*); a species that is identified as vulnerable across its natural range. Small forest patches of c.1.00 ha that had been exempt from clearing during plantation establishment are likely to be species poor and host small populations of extant species only. All species were found to make extensive use of downed woody debris for movement, and showed varied responses to a range of habitat edges including forest roads, acacia plantation compartments, old haul trails, clearings and riparian areas. Two species of treeshrew; long-footed treeshrew (*Tupaia longipes*) and painted treeshrew (*T. picta*) were shown to be able to move between the forest patch and the acacia forest while the same edges were shown to pose barriers to the brown spiny rat (*M. rajah*) and large treeshew (*T. tana*) illustrating the different ways that species may perceive and use habitat features such as corridors.

Despite *T. picta* being common in the PFZ, comparatively little has been published on its ecology and behaviour compared with the other Bornean tupaiids. Therefore this study also reports on the movement and behaviour of this species within its own home territory as revealed from both radio telemetry and spool-and-line tracking. Home range size, dimension, average daily movement distances and nest site construction was found to be similar to other Tupaiids studied in secondary forests in Sabah, and home ranges were found to be dictated by anthropogenic landscape features such as forest roads and open areas across which no movement was recorded. Painted treeshrews were found to favour logs and fallen woody debris as movement substrates and spend the large majority of their movement at ground level. Camera trapping revealed possible interspecific nest sharing between the painted treeshrew and the three-striped ground squirrel (*Lariscus insignis*), fuelling the debate on whether or not treeshrews construct their own nests or use nests constructed by squirrels.

SHARMA, MONIKA (2012)
NEW APPROACHES TO WOOD QUALITY ASSESSMENT

This study approaches wood quality in young trees by very early screening – and consequent selection for propagation – on the basis of physical and mechanical properties.

In chapter 1 corewood properties are reviewed and the importance and problems associated with early screening are discussed. Due to randomly distributed reaction wood in young trees it is advantageous to lean trees to avoid intermixing of the two wood types and minimise any uncertainty in the results.

In chapter 2 physical and mechanical properties are described for opposite and compression wood in a population of *Pinus radiata* comprising of 50 families, at a young (<3 years) age. The dynamic stiffness was determined using the resonance acoustic technique. Density was measured using water

displacement method, and longitudinal and volumetric shrinkage were measured from green to ~5% moisture content. The compression wood and opposite wood differ significantly in all the measured properties. Compression wood was characterised by high density and high longitudinal shrinkage. The mean stiffness of opposite wood was 3.0 GPa with a mean standard deviation of 0.39, and the mean longitudinal shrinkage of opposite wood was 0.99% with mean standard deviation of 0.31 across the samples examined. This variation in stiffness and longitudinal shrinkage in opposite wood can be exploited to screen for wood quality. The variation in stiffness and longitudinal shrinkage within a family was comparable to variation among families. In spite of large within site variability it was possible to distinguish between the worst and the best families in opposite wood at young age.

In chapter 3 ranking of selected families of *Pinus radiata* was done based on microfibril angle, which is considered as the main factor influencing both stiffness and longitudinal shrinkage. The ranking was compared with ranking done using acoustic velocity which is more practical and fast method of screening trees. The mean MFA in opposite wood was 39° with a mean standard deviation of 3.7 and in compression wood the mean MFA was 44° with a mean standard deviation of 2.9. The variation in MFA in opposite wood offers opportunities to breed for trees with low MFA. A strong negative correlation (R=-0.68) between acoustic velocity squared and MFA in opposite wood suggested that the resonance technique can be used effectively to screen very young wood rather than using MFA.

At high MFA, the cell wall matrix also plays an important role in determining the mechanical and physical properties of the wood. At present the chemical composition of wood samples is determined by wet chemical analysis, which is time consuming and laborious. Therefore, it is impractical to characterise large numbers of samples. Mechanical properties, particularly tanδ (dissipation of energy), which changes with temperature and frequency as the structure of the material changes at the molecular level, was studied using dynamic mechanical analysis (DMA). The idea was to assess if it can be used as a quality trait for tree screening instead of wet chemical analysis. Compression wood and opposite wood were characterised for storage modulus and tanδ at constant moisture content. In practice the instrument used, TA instrument Q800, was unable to provide the desired range of temperature and humidity so no glass transition at 9% moisture content in the temperature range of 10°C to 85°C at 1 and 10 Hz frequency was observed that might be attributed to the hemicelluloses (or lignin). In spite of the huge difference in chemical composition of opposite and compression wood, the difference in their mean tanδ at 25°C and 1 Hz values was just 7%. The positive correlation between MFA and tanδ in opposite wood suggested that MFA also plays a role in the dissipation of energy. The strong relationship between storage modulus and dynamic modulus (R=0.74) again justifies the reliability of resonance technique to screen young wood for stiffness.

Concurrently eighty seven, two-year-old leant *Eucalyptus regnans* were studied for growth strains along with other physical and mechanical properties, independently in tension and opposite wood. The leant trees in *Eucalyptus regnans* vary in their average growth strain. Strong correlation between measured and calculated strain (R=0.93) suggests that the quick split method can be used to screen large populations for growth stresses. Tension wood was characterised by high density and was three times stiffer than opposite wood and twice as high in volumetric shrinkage. The high longitudinal shrinkage in opposite wood could be due to comparatively high MFAs in opposite wood of the young trees. There was no correlation between growth strain values and other measured properties in opposite wood. It is possible to screen for growth strain at age two, without any adverse effect on stiffness and shrinkage properties.

SHARMA, RAJESH K (2008)
COMPARISON OF DEVELOPMENT OF RADIATA PINE (*PINUS RADIATA* D. DON) CLONES IN MONOCLONAL AND CLONAL MIXTURE PLOTS

The development of radiata pine (*Pinus radiata* D. Don) clones was compared in monoclonal and clonal mixture plots planted in an experiment established at Dalethorpe, Canterbury, New Zealand

with ten radiata pine clones in September 1993. Clones were deployed in a randomised complete block plot design with three replications. Each replication contained ten treatments of monoclonal plots and one in which all the clones were intimately mixed in equal proportions.

Clones significantly differed in initial morphologies, survival and stem slenderness. Sturdiness and initial heights were found to be the best predictors of initial survivals. The study revealed that mode of deployment did not affect overall productivity, but individual clone exhibited significantly different productivities between modes of deployment. All clones contributed similarly to overall productivity in the monoclonal mode of deployment, whereas the contribution of clones in the clonal mixture mode of deployment was disproportionate. A minority of the clones contributed a majority of overall productivity in the clonal mixture mode of deployment.

The inclusion of competition index as an independent variable in a distance-dependent individual tree diameter increment model explained a significant amount of variability in diameter growth. The use of an inverse-squared distance to neighbouring plants in the competition index provided a slightly superior fit to the data compared to one that employed a simple inverse of distance. Addition of genotype information in the competition index further improved the fit of the model. Clones experienced different levels of competition in monoclonal and clonal mixture modes of deployment. Competition in monoclonal plots remained uniform over time, whereas some clones experienced greater competition in clonal mixture plots which led to greater variability in their tree sizes. This study indicated that single tree plot progeny test selections and early selections may miss out some good genotypes that can grow rapidly if deployed monoclonally.

Stand level modelling revealed that clones differed significantly in modelled yield patterns and model asymptotes. Clones formed two distinct groups having significantly different yield models. The study also demonstrated that models developed from an initial few years' data were biased indicators of their relative future performances.

Evaluation of effectiveness of the 3-PG hybrid model using parameter values obtained from destructive sampling and species-specific values from different studies revealed that it is possible to calibrate this model for simulating the productivity of clones, and predictions from this model might inform clonal selections at different sites under differing climatic conditions. Destructive sampling at age 5 years revealed that clones significantly differed in foliage and stem biomass. The differences in productivities of clones were mainly due to differences in biomass partitioning and specific leaf areas.

Clones significantly differed in dynamic wood stiffness, stem-slenderness, branch diameter, branch index and branch angle at an initial stocking of 1250 stems/ha. Mode of deployment affected stem slenderness, which is sometimes related to stiffness. Although dynamic stiffness was correlated with stem slenderness and stem slenderness exhibited a significant influence on stiffness, clones did not exhibit statistically significant differences in dynamic stiffness. Increasing initial stocking from 833 stems/ha to 2500 stems/ha resulted in a 56% decrease in branch diameter and a 17% increase in branch angle.

Trees in the monoclonal mode of deployment exhibited greater uniformity with respect to tree size, stem-slenderness, and competition experienced by clones compared to those in the clonal mixture mode of deployment. Susceptibility of one clone to Woolly aphid suggested that greater risks were associated with large scale deployment of susceptible clones in a monoclonal mode of deployment.

This study also indicated that if the plants were to be deployed in a monoclonal mode then block plot selections would have greater potential to enhance productivity.

TULOD, ADRIAN (2019)
RESTORATION OF CANOPY TREE SPECIES IN DEGRADED EASTERN SOUTH ISLAND ECOSYSTEMS

The history of ecosystem disturbances has altered most of the original forest ecosystems in New Zealand especially those associated with the eastern zone of the South Island where fire and pastoral farming have transformed much of the forestlands into degraded grasslands and shrublands. While these communities are viable conservation areas for biodiversity in restoration schemes, they require active human intervention to facilitate natural regeneration and the success of restoration planting project. Thus, in the context of managing early- successional communities for forest restoration, understanding the effects of any intervention will have important implications to the sustainability of any restoration measure as restoration outcomes may vary with target species, vegetation, and disturbance regimes involved.

This research addresses three key research questions: (1) Whether long-term protection alone (e.g. grazing exclusion) is sufficient to facilitate the establishment of canopy trees and other native woody species in regenerating communities; (2) Whether canopy disturbance regime can be a viable intervention to accelerate forest succession and/or establishment of canopy species in degraded early-successional communities; and (3) Whether early-successional communities can be managed as nurse vegetation for canopy species restoration in degraded and stressful environment. To answer these questions, I examined the succession in an intact canopy of regenerating kānuka (*Kunzea robusta*, Myrtaceae) forest in abandoned pastureland by utilizing long-term data from permanent vegetation plots to describe the changes in species composition, density, and growth of native woody species over time. Two separate restoration trials were then established within the regenerating kānuka forest to examine respectively the succession of native woody species in response to artificial canopy gaps and the establishment of canopy species in response to different canopy manipulation methods. Nurse-protégé or plant-to-plant interaction between canopy species and early-successional shrubland communities with different canopy interventions were also assessed in a degraded high-country environment to determine whether regenerating shrub communities can be managed to serve as nurse plants to restoration planting in post-disturbance grasslands.

The findings of this research demonstrate that canopy intervention, particularly small- scale canopy gaps, is a viable management option to facilitate the regeneration and establishment of canopy species within degraded and dense early-successional communities. Small-scale canopy gaps can provide favourable growing conditions for canopy species including the mitigation of the intensity of competition, improvement of species tolerance to the impacts of herbivory by ungulates, and the provision of opportunities for co-existence with other regenerating native woody species with different shade tolerance traits. The findings, however, show that while succession can benefit from canopy intervention, regeneration can be slow even in gap environments especially in degraded seral communities with inadequate seed sources or with seed dispersal limitation. Moreover, results from the nurse-protégé interactions between canopy species and shrub communities in post-disturbance grasslands indicated that dense early-successional communities can be managed to serve as a nurse vegetation to facilitate the initial growth and survival of canopy species in stressful environment.

These restoration benefits from canopy interventions are relevant to the management goals in New Zealand Canterbury region that include conservation of native biodiversity and restoration of representative habitats and ecosystems that have been lost or severely degraded. While the focus of this research was the eastern South Island, the findings are likely to be relevant as well to other areas in New Zealand and in many parts of the world as the dominance of early-successional communities such as grassland and shrubland in stressful or degraded conditions are typical over large areas especially in tropical and subtropical environments.

WAGHORN, MATTHEW (2016)
UNDERSTANDING THE ECOPHYSIOLOGICAL AND BIOMECHANICAL PROPERTIES OF JUVENILE *PINUS RADIATA* IN RESPONSE TO WATER DEFICITS

As the frequency and severity of drought events are expected to increase globally, drought induced reductions in plantation productivity are likely to become more important. This will concern forest managers who wish to improve forest productivity during the establishment and initial growth phases of plantation-grown *Pinus radiata* D. Don. Wood grown during the initial growth phases is in the corewood zone, which in *Pinus radiata* generally has poor wood properties. This restricts its usability, particular for solid timber applications. Therefore, understanding how water deficits impact on patterns of juvenile *P. radiata* productivity and wood variation is important. The objective of this research was to assess how key morphological and physiological processes, carbon fluxes and partitioning, and wood property formation in juvenile *P. radiat*a responded to the timing and duration of water deficits.

Using two-year-old *P. radiata* cultivated in a controlled environment, trees were subjected to a well watered control, plus early season cyclical drought, late season cyclical drought and summer drought treatments over the course of one growing season. Needle water potential, tree growth, crown characteristics, biomass partitioning, leaf characteristics, physiological processes and water use efficiency were measured. A carbon balance approach was used to examine how the timing and duration of water deficits modified gross primary production (GPP), net primary production (NPP), carbon fluxes to aboveground net primary production (ANPP) and total belowground carbon flux (TBCF), and the partitioning of GPP to ANPP and TBCF. Wood samples were analysed by X-ray absorption, X-ray diffraction and automated image analysis using Silviscan. Measures of wood density, microfibril angle (MFA), fibre dimensions and modulus of elasticity (E) were examined by matching seasonal variation in growth, measured temporally, with variation in wood properties, measured spatially. Further wood samples were assessed for longitudinal shrinkage and acoustic velocity.

Cyclical drought treatments resulted in large fluctuations in needle water potential, while the summer drought treatment resulted in a sustained negative needle water potential over the summer months. Water stress integrals (S_ψ) were 41.4, 66.8, 55.2 and 97.6 MPa-days for the well watered, early season cyclical drought, late season cyclical drought and summer drought treatments, respectively. In general, water deficits decreased tree growth, reduced crown size, reduced biomass accumulation and leaf area, reduced physiological activity and resulted in more enriched values of $\delta^{13}C$, all of which were significantly ($P < 0.05$) affected by treatment. Although the early season drought treatment experienced greater levels of water stress, growth and productivity were superior to those of the late season drought treatment. Summer drought reduced height, diameter and basal area by 24.7%, 33.1%, and 52.3%, respectively, while aboveground biomass was reduced by 68.3% and total leaf area by 40.0%.

Water deficits substantially decreased fluxes to GPP, NPP, ANPP and TBCF following gradients of tree productivity. Treatment values of GPP were between 1470 and 4142 g C per tree per year. Partitioning of GPP to ANPP and TBCF was not affected by treatment, nor were the F_S /ΔC_R, TBCF/ANPP and ΔC_R/ANPP ratios. Partitioning of GPP was predominantly to TBCF (45 - 56%) for all treatments. Partitioning of soil respiration (F_S) did not significantly differ with treatment but F_S was the dominant component of TBCF (77 - 88%) for all treatments.

Wood properties of juvenile *P. radiata* were sensitive to temporal changes in water availability and associated growth rates. Imposition of seasonal water deficits resulted in higher values of air-dry density and modulus of elasticity (E) and decreases in microfibril angle (MFA). These differences were more evident for the late season drought treatment than for the early season drought treatment when compared to the well watered treatment. Late season drought increased density by 10%, E by 18% and decreased MFA by 5%, compared with the well watered trees. Seasonal water deficits had

no impact on annual average values of density, E and MFA in this experiment but significant annual differences existed in cell wall thickness, cell radial diameter and cell populations between the faster and slower growing trees. Well watered trees had higher velocity and also greater longitudinal shrinkage which were significantly different ($P < 0.05$) from the water deficit treatments. Within treatment variation for acoustic velocity and longitudinal shrinkage was greatest for the well watered treatment. Weak to non-existent relationships were observed between longitudinal shrinkage and other wood properties.

The results provide insight for forest managers of *P. radiata* into the importance of managing water deficits to maximise forest production and improve wood quality of juvenile trees. This study demonstrated that late season drought has a more marked impact on absolute growth and wood properties than early season drought, and that water deficits have a greater impact on growth than on partitioning of carbon or ring level wood properties.

WEKESA, ANNE (2022)

THE ESTIMATION AND MODELLING OF CARBON STOCKS FROM HARVESTED WOOD PRODUCTS IN NEW ZEALAND

Harvested Wood Products (HWP) have become increasingly important in climate change mitigation because of the role they play in carbon storage. While the evidence for this significance has been promising, reliable information on the end-use products made from harvested wood, and their associated duration of carbon storage is little known and not explored in relation to New Zealand. This information is very important as it allows better reporting of carbon stock estimates from the HWP pool.

The purpose of this research was to improve estimates of carbon stocks from HWP in New Zealand. To achieve this, a survey of wood processing companies across New Zealand was conducted to develop a material flow of roundwood logs harvested and processed in the domestic market. This provided information on country-specific end-use products that was then used to calculate country-specific half-life values. The country-specific half-life values estimated for end-use products made from sawnwood and wood-based panels were then inputted in an existing New Zealand HWP model and used to calculate HWP carbon stocks. The HWP carbon stocks were estimated using the production approach as stipulated in the 2013 revised Intergovernmental Panel on Climate Change (IPCC) guidelines.

This research has made several significant contributions. Firstly, this project updated data on the end-use products made from logs harvested and processed in the domestic market. Overall, 57% of harvested wood was used in construction. The majority of sawn timber supplied to the domestic market was used to manufacture long-lived wood products – construction was the main end-use product, while wooden packaging was the second highest end-use product. In the export market, wooden packaging was the main sawn timber end-use product. Pulp, MDF and particleboard mills processed about 50% of wood processing residues, whereas the rest was used for other end-uses. Secondly, this was the first study to investigate country-specific half-life values for end-use products made from wood harvested, processed and consumed in New Zealand. The country-specific half-life values were 36 years for sawnwood, 28 years for wood-based panels and 39 years for roundwood products – and these estimates were quite similar to the IPCC default half-life values. Thirdly, this research was the first to use country-specific half-life values to estimate HWP carbon stocks in New Zealand. In 2019, the net emissions from HWP were -13,466.86 kt CO_2-e. The net removals for end-use products made from sawnwood increased by about 16% when country-specific half-life values were used, while it was only 1% - 5% for wood-based panels. This was because the majority of sawnwood end-use products were long-lived, thus, demonstrating the importance of long-lived wood products in increasing HWP carbon stocks.

WILLIAMS, ALWYN (2011)

ON THE ECOLOGY AND RESTORATION OF *PODOCARPUS CUNNINGHAMII* IN THE EASTERN SOUTH ISLAND HIGH COUNTRY

Podocarpus cunninghamii is an endemic New Zealand conifer that, in pre-human times, formed extensive forest communities across the eastern South Island high country. Anthropogenic disturbances have reduced the distribution of *Podocarpus cunninghamii* communities such that they now exist mainly as small and isolated remnants within a highly modified, predominantly pastoral landscape. Very little is known of the ecology of high country *Podocarpus cunninghamii* communities, and without this information it is not possible to develop an ecological basis for their restoration. This thesis explores the ecology of *Podocarpus cunninghamii* in the eastern South Island high country, investigating factors that potentially affect the restoration of *Podocarpus cunninghamii* within this environment, with special attention paid to the role of arbuscular mycorrhizal fungi (AMF).

Field investigations of *Podocarpus cunninghamii* communities showed that they contain a high degree of floristic and structural variation determined by soil and climatic variables. Analysis of age and size class distributions suggest that *Podocarpus cunninghamii* has more than one regeneration strategy, and can regenerate within intact forest following the opening of small canopy gaps or can undergo large-scale recruitment following catastrophic disturbance. Field and glasshouse experiments investigating growth and nutrient responses of *Podocarpus cunninghamii* to different AMF inoculants found that *Podocarpus cunninghamii* responses are dependent on both AMF type and grass competition. Finally, investigation of *Podocarpus cunninghamii* carbon stocks showed that they are less than that of other New Zealand forest types, but are greater than that of grazed pastures.

Successful restoration of high country *Podocarpus cunninghamii* communities will require the incorporation of associated species based on local environmental conditions, and will also need to allow for disturbance processes. AMF may have an important role to play in restoration by reducing seedling production times and by increasing the competitiveness of *Podocarpus cunninghamii* when in competition with exotic grasses.

XU, CONG (2017)

OBTAINING FOREST DESCRIPTION FOR SMALL-SCALE FORESTS USING AN INTEGRATED REMOTE SENSING APPROACH

The estimated total forest plantation area in New Zealand is approximately 1.70 million ha. Approximately 70% of the plantations with area of 1000 ha are owned by large-scale owners, whose forests undergo regular monitoring and assessment. The remaining 30% of plantation forests are small-scale and are less likely to have regular area and yield assessments. Knowledge of these small-scale forests, especially those under 100 ha, remains very limited, yet they are expected to comprise over 40% of the total radiata pine (*Pinus radiata* D. Don) harvest volume by 2020. It is critical to better understand the small-scale forest resource in order to plan effectively for marketing, harvesting, logistics and transport capacity for this future resource. A remote sensing solution to small-scale forest description is necessary because conducting a comprehensive survey and field assessment on those patchy forests is impractical. The objective of this research is to apply multi-sensor remote sensing techniques – LiDAR and RapidEye to derive area, stand age and yield information for small-scale forests in New Zealand.

This research compared a factorial combination of two classification approaches (Nearest Neighbour and Classification and Regression Tree) and two remote sensing datasets (RapidEye and RapidEye plus LiDAR) for their ability to accurately classify land cover, specifically planted forest area. The

research further determined the optimal modelling approach for deriving forest stand variables – mean top height, basal area, volume and stand age by comparing the performance of two parametric models (multiple linear regression and seemingly unrelated regression) and two non-parametric models (k-Nearest Neighbour and Random Forest) with RapidEye-derived metrics, LiDAR-derived metrics and a combination of both. The optimal mapping and modelling approaches developed on a training area, was then applied to the entire study area, the Wairarapa Region of New Zealand.

CART using a combination of RapidEye and LiDAR metrics outperformed the other three approaches producing the highest accuracy for mapping forest plantations. This method was further examined by comparing the mapped plantations with manually digitized plantations based on aerial photography. Across all sample grids, the mapping approach overestimated the plantation area by 3%. It was also found that forest patches exceeding 10 ha achieved higher conformance with the digitized areas.

LiDAR-derived metrics were found to be more useful in estimating all four forest stand variables relative to RapidEye metrics; combining LiDAR metrics with RapidEye metrics did not provide significant gains (on average 0.2% reduction in RMSE) in variable prediction. Non-parametric models and parametric models performed similarly, likely due to the narrow range of structural characteristics in the collected field data. Overall, multiple linear regression was deemed to be the best option for estimating forest variables for less well-known forests as the approach has provided sound and consistent estimation of stand variables and it is relatively easy to understand and interpret.

The optimal area mapping and modelling approaches were applied to the Wairarapa region (594 000 ha), resulting in area and yield description for the region. Overall the mapped plantation area was 3.4% lower than the National Exotic Forest Description (NEFD) recorded plantation area. NEFD is an annual report that provides detailed area and yield description for New Zealand's plantation forests. The description of the large-scale forests from NEFD is reliable as it is captured directly from surveys collected from forest owners, whereas the description of small-scale forests is less reliable as the information from over half of these forests is imputed indirectly based on nursery studies. Forest stand variables mean top height, basal area, volume and age were modelled for the region using multiple linear regression with LiDAR-derived metrics. Based on the modelled stand variables, the recoverable volume at different ages (yield table) was generated. The yield tables developed using modelled information were within a realistic range and were slightly lower than NEFD yield tables.

Overall, the mapping and modelling approach developed in this research provided a proof of concept for deriving area and yield information using remote sensing data, and is especially relevant for small-scale forests where limited information is currently available. The wood availability from these small-scale forests could be more accurately addressed at a anational level using this approach.

YE, NING (2023)

OPTIMISING AUTOMATED SPECIES CLASSIFICATION FOR NEW ZEALAND'S INDIGENOUS FORESTS WITH ADVANCED PHENOLOGICAL REMOTE SENSING TECHNIQUES

Understanding the composition and the changes of New Zealand's woody vegetation communities is important for effective management. However, past national-scale classification maps emphasised mature rather than seral vegetation communities and forests were mapped at relatively coarse spatial resolution. The integration of Sentinel-2 (S-2) and PlanetScope (PS) satellite imagery provides an opportunity for forest mapping with low cost and high accuracy by combining the high spectral resolution of S-2 with the high spatial resolution of PS. In addition, describing phenological changes in spectral response using time- series data may help to distinguish vegetation types, thereby allowing for more specificity within vegetation classification. However, it is not known whether phenological features derived from vegetation indices (VI) are helpful for accurate land cover classification.

The thesis aims to optimise automated species classification for New Zealand's indigenous forests with advanced remote sensing techniques. The study was undertaken in a podocarp forest in New Zealand's central north island. Nine land cover classes were classified, including broadleaf evergreen, highland softwood, wetland vegetation, water, dead tree, lowland softwood, and low- conifer, low-layer vegetation, density vegetation and bare soil. The current study started with the evaluation of machine learning methods and integrated S-2-PS imagery, followed by including phenological features in the classification procedure and finally analysing the contribution of phenological features in detail.

Chapter 2 investigated the feasibility of the integrated image for detailed forest mapping. Free satellite data (S-2, PS, fused data) were compared with commercial data (WorldView-2, and WorldView-2 resampled to S-2 and PS spatial resolutions) by conducting pixel-based classifications with three machine learning classifiers (Support Vector Machine radial basis function kernel, Random Forest, Artificial Neural Network). Spectral features (single bands and VIs), textural features, and an 8-m resolution digital terrain model (DTM) were used in classifications; the relative importance of these input features was also assessed. It was found that the overall classification accuracy was dependent on the combination of classifier and imagery, with different combinations resulting in a range of accuracies between 66.9% and 95.6%. The best overall accuracy was achieved by integrating S-2 and PS imagery (95.6%) which was even greater than that of WorldView-2 (95.1%). The DTM was the most important feature for all scenarios; Gray-Level Co-Occurrence Matrix-Mean was the most important texture variable for WorldView-2 and integrated images. Original bands, as well as Greenness Index (GI), Normalised Green (Norm-G), and Simple NIR and Red Ratio (SR-NIRR), were also crucial for vegetation classification.

Chapter 3 tested the potential of phenological features in the classification of native vegetation. Phenological features, based on S-2 imagery, were extracted, including the enhanced vegetation index (EVI), enhanced vegetation index 2 (EVI2) and normalised difference vegetation index (NDVI). Google Earth Engine (GEE) harmonic analysis and TIMESAT double logistic fitting function were used to extract phenological features. Pixel-based classifications were performed using a Neural Network on six different scenarios. The accuracy of the classification scenarios was determined, and the importance score for each feature was evaluated. Using only the fused PS and S-2 bands, the land cover in the study area was classified with 90.1% accuracy. Adding phenological features increased the classification accuracy to 93.1%. When combined with vegetation indices (VIs), texture features, and a DTM, the addition of phenological features increased the classification accuracy to 96.6%. Including GEE-generated phenological features resulted in better classification accuracies than TIMESAT features. and NDVI-generated phenological features all had high importance scores; the effectiveness of EVI In terms of feature importance evaluation, EVI2- features could potentially have been limited by the quality of the blue band. The results demonstrate that it is possible to produce a more accurate classification of New Zealand's native vegetation by using phenological features. Feature selection could potentially solve this problem. In Chapter 4, phenological feature importance and feature selection were tested by using S-2 time-series data and PS. PS and S-2 data were fused to a base image with the same spatial resolution as PS and 8 bands containing spectral data from S-2; this image was used to produce 30 VIs. Phenological features – amplitude (AMP) and phase (PH) were extracted from these 30 VIs using harmonic analysis in GEE. For the purpose of accurately classifying forests and identifying the most important phenological features, three classification scenarios (fused bands & VIs, fused bands & phenological features, fused bands & VIs & phenological features) were developed using a Neural Network. Variable Selection Using Random Forest (VSURF) was applied to the three scenarios to evaluate the impact of feature selection. Results indicate that VSURF could reduce the time needed to complete the classification while maintaining a comparable level of classification accuracy. Phenological features improved accuracy from 90% to 94%, driven mostly by Red-Edge Triangular Vegetation Index (RTVIcore)-AMP&PH, Normalised Near-Infrared (Norm-NIR)-PH, GI-PH, Water Body Index (WBI-PH), NDVI-PH, Norm-G- PH, Red-Edge Normalised Difference Vegetation Index (NDVIre)-PH, Leaf Chlorophyll Content (LChloC)-AMP, and Simple NIR and Blue Ratio (SR-NIRB)-PH. These features reflect changes in the structure, biochemical, and physiological characteristics of the canopy. A lack of ground-based measurements of seasonal

dynamics precluded an evaluation of the accuracy of these phenological aspects and an explanation of their distinctive contribution to the model.

Overall, the findings show that the integrated S-2-PS imagery can improve the classification of New Zealand's natural vegetation. The cost savings of the integrated approach might prove critical, especially as New Zealand's indigenous forests cover a vast land area that would require substantial financial investment if it were all captured by commercial satellites. The use of phenological features and feature selection algorithms also offers a potential cost-saving when classifying land cover from satellite imagery, as the platforms for phenological feature extraction, feature selection, and classification are free to use. Using the methods developed in the research, there are opportunities to classify highly-diverse New Zealand's native vegetation at a finer scale.

MFORSC THESIS ABSTRACTS

ADKINS, NICK E.H. (2013)
VEGETATION ASSESSMENT TO UNDERSTAND THE EFFECT OF FERAL GOAT POPULATIONS ON NATIVE FLORA COMPOSITION

A vegetation assessment was conducted to understand the effect of feral goats (*Capra hircus*) on the vegetation of Isolated Hill Scenic Reserve located in Southern Marlborough.

New Zealand forests evolved without the pressure of mammalian herbivores but following human settlement they became subject to intensive browsing following the introduction of exotic mammals.

This study focuses on the presence of feral goats. Interest arises from the settlement of other countries and the subsequent liberations of feral goats which are now considered to be responsible for the significant removal of native vegetation as well as playing a dominant role in erosion. Changes in plant communities have occurred with the pressure of goat browsing as well as secondary effects such as habitat degradation

The purpose of this research was to investigate the changes in plant species composition since the initial and subsequent research conducted in 1985 and 1994. An analysis of previous work on the diet of multiple introduced ungulate species was also conducted. Previous studies were not limited to only feral goat studies and included other introduced herbivores to provide a broad overview of diets.

The New Zealand Forest Service implemented a programme for monitoring the seral forest in Isolated Hill Scenic Reserve using standard Forest Service vegetation quadrants. 32 quadrants were established, including three exclosures, in various locations around the Reserve to allow assessment of feral goat impacts on seral forests (forest whose constituents are of varied age classes). Nine forest service plots, including three exclosures were re-measured and an additional nine plots were measured.

Given the progression of vegetation change that has been observed during the course of this study, both analytically and observationally, Isolated Hill Scenic Reserve in its current state, involving the notable presence of feral goats and the vegetation types will continue to diminish in diversity.

ADU OPARAH, IRENE (2013)
PHOTOSYNTHETIC ACCLIMATION TO TEMPERATURE OF FOUR *EUCALYPTUS* SPECIES AND *SEQUOIA SEMPERVIRENS*

The 3-PG physiological/mensurational hybrid model is a useful forest management tool capable of producing accurate growth results across a number of parameterised species. The temperature data used in the model are the average maximum and minimum values for photosynthesis above the compensation point (Landsberg and Sands 2011). There is a minimum temperature below which positive net CO2 exchange will not occur, a maximum temperature above which it will not occur and an optimum temperature at which it is maximised. These parameters are used in the 3-PG physiological model of forest production. However, a species' photosynthetic response to short-term variation may differ from one season to another as species acclimate to temperatures over periods of a few weeks.

In this study, acclimation responses of four species of eucalypt and *Sequoia sempervirens* to long-term temperatures were studied over a wide range of short-term temperature changes in order to identify the minimum, optimum and maximum temperatures of CO2 assimilation for physiological/mensurational hybrid modelling, and also to identify the sites for which the species would be best suited. In order to achieve the aims of this study, a growth chamber experiment was established.

Seedlings of four eucalypt species and *Sequoia sempervirens* were grown at base-line day/night temperatures of 30/16, 22/12 and 10/5°C in controlled environment chambers for three months and leaf gas exchange measurements were made of the species at seven short- term temperature levels (5, 10, 15, 20, 25, 30 and 35°C). The optimum and the maximum temperatures for net photosynthesis increased with an increase in base-line temperature for all species. The highest optimum temperature and net photosynthetic rates recorded were in plants grown at 30/16°C and the lowest were in those grown at 10/5°C.

The maximum rate of net CO_2 assimilation increased with the temperature at which plants were grown partly because of acclimation in key photosynthetic processes in the Calvin cycle. Responses of maximal carboxylation rate (Vcmax) and also the maximal light-driven electron flux (J_{max}) to short-term temperature change varied with base-line temperature for all species studied. Net photosynthesis and photosynthetic parameters measured did not vary significantly with effects of nitrogen, phosphorus and their interaction ($p = 0.1468$).

The ratio of J_{max} to V_{cmax} decreased with increasing leaf temperatures for all species ($p < 0.001$).

These results indicate that the species studied will adapt to long-run changes in temperature, and the parameters obtained from these studies can be used for models that simulate the physiology and growth of the species.

ANDERSON, STUART (2009)
FUEL MOISTURE AND DEVELOPMENT OF IGNITION AND FIRE SPREAD THRESHOLDS IN GORSE (*ULEX EUROPAEUS*)

Shrub fuels are capable of extreme fire behaviour under conditions that are often moderate in other fuels. There is also a narrow range of conditions that determine fire success in these fuels, below which fires may ignite but hardly spread and above which they ignite and develop into fast moving and high intensity fires. This is due to the elevated dead fine fuels that dry rapidly and carry fire. Fire danger rating systems designed for forest and grassland fuels do not predict fire potential in shrub fuels very well. Fire management requires fire danger rating systems to provide accurate and timely information on fire potential for all important fuel types.

Studies of fuel moisture, ignition and fire spread were carried out in the field in gorse (*Ulex europaeu*s L.) shrub fuels to predict the moisture content of the elevated dead fuels and to define the conditions that govern fire development. The accuracy of the Fine Fuel Moisture Code (FFMC) of the Canadian Forest Fire Weather Index (FWI) System to predict moisture content of this layer was assessed. A bookkeeping method to predict moisture content was developed based on semi-physical models of equilibrium moisture content, fuel response time and the FFMC.

The FFMC predicted moisture content poorly, because the FWI System is based on the litter layer of a mature conifer forest. The gorse elevated dead fuel layer is more aerated and dries faster than this conifer forest litter layer. The bookkeeping method was reliable and allowed adjustment of fuel response time based on weather conditions. Difficulties in modelling meteorological conditions under the gorse canopy limited its accuracy. Separate thresholds determined ignition and fire spread success, with both based on the elevated dead fuel moisture content. Options to improve the shrub fire danger rating system were presented based on these findings. The results are significant because they are based on data collected in the field under real conditions. Validation of these results and extension to other shrub fuels is required before the findings are used to change current models. However, the study has significantly advanced the knowledge of fire behaviour in shrub fuels and will contribute to safe and effective fire management in these fuels.

BERKETT, HAMISH (2012)

AN EXAMINATION OF THE CURERNT SLOPE GRADIENTS BEING EXPERIENCED BY GROUND-BASED FOREST MACHINES IN NEW ZEALAND PLANTATION FORESTS

Harvesting is typically one of the largest cost components within a plantation forest rotation. A large proportion of New Zealand's future harvest will be on steep terrain. Currently steep terrain harvesting is characterised by lower productivity and higher cost. It also has higher levels of manual or motor manual tasks such as setting chokers or tree felling, with a corresponding higher safety risk. The utilisation of ground-based machines on steep terrain has the potential to decrease harvest costs and improve safety. There is currently a push in New Zealand to increase the operating range. This is being done with a poor understanding of the slopes on which machines are currently operating and little understanding of the new risks steeper slopes might introduce. To better understand the true range of slopes on which forest machines are operating, a digital accelerometer was attached to 22 forest machines and provided real-time measurements of slope. The evaluated machines were grouped into one of four machine types; felling (n=4), shovelling (n=5), skidder (n=9) or European (n=4). The machine types were then analysed with respect to their machine slope (actual) and terrain slope (predicted) based on a digital terrain map. Two methods of calculating terrain slope were used, method one was based on a triangular irregular network (TIN) file with method two based off a raster file. Linear regression indicated that there was a relationship between machine slope and terrain slope for all four machine types, with the exception of European based machines, using the TIN method of slope calculation. All variables showed a poor coefficient of determination with the highest adjusted R squared single variable explaining 17% of the variation. All machines operated on slopes that exceed the New Zealand approved code of practice guideline of 30% and 40% slope for wheeled and tracked machines respectively. New Zealand based machines were shown to exceed the guidelines for terrain slope much more frequently, and by a greater margin, than European based machines.

CAMPBELL, THORNTON (2016)

ASSESSMENT OF THE OPPORTUNITY OF MODERN CABLE YARDERS FOR APPLICATION IN NEW ZEALAND

This study examined the opportunity of implementing modern yarder machinery to increase the productivity and worker safety of cable logging operations within New Zealand. Cable yarding equipment used in New Zealand is generally based on designs from pre-1980 with the majority of the machines built around that time in the Pacific Northwest, USA. New yarder designs have a number of features that may give them an advantage, including being; smaller, quieter, more fuel efficient, safer and more ergonomic to operate. These benefits can be of even greater value as the forest industry transitions from predominantly larger scale commercial plantations, to a significant proportion of woodlot scale operations.

Field studies ranging from three to five day of duration were carried out on three new machines believed to have potential in New Zealand; the Active 70 at two locations in the central North Island region of New Zealand, the Koller 602h in the Gisborne region of New Zealand and for comparison the Koller 507 in Austria. The studies focussed on assessing productivity and ergonomic advantages. Productivity was measured with a time and motion study and the potential ergonomic advantages were assessed using choker-setter heart rates and machine noise emissions.

The time and motion study found a productivity level for the Active 70 of 23.5m^3/SMH with a utilisation rate of 65% at site one and 24.5m^3/SMH at a utilisation rate of 76% for site two. The productivity for the Koller 602h was 21.0m^3/SMH at an utilisation rate of 55% and 7.9m^3/SMH for the Koller 507 at an utilisation rate of 55%. Productivity was deemed to be negatively impacted by poor site conditions for the Active 70 and Koller 507, and utilisation was low for the Koller 602h which was mainly attributed to the lack of crew experience with the new machine. Choker-setter heart rate results showed choker-setters to be working at the level of 'hard continuous work' ('relative heart

rate at work' over 30%, but less than 40%). In this study the motorised carriage used at the first Active 70 study site offered no ergonomic advantages over the traditional North Bend system at the second site. Decibel analysis found that the modern equipment was significantly quieter, resulting in smaller zones in which hearing protection is required. In particular, the Koller K602h recorded 70dB at 5 meters during operation, well below the 85dB level that is common recognised as the decibel threshold for hearing damage.

During these case studies the machines all operated below the average New Zealand productivity rate of 26.3m^3/SMH and no clear ergonomic advantage was established for the choker-setters. As such these machines are not likely to out-compete existing machinery choices in either productivity or choker-setter work rate. However, cost-benefit analyses were not possible because of limited information about operating cost and the absence of truly comparable settings. Advantages such as the advanced control systems and lower noise levels, while still achieving respectable productivity figures, indicate that they are viable alternatives for New Zealand cable yarding if applied correctly.

COKER, GRAHAM W.R. (2006)
LEAF AREA INDEX IN CLOSED CANOPIES: AN INDICATOR OF SITE QUALITY

This study examined leaf area index (LAI) and relationships with corresponding tree growth, climate and soil characteristics across New Zealand forest plantations. The aim of this study was to determine if quick measures of projected leaf area across environmental gradients of New Zealand were an accurate indicator of site quality. Projected leaf areas of *Pinus radiata* D. Don and *Cupressus lusitanica* Mills seedlings were measured using a Li-Cor LAI-2000 plant canopy analyser at 22 locations representing the soil and climatic diversity across New Zealand plantation forests. Seedlings planted at 40 000 stems per hectare were used to test treatment effects of fertiliser, site disturbance and species over a 4 year period. It was hypothesised that collected climate and soil information would explain differences in LAI development patterns across sites as the canopies approached site and seasonal maxima.

Averaged across sites *Cupressus lusitanica* 7.28 (± 2.59 Std.) m^2m^{-2} had significantly ($p = 0.0094$) greater projected LAI's than *Pinus radiata* 6.47 (± 2.29) m^2m^{-2}. Maximum site LAI (LAI_{max}) varied from 2.9 to 11.8 m^2m^{-2} for *Pinus radiata* and from 3.1 to 12.6 m^2m^{-2} for *Cupressus lusitanica*. LAI_{max} of both species was significantly and positively correlated with vapour pressure deficit, soil carbon, nitrogen, phosphorous and CEC, but negatively with solar radiation, temperature and soil bulk density. A seasonal model of LAI across sites illustrated an 8.5% fluctuation in LAI of established canopies over the course of a year. Despite considerable variation in climate and soil characteristics across sites the combined effects of LAI at harvest and temperature were significantly correlated with site productivity ($r^2 = 0.84$ and 0.76 for *Pinus radiata* and *Cupressus lusitanica* respectively). A national model of LAI_{max} ($r^2 = 0.96$) was proposed for *Pinus radiata* across climate and soil environments and the significance of LAI_{max} as a component of site quality monitoring tools is discussed.

CUEVAS, EDMUND B (2005)
BIOSECURITY AND BIOSAFETY SYSTEMS IN THE PHILIPPINES AND NEW ZEALAND: A CROSS-CASE ANALYSIS

There is a growing importance for both biosecurity and biosafety globally and locally. In this context, this study examined and compared the biosecurity and biosafety systems of the Philippines and New Zealand. This study also considered the central issue of whether the international idea that biosecurity should be the strategic and integrated approach covering and encompassing biosafety and other related instruments, is present or being practised in the national context. This study utilised a qualitative research framework. It followed a case study approach as a process and a product of analysis, and

employed triangulation technique of in-depth interviews, observation and used of pertinent/documents in gathering the relevant data and information. This study found that there are complexity of systems, policies, legislation, regulations, and cross-cutting issues that surround biosecurity and biosafety in the Philippines and New Zealand. In terms of biosecurity encompassing biosafety in the local context, this study revealed that such a concept is not yet present in the Philippines, whilst, to some extent it is happening in New Zealand. This study concluded that unless steps are taken to make national policies better informed, enhance understanding of the nature and relevance of biosecurity, and set strategic and operational priorities, then there will be a continuing overlap between biosecurity and biosafety at the national or local level.

DAVIES, NICHOLAS (2014)
REVERSE ENGINEERING THE TREE

The aim of this thesis was to investigate the typical radial pattern of density and microfibril angle within *Pinus radiata* with respect to structural stability. In order to investigate changes in mechanical stability with different radial patterns, first experimental work was carried out in order to obtain elastic constants, Poisson ratios and limits of proportionality for green corewood and outerwood, these values, a discussion on their accuracy and the implications of the values are included along with a comparison to previous literature. These constants were used to parametrise a finite element model of a tree stem with different radial patterns, including patterns not observed in nature, wind loadings were applied to the stem and failure evaluated. It was found that patterns consisting of high density stiff wood and/or low density high flexibility wood could withstand the great wind speeds for a given stem and canopy, while high density flexible and low density stiff profiles generally performed poorly. The analysis was considered at ages 5, 10 and 15 years, each providing similar results. Why these profiles perform best, what errors need to be considered, and other evolutionary pressures which could narrow this list of profiles were discussed. The need for further research, and the directions for this research are suggested.

DENNY, JEMMA P.S.S. (2012)
OFFSET BANKING IN NEW ZEALAND: TOWARDS SUSTAINABLE DEVELOPMENT, WITH INSIGHT FROM INTERNATIONAL MODELS

Biodiversity loss is an important issue for New Zealand: for the domestic environment, economy and society, but also for New Zealand as a member of the international community. Biodiversity offset banking is making an important contribution to addressing such issues in a number of countries around the world. Developing the ability to participate and take advantage of possible benefits requires comprehensively understanding both the fundamental principles and varying concepts, and supports the analysis necessary for New Zealand to progress towards offset banking. New Zealand can learn much from observing and investigating overseas models and use them as valuable templates. California and New South Wales provide examples of potential policies and frameworks (both economic and social) to establish and operate successful offset banking systems.

Discussions of offset banking, both in theory and practice, frequently concern the potential failings of the system. These issues can be conceptualised as various forms of risk. Considering offset banking as sustainable development, this thesis addresses such risks to reflect the tripartite biological, financial and social framework of sustainable development. Biologically, risk is in the potential biodiversity outcomes are inadequate, unexpected or undesirable. Scientific uncertainty underlies this, both inherently and from the limits of current scientific disciplines. Through expanding scientific knowledge and experience, measures for reducing or accommodating the risk of uncertainty are emerging. Financial risk represents concerns that individual banks may lack the monetary support to achieve the specific biodiversity conservation required for the site. Also the system of interacting banks, bankers and traders may fail to produce financial outcomes that support effective and efficient biodiversity conservation over the breath of the scheme. Social risk lies in the potential that societies'

individuals conduct themselves in ways that conflict with achieving biodiversity conservation through malfeasance or negligence. Additionally, there is social risk that an offset banking system fails to respond appropriately to broader society and human, such as equity and intergenerational justice.

Here, deliberating these risks is primary to appreciating how design elements and emergent properties minimize risks. Given comprehensive understanding, components of a system can be designed and allow informed policy, regulations and rules to offer successful risk mitigation. For this reason policy, rules and regulations observed within California and New South Wales helps to discuss this and establish guidance for New Zealand offset banking design to draw upon. Californian systems are achieving promising conservation and continued growth; New South Wales' Biobanking scheme is robustly designed and in its early stages. Each contrasts in design and carries varying criticisms. California has been observed as potentially shortcoming biologically, whereas New South Wales Biobanking has been questioned based on the strength and character of its economic underpinnings.

In addition to these considerations, New Zealand has significant societal perspectives to incorporate given current popular, socio-democratic conservation modus operandi.

Identifying the three forms of risk present highlights the importance of allocating appropriate consideration and expertise to the biological, economic and social components of offset banking. Successful sustainable development, biodiversity conservation and risk mitigation may be achieved through designing mechanisms, regulations and governing policy for offset banking. New Zealand may therefore expand the success and application of current offsetting by taking guidance from examples and analysis presented here.

DOWLING, LESLIE (2015)

STOCHASTIC FOREST GROWTH SIMULATION: INCORPORATING GROWTH PREDICTION UNCERTAINTY WITH WIND AND FIRE DAMAGE INTO CARBON SEQUESTRATION ESTIMATES AND DISCOUNTED CASH FLOW ANALYSIS

This study simulates tree growth and damage from wind and fire to show how uncertainty in forest productivity prediction affects the appeal of forestry as an investment. Prediction error in geographic estimations of site productivity and assessment on the occurrence of wind and fire damage is used to simulate uncertainty in forest carbon sequestration and discounted value calculations. Uncertainty in prediction is used to stochastically model forest growth. From the forest growth simulations wind and fire damage is applied based on simulated tree volume and crown metrics. The results show the effect of uncertainty in productivity estimates and variable forest volume reduction from catastrophic damage on estimates of carbon sequestration and forest value.

The stochastic forest modelling system utilises repeated runs of the 300 Index growth model (Kimberley, West *et al*. 2005) inside the Atlas Forecaster forest modelling software (Snook, 2010). This modelling system predicts the growth of radiata pine (*Pinus radiata* D. Don) for a given site and incorporates the variation around the expected Site productivity from geographic productivity estimates (Palmer, Hock *et al*. 2009) as well as the influence of wind and fire damage (Moore, Manley *et al*. 2011, Anderson, Doherty *et al.* 2008). By combining the variation from productivity indices with simulated catastrophic damage from wind and fire all sources of forest variation are included in the overall combined model; both those sources of variation which reduce forest growth and catastrophic damage which is severe enough to economically justify abandoning the tree crop.

The simulations run in this research indicate a reduction in carbon sequestered due to wind and fire of between 3 and 5% for forests in the Central North Island of New Zealand. However, there was a large amount of variation in the simulations around these means and the results were not statistically significant. Confidence intervals for estimates of carbon sequestration without wind and fire damage were between 5% and 10% of the mean, and the addition of wind and fire damage increased confidence

intervals to 20% of the mean. The addition of wind and fire damage to Net Present Value (NPV) estimates lowered the mean NPV especially for high productivity sites. However, the stochastic NPV estimates contained even larger variation and no statistically significant results were achieved. The addition of wind and fire damage to the carbon and NPV simulations introduced a significant tail to the shape of the distribution of probable quantities of carbon sequestered and NPVs, showing th significance of wind and fire damage for potential carbon forestry investors.

FONG, STEPHANIE (2019)
EFFECTIVE MANAGEMENT OF NEW ZEALAND'S URBAN FOREST: GOVERNANCE AND LEGISLATION

This research presented in this thesis seeks to understand the context of urban forest management within New Zealand. In particular, it focuses on examining the understanding of local government authority (LGA) employees and the interactions these people have with urban forests. It also explores how central government plays a key role in supporting this resource. While this research is situated across New Zealand, it is designed to assist the global understanding of using trees in urban environments.

Concerns regarding the shift in population from rural to urban life has generated discussion about the use of the environment and its natural capital. As this becomes a new life for human populations, there is a need to understand how nature can be used to combat some of the new challenges. It also aims to examine how stakeholders have different perspectives based on their values and how this supports or hinders urban forest management. Drawing on the literature used for this topic (both qualitative and quantitative), this research is interested in understanding how urban forests are supported by local council and the impact of central government on this type of green infrastructure.

FORTUNE, ADRIENNE L. (2006)
BIOSECURITY AT THE EXTREME: PATHWAYS AND VECTORS BETWEEN NEW ZEALAND AND SCOTT BASE, ANTARCTICA

Biosecurity is one of the main mechanisms used to protect and mitigate the introduction of non-indigenous species. Effective biosecurity requires a knowledge and understanding of pathways and vectors along which invasion can occur. This study contributes to our knowledge and understanding of possible biosecurity risk factors in the Antarctic by identifying potential vectors for invasive species in the pathway between New Zealand and the Antarctic. The Antarctic has important indigenous terrestrial and marine, plant and animal species, all of which contribute to the food chain in Antarctica and the Southern Ocean.

This study seeks to contribute some baseline data about pathways and vectors between the two regions and the implications for the biosecurity of both. An assessment of some of the risks associated with human activities within the Antarctic region, including the traffic of people and goods to and from the area, are the focus of this thesis. Current biosecurity practices with regard to personnel, shipping containers, and fresh produce are examined and where appropriate, recommendations to alleviate any detected risks are made.

The results of the research indicate a significant volume of seed and plant material being unintentionally transported to Antarctica. The most striking finding was the presence of seeds in new clothes, which have previously been assumed not to be vectors. The presence of seeds in soil samples in Antarctica suggests that seeds have probably already been transported to Antarctica. Presently the climate in Scott Base seems to prevent non-indigenous species from becoming established. However,

with the increases in temperature being experienced in Antarctica, this may not always be the case, therefore greater attention to biosecurity legislation and its implementation is required.

FOSTER, JOSHUA (2020)

USING THE LANDSAT CATALOGUE TO ASSESS THIRTY YEARS OF CHANGE IN NATIVE WOODY VEGETATION IN THREE NEW ZEALAND SHEEP AND BEEF FARMING REGIONS

The aim of this research was to produce a time series analysis of change in native woody vegetation in selected sheep and beef farming regions using satellite imagery attained from the Landsat programme. This was proposed to be achieved by training a machine learning classifier to accurately estimate vegetation attributes in modern imagery and applying the produced models to historic imagery that predates the New Zealand Land Cover Database. Training machine learning classifiers to recognise the desired suite of land cover classes in modern satellite imagery proved to be a challenging task in itself, and due to image incomparability issues, applying these trained classifiers to historic satellite imagery and quantifying accuracy was not possible in the given time frame. As the challenges in achieving the original aims of this research project were realised, lines of enquiry were altered to more thoroughly investigate novel areas of the workflow where no sufficiently detailed literature exists.
This thesis describes the data preparation and classification methods developed as a foundation on which research into data comparability solutions and classification optimisation methods can be built. Concisely, the three most important outcomes of this work were:

1. Development of a method for preparing classifier training datasets compatible with both the source data (Landsat imagery) and the classifier (a Convolutional Neural Network based hybrid method implemented through Trimble eCognition) for achieving optimal classification accuracy.
2. Development of a classification framework that draws a compromise between the two aims of classifying land cover with high accuracy and classifying land cover with environmentally relevant detail.
3. Development of a functional machine learning classifier able to detect the desired land cover classes in Landsat imagery, including those that are not visible to the human observer.

Importantly, this thesis also describes the major barriers to further development of a method for producing an accurate time series of land cover change. The two most important problems encountered are:

1. Classifier models trained to detect land cover classes with modern Landsat imagery did not achieve any level of useful classification accuracy when applied to historic image datasets.
2. Accuracy assessment of classified maps produced by application of pre-trained classifier models to significantly older datasets proved to be incalculable through conventional methods.

In overview, this thesis should serve as an easily digestible resource to assist in future development of a software solution that can produce classified, time-series maps of native woody vegetation on New Zealand's sheep and beef farmland at a low cost. The intended purpose of this software is to assist Beef and Lamb New Zealand in achieving the goals set out in their Environment Strategy and Implementation Plan so that they can better support their farmers in acting as effective kaitiaki of the land and remaining compliant and self-regulating as environmental policy in the agriculture sector develops.

GOVINA, JAMES K. (2017)
RESIN AND RESIN CANALS IN FAMILIES AND CLONES OF *PINUS RADIATA* (D. DON)

Resin and resin canals are seen as defects in softwoods. The occurrence of these defects in appearance-grade radiata pine timbers causes devaluation. Living trees use resins and the resin canal networks as a defensive mechanism against pest and diseases by sealing wounds This study determined the variation in resin quantity and resin canal features (density, percentage canal area, and canal size) between 2 year-old radiata pines grown from different genetic material. Out of an experiment for NZ radiata pine seed and clonal commercial deployment populations, 10 clones and 20 families were selected for the study. Near infrared (NIR) spectroscopy was used to estimate resin quantity whereas microscopy was used to assess resin canal features. Wood samples were heated to help gather resin at the cross-section followed by the collection of absorbance spectra with an NIR fibre optic probe. Wood sections (~20 µm thick) were imaged with a 2400 dpi flatbed scanner in polarised light. ImageJ software was used to analyse the images and to determine the resin canal features. Data were analysed with the R statistical software. Resin quantity obtained by NIR varied significantly ($p < 0.01$) between clones and families with average values of 2.71 and 3.68 (AU) respectively. Average canal density was 0.69 canal/mm^2 for clones and 1.53 canal/mm^2 for families ($p < 0.01$). In both families and clones, resin canals were of homogenous size of approximately 0.02 mm^2. There were weak genetic correlations between resin quantity and other canal features (4 = 0.07 with canal density, r = 0.10 with percentage canal area). Resin canal frequency was strongly correlated with percentage canal area (4 = 0.94). Variability between clones and families was present for all variables and summarised by the coefficient of variation (CV). Resin quantity had a CV of 61% and 51% for clones and families respectively. Resin canal features had CVs ranging between 10% and 31% across the familes and clones. Resin quantity determined by NIR across the families and clones had 4% heritability, whereas the resin canal features had ~30%. The low heritability found for resin quantity could be due to the indirect NIR assessment. The resin features correlated favourably with modulus of elasticity and longitudinal shrinkage. The lesser the resin features the stiffer the wood and the lesser longitudinal shrinkage. Basis density and volumetric shrinkage had no correlation with resin features. These results suggest that, presently, radiata pine growers can identify genetic material that is more suited for high-value appearance-grade timber as well as maintaining improved wood properties (stiffness, density, growth and form) in the markets.

HANSEN, HELGE (2006)
ACOUSTIC STUDIES ON WOOD

Several acoustic techniques have been used to determine elastic and damping properties of trees, logs and beams.

Time of flight (TOF) measurements in the outerwood of 14-year-old *Pinus radiata* trees showed that pruning operations increased the outerwood stiffness by up to 25% compared with unpruned trees. However, at the most 5% to 10% of the increased stiffness can be explained by the fact that the outerwood of the pruned trees is free of knots, as TOF measurements are little affected by knots. Thus, it is not known what causes the increase of outerwood stiffness in the pruned trees. One possible explanation could be a smaller microfibril angle (MFA) in the S2 layer of the outerwood cells, which would cause a significant increase in stiffness. Thinning operations decreased the outerwood stiffness by up to 8%.

In small *Eucalyptus nitens* and *Pinus radiata* logs, which had branch nodes and nodal whorls at specific locations, MOE calculations (using the resonance technique) based on different harmonics gave different results. This indicates that defects do interact with acoustic waves.

Acoustic tests on laminated beams with artificial defects (holes filled with dowels) at specific locations also had a significant impact on the MOE. Moreover, it was evident that the damping ratio (evaluated from the Q- factor) of the beams increased with increasing diameter of the holes.

However, it was found that holes in laminated beams decreased stiffness while branch nodes and nodal whorls increased stiffness. This shows that relatively small defects, occupying a small volume of the beam, have an impact on acoustic measurements. It is not appropriate to base the MOE calculation on a single harmonic, considering that different harmonics investigate different parts of the specimen.

HENSHAW, ALEX (2012)
FACTORS INFLUENCING FUTURE CANOPY COMPOSITION AT TIROMOANA BUSH, NORTH CANTERBURY, NEW ZEALAND

The purpose of this study was to investigate seedling recruitment beneath kanuka forest at Tiromoana Bush, North Canterbury. The regeneration of broadleaved tree species is evident throughout Tiromoana Bush. This research aimed to quantify the biotic and abiotic factors influencing the distribution of small and large seedlings of canopy tree species, their relative growth rates, their survival, abundance and composition throughout the forest understorey of Tiromoana Bush. Tiromoana Bush is a forest restoration area of 410 hectares adjacent to the Kate Valley landfill.

To determine the future tree species composition at Tiromoana Bush, seedling recruitment, growth and survival was quantified through remeasuring tagged seedlings in 26 permanent vegetation monitoring plots located in the major forest patches at Tiromoana Bush. In addition, seedling data from 78 temporary vegetation survey plots established in three major forest patches were used to assess the influence of different factors on seedling abundance.

At Tiromoana Bush, the most common canopy tree species as seedlings in the permanent vegetation monitoring plots was mahoe followed by fivefinger. Mahoe seedling density was significantly affected by canopy openness, distance to seed sources, light index, shrub cover and slope, but not by aspect, basal area and time. For fivefinger, seedlings increased in abundance with time, but the difference was not statistically significant. The relative growth rate of mahoe in the 20-49cm height class (in which most seedlings occurred) was significantly affected by shrub cover, light index and canopy openness. Mahoe seedling recruits were significantly affected by light index and canopy openness. Survivability of mahoe was affected by aspect. For fivefinger, individual relative growth rates were significantly affected by canopy openness and light index.

Similar results were found for tree species seedlings present in the temporary survey plots provided with mahoe and fivefinger again the most common species, followed by kohuhu. Light index significantly affected golden akeake small seedlings as well as canopy openness. Light index significantly affected ngaio large seedling distribution. Aspect was the only significant factor for kohuhu large seedling distribution. Distance from seed sources significantly affected fivefinger small seedling distribution as seedlings are dependent upon dispersal away from the parent trees. Slope significantly affected the distribution of red matipou small seedlings.

The most important environmental attribute influencing seedling abundance is light. This is evident in both the permanent seedling monitoring plots and the temporary vegetation survey plots. Based on data from the temporary vegetation survey plots, mahoe, fivefinger and kohuhu are most abundant suggesting that these three canopy tree species will dominate the forest canopy at Tiromoana Bush once the kanuka starts to senesce.

HIRO, CARLOS (2022)
TREE DIVERSITY, COMPOSITION AND STAND STRUCTURE ACROSS POST-LOGGED LOWLAND TROPICAL FOREST ON SANTA ISABEL, SOLOMON ISLANDS

The rate of deforestation in the Solomon Islands is alarming with more than half of the nation's primary commercial forest resource having already been subject to timber harvesting leaving behind extensive areas of degraded forest without current management. This study aims to determine the species composition, tree species diversity and stand structure of the post-logged lowland tropical forest on Isabel Island, Solomon Islands. In this study, I compared the species composition, tree diversity and stand structure of the understory saplings and canopy trees in an unlogged forest and forests that were logged 3-years and 20-years ago to assess the recovery dynamics of these forest after selective timber harvesting.

A total of 168 different tree species from 92 genera and 43 families were identified in all the forest categories. The total number of species identified across the three forest types were 95, 110 and 116 in the 3-year-old forest, the 20-year-old forest and the unlogged forest, respectively. This study determined that even 20-years after timber harvesting, the tree community composition in the post-logged forests has not recovered for both the saplings and canopy vegetation. Tree diversity for saplings and canopy trees in the 3-year-old logged forest was significantly lower than the unlogged forest. Tree species richness was significantly higher for the saplings but considerably lower for the canopy vegetation in the 3-year logged forest. However, tree species diversity and richness for the sapling and canopy vegetation in the older 20-year-old logged forest were more similar to the unlogged state.

In terms of stand structure, there is rapid regeneration of pioneer trees dominated by *Macaranga* species in the newly logged (3-years) forest which has a considerably high stem density and basal area in the understory saplings compared to the saplings of the old logged (20-years) forest and the unlogged forest. Stem density for the canopy vegetation of the 3-year-old logged forest was significantly lower while the 20-year-old forest stem density did not differ to that of the unlogged forest. With increasing diameter class, the stem density reduced for the mature commercial tree species in the 20-year-old logged forest compared to the unlogged forest. This study shows that stem density for mature trees DBH $\geq$ 60 cm in the two logged forest was considerably reduced. Basal area of the canopy trees in the logged forest was also significantly lower compared to the unlogged forest. This highlights that timber harvesting has dramatically reduced the commercial tree species and timber stocking in the lowland forest in Isabel Island, which requires more than two decades for the forest to replenish for another commercial crop.

Managing the forest resources for the logged and unlogged forest is crucial for continuous provision of forest goods and services. I suggest that communities and resource owners can utilise and manage their forest through a number of management strategies such as land-use planning, small-scale sawmilling and enrichment planting. Land-use planning ensures resource owners properly assess the forested land and its potential for various land uses. Emphasis on allowing ample time for the forest to recover after initial logging before the next harvesting is paramount to ensure restocking and the continuous supply of timber. Small-scale sawmilling and enrichment planting are equally vital for sustainable harvesting of timber and to established mature-phase and diverse tree species that support resilient forest communities.

ISNAINI, HIKMAH (2018)
GROWTH AND YIELD MODELLING FOR UNTHINNED *ACACIA MANGIUM, ACACIA CRASSICARPA* AND *EUCALYPTUS PELLITA* PLANTATIONS IN INDONESIA

Several species, including *Acacia crassicarpa* (Sugesty, Kardiansyah, & Pratiwi, 2015) and *Eucalyptus pellita* (Lee, 2003) have been used as alternatives for *Acacia mangium* in Indonesia due to

reductions in site quality in successive rotations (Sugesty et al., 2015) or because of a root disease (Lee, 2003). Growth and yield models of these species have not been adequately researched. Some studies (Krisnawati, Wang, & Ades, 2010; Kurinobu, Arisman, Hardiyanto, & Miyaura, 2006; Lazuardi, 2009; Lumbres et al., 2015) have been carried out for *Acacia mangium* in Indonesia, but no growth and yield model has been built in the study area. This study aimed to create stand level and diameter distribution models for these species. Additional objectives were to create generalised height and diameter equations for these species and compatible taper and volume equations for *Acacia mangium.*

Data were collected from Permanent Sample Plots (PSPs) in parts of Riau Province for *Acacia crassicarpa* and *Eucalyptus pellita,* and also parts of East Kalimantan for *Acacia mangium*. Data for taper and volume equations were derived from stem analysis of 192 trees. All these species are used for pulp and paper production and no thinnings are involved in their silvicultural regimes. We used an all-possible interval approach to create mean top height, basal area, maximum diameter over bark at breast height (dbhob) and standard deviation of dbhob models. Particularly for mortality, we compared three approaches by using all-possible interval, one-year interval and longest interval approaches.

We found that the Näslund (1937) equation was the best two-parameter height–diameter model for all species. Generalised height–diameter equations were created by adding stand variables (site index, basal area/ha, stocking/ha, age and elevation) into parameters in that equation. The stand variables that affected height estimations varied among the species. A general combined variable with scaled power transformations was selected for predicting the volume of *Acacia mangium* and a four-parameter polynomial equation was chosen as the best taper equation for this species.

A von Bertalanffy–Richards polymorphic was the best equation for mean top height projections for all species and a two-parameter Schumacher polymorphic was the best equation for basal area projection for all species. A two-step regression procedure (Woollons, 1998) with a one- year interval was selected for projecting mortality, because it produced the smallest bias compared with other approaches. Mortality equations were specific for each species. We found that a Weibull anamorphic equation was the best mortality model for *Acacia crassicarpa,* and an exponential decay anamorphic and a two-parameter Schumacher polymorphic equation were the best models for *Acacia mangium* and *Eucalyptus pellita* respectively.

The best model for estimating the standard deviation of dbhob was the von Bertalanffy– Richards polymorphic. A von Bertalanffy–Richards polymorphic was also the best model for estimating maximum dbhob for both *Acacia* species. Meanwhile, a two-parameter Schumacher polymorphic was the best model for *Eucalyptus pellita*.

Site variability and climatic factors for augmented models were elevation, mean annual temperature and mean annual rainfall. We found that elevation had an effect on mean top height for all species and on basal area for *Acacia mangium*. Meanwhile, mean annual rainfall had an effect on basal area for all species and on maximum dbhob for *Acacia mangium*. The augmented mortality models, the augmented models of maximum dbhob and standard deviation of dbhob for *Acacia crassicarpa* and *Eucalyptus pellita* were not recommended from this analysis. However, improvement for all these augmented models gave less than 5% reduction of standard error compared with their empirical models.

Diameter distributions of forest stands can be estimated using reverse three-parameter Weibull distributions by employing stand level models, maximum dbhob and standard deviation of dbhob models. Furthermore, by using volume equations and the mid-point of each diameter classes, the total volume of each dbh class can be projected. For commercial purposes, this estimation will help forest managers obtain information about commercial logs available in larger trees.

K C, MOHAN (2018)

INFLUENCE OF STOCKING, CLONE, FERTILIZATION, AND WEED CONTROL ON ABOVE-GROUND BIOMASS AND SOIL CO_2 EFFLUX IN A *PINUS RADIATA* D. DON SILVICULTURAL TRIAL, CANTERBURY, NEW ZEALAND

Pinus radiata D. Don is a widely planted exotic tree species in New Zealand as it is a major source of carbon (C) sequestration and industrial timber. Developing precise biomass models is the most essential step in assessing carbon sequestration potential of the forests. Common silvicultural practices comprise site preparation, weed control and fertilization, with clonal forestry playing an increasing role in improving stand productivity and wood quality. These management practices, along with environmental variables, are known to influence above- and below-ground carbon dynamics.

The experimental site was located just south of Rolleston within the Canterbury region of New Zealand. The experiment consisted of 48 permanent plots with a randomized complete block split-split design (Mason, 2008), with an arrangement of factors within four complete blocks. The main plots consisted of three levels of stocking. A first split consisted of four levels of fertilization and follow-up weed control treatment. A second split consisted of five different embryogenic clones randomly allocated to all plots. Three studies were carried out: (a) to find the best models to predict above-ground biomass for Pinus radiata; (b) to assess the effects of silvicultural treatments along with environmental variables on soil CO_2 efflux (F_S); and (c) to examine the linkage between above-ground biomass and F_S across silvicultural treatments.

In a first study, two broad procedures were implemented for biomass modelling: (a) independent, and (b) additive. In the independent procedure, linear ordinary least-squares regression with scaled power transformations and y-intercepts produced more precise models than nonlinear biomass estimation methods using power equations and no y-intercepts. In the additive procedure, models fitted in a joint generalized linear least-squares regression, also called seemingly unrelated regression (SUR), provided better goodness-of-fit statistics, standard errors of estimates, residual plots, and histograms of residuals. Compared with independent and additive procedures, additive equations fitted in SUR recorded unbiased estimates of biomass in contrast to linear ordinary least-squares regressions. SUR produced the best goodness-of-fit statistics with unbiased estimates in seven out of ten biomass components. Separate allometric equations were developed to predict biomass for six components, three subtotals of two or more components and total

In a second study, the effects of silvicultural treatments on F_S, soil temperature (T_S), and volumetric water content θv for the whole period of the experiment, as well as separately for each season, were evaluated using mixed-effect models. The relationships among F_S, T_S, and θv were investigated by linear and nonlinear regressions. Season, stocking, and clone had a significant influence on F_S. Estimated mean F_S rate was 22.71 tonnes CO_2 ha^{-1} yr^{-1} (≈ 6.2 tonne C ha^{-1} yr^{-1}). No significant effects of fertilization and follow-up weed control on F_S were observed. Autumn (27.76 tonne CO_2 ha^{-1} yr^{-1}) and winter (15.64 tonne CO_2 ha^{-1} yr^{-1}) exhibited the greatest and smallest rate of F_S, respectively. Greatest F_S rates were observed at 1,250 stems ha^{-1}, without weed control and for clone 3. A soil moisture threshold was determined (i.e. 14.3%) to separate whether F_S was limited by T_S or θv. Above this threshold, a clear exponential relationship between F_S and T_S was observed. The values of T_S and θv jointly explained relatively high variability (27.90–48.94%) in F_S compared to simply T_S (26.63–47.82%), based on modelling across all silvicultural treatments. Seasonal changes in T_S and θv influenced F_S.

In a third study, effects of silvicultural treatments on below-ground soil respiration (BSR), above-ground biomass production (AGB), the ratio (BSR/AGB), tree diameter (DBH), height (H), basal area

(G), and leaf area index (LAI) were examined. Mixed-effects analysis of variance was carried out. Stocking, follow-up weed control, and clone significantly influenced above-ground production and below-ground carbon partitioning. Increased above-ground biomass production with stand density was primarily determined by the better use of site resources. Decreased BSR/AGB with stand density was mostly associated to greater resource limitation due to competition. AGB and G increased while DBH and H decreased as stand density increased. Follow-up weed control enhanced above-ground growth by reducing BSR suggesting weed control would decrease competition for below-ground resources. Clones with poorer growth above ground partitioned proportionally more carbon below ground, and vice versa. In conclusion, certain clones were more productive above-ground at the expense of less carbon partitioning below-ground, stocking controlled F_S, T_S and θv, and follow-up weed control increased above-ground growth by reducing BSR compared to the treatment without follow-up weed control, which may suggest that weed control reduced competition for below- ground resources.

KARSIDI, AHMAD (2019)

REVIEW OF FSC CERTIFICATION IMPACTS: EXPERIENCE OF NATURAL FOREST CONCESSIONAIRES WITHIN IDH AND TBI SUPPORT IN INDONESIA

Voluntary certification is an option to support the sustainable environmental, economic and social development of enterprises operating in natural forests. FSC certification is the oldest and most preferred voluntary scheme for natural forest concessionaires in Indonesia. After three decades, the progress of certification in Indonesia is considered slow and still depends on financial support from foreign donors such as IDH. Consequently, this research has been undertaken to: 1) understand the problems faced by natural forest concessionaires prior to certification; 2) review the impacts of certification regarding costs, advantages, disadvantages and challenges; 3) understand the causes of certification withdrawal through a case in the concessionaires with suspended FSC certification status, namely KLIA and BIOS operating in natural mangrove forests. The impacts of certification at the concessionaire level have been analysed by examining public audit summaries paired with a survey of the concessionaire managers. This research was undertaken to focus on companies under IDH and TBI support in Indonesia that represent more than 50% of the natural forest enterprises certified by FSC in the country in 2018.

Audit reports and the survey revealed that significant improvements in forest management have occurred as a result of certification, especially in environmental and health and safety features. These aspects were found to be the most frequently mentioned issues before certification in more than 80% of assessed logging companies. This research also found that the estimated cost of certification ranges from less than US$2 to US$7/ha. The estimated price premium and additional sales as a result of certification varied from 0% to 20% and 0% to 40% respectively. The disadvantages of certification were found to be the costs (preparation and audits) and the length of time taken in the process of certification. Meanwhile, raising staff awareness and post-certification costs remain as considerable challenges after the certificate has been granted. The case study found that certification might be more challenging in small business operations and non-integrated companies although the group scheme has been widely promoted to address the cost issue. Hence, small enterprises continue to depend on the assistance of external parties. Overall, FSC certification impacts on the social and environmental factors are considered prominent while monetary benefits are still low.

LE, THAI SON (2018)
A STRATIFIED GIS-BASED MODEL TO IDENTIFY OPTIMAL LOCATIONS FOR ESTABLISHING NEW PERMANENT SAMPLE PLOTS FOR *EUCLYPTUS BOSISTOANA* AND *EUCALYPTUS GLOBOIDEA* IN NEW ZEALAND

As part of an effort to develop a forest industry based on durable hardwood eucalypts in New Zealand, the New Zealand Dryland Forests Initiative (NZDFI) have considered *Eucalyptus bosistoana* and *Eucalyptus globoidea* as two candidate species. There have been 158 permanent sample plots (PSPs) of the two species established in seven trial sites across the two main islands of the country. The network of these PSPs has provided information for the NZDFI's research program, especially for growth and yield modelling for the target species to examine the relationship between trial sites and the species (i.e. site-species matching). However, the existing PSPs do not cover the entire range of environmental conditions in New Zealand, nor do they cover the range of conditions the species are capable of growing in. Hence, the PSP network could be strategically expanded into new areas. This thesis describes a methodology, which combines habitat modelling and stratified random sampling approaches with the capability of geographic information systems (GIS), to build a GIS-based habitat model for a strategic expansion of the current PSP network.

The method applied in this study consisted of three main stages. In the first stage, the study selected 17 model variables in three categories (i.e. topography, climate, and soil), defined their importance, and tested them for multicollinearity. For each model variable, data were collected for three geographic zones: (1) the native habitat of the species, (2) all of New Zealand, and (3) the existing PSPs. The second stage was to process data to build the model. The third stage applied variable restriction and stratification analyses to calculate a priority index for the complete study area. This index represented the priority for establishing new PSPs in the study area, based on under-represented environmental characteristics.

The result chapter presents available areas for the expansion of the PSP network after the restriction process as the potential habitat for the target species. Besides excluded areas (i.e. not suitable for plantations of *E. bosistoana* and *E. globoidea* in the study area), by assessing the priority index in the available areas, the result map highlighted: (1) over-represented areas (i.e. high environmental similarity, where the environmental conditions have been described by many PSPs in the existing network), and (2) under-represented areas (i.e. high environmental dissimilarity, where the environmental conditions have been described by no or few PSPs in the existing network). The results suggest that new PSPs for the two species should be established in Rangitikei District and Taupo District. Other high-priority areas include Northland and Auckland regions, the east coast of the Gisborne region, and southeast-facing hillsides of the mountain chains in the central South Island.

Overall, the study built a stratified GIS-based habitat model that successfully determined locations for strategic expansion of the PSP networks of two different species, *E. bosistoana* and *E. globoidea,* in New Zealand. With the strengths of GIS and the availability of global GIS data, the methodology in this thesis has high potential to be applied more broadly for different species, different PSP networks, and different study areas.

LESLIE, CAMERON (2019)
PRODUCTIVITY AND UTILISATION OF WINCH-ASSIST HARVESTING SYSTEMS: CASE STUDIES IN NEW ZEALAND AND CANADA

Winch-assist technology is now a well-established system to support forest harvesting on steep slopes. The winch-assist harvesting system is a combination of the winch-assist machine (WAM) at the top of the slope that allows steep slope machines (SSM) to manoeuvre down slopes. The SSM is attached

to a winch rope from the WAM to carry out tasks such as mechanised felling. Winch- assist harvesting systems are expensive and little is known about their productivity and utilisation rates, or the factors that affect this. This research aimed to improve knowledge of winch-assist harvesting systems in terms of productivity and utilisation through six case studies in New Zealand and Canada.

Two to five days of continuous operational data were collected at each of the six case studies. Productivity of the winch-assist harvesting system was determined by measuring the volume harvested in the time that the SSM was carrying out its primary tasks of felling, bunching, moving between trees, and brushing. The Utilisation is then the ratio of the productive machine time (PMH) as a percentage of the total scheduled machine time (SMH). The difference between PMH and SMH will be the system working on tasks other that its primary tasks, or in delay. Delay time was further defined as operational, mechanical, or personal. Productivity per SMH is then the product of the m^3/PMH and utilisation (%) and calculated using the product of the utilisation rate and the volume harvested per PMH.

The average productivity recorded through the six case studies was 61 m^3/PMH, ranging from 34 m^3/PMH to 102 m^3/PMH. The site with the lowest productivity was a result of small piece size and while the site with the largest productivity was a result of large piece size and long even slopes leading to less WAM relocations.

The average winch-assist harvesting system utilisation recorded in these six case studies was 52%, ranging from 25% to 63%. Delays and shovelling were common, accounting for 48% of the total recorded time (delay 37%, shovelling 11%). Operational delays summed 69% of total delay time; these delays included relocating the WAM, moving setting, setting up and planning, line handling, diesel activities, radio communication and assisting with other operations. Short corridor lengths meant increased WAM relocations and had the largest relation to operational delay. Mechanical delays, when the machine was not able to work due to repair or maintenance, accounted for 17% of total delays. Mechanical delays included greasing the machines, chain and bar issues and general maintenance. Thick undergrowth and small trees within the forest stand had a large impact on chain and bar issues. Personal delays involving the operator taking a break were 14% of total delays.

As a result, average productivity per SMH was 33 m^3/SMH, and ranged from 11 m^3/SMH to 58 m^3/SMH in the six case studies. This highlights the effect of low utilisation in that it almost halves the productivity potential, but it is important to understand the reasons for delays, many of which are unavoidable.

Winch-assist supported shovelling, while being considered an operational delay in this study because it limits the SSM in its felling task, was a common practice through the six case studies. Shovelling is in support of the extraction activity, for example moving stems to a visible location for cable extraction or to an area able to be accessed by ground based extraction machines. So while this effectively increases the felling cost, it increases the productivity of the next process in the harvesting system.

LOO, ADRIAN (2022)

A GEOSPATIAL AND ECONOMIC ANALYSIS OF POTENTIAL FOR AFFORESTATION IN CANTERBURY, NEW ZEALAND

Canterbury's plantation forest area has been declining due to land use change. The future size of the forestry industry is uncertain and without afforestation is predicted to be significantly smaller. A reduction in the plantation forestry area will reduce available log supply which will negatively impact local domestic processors.

To explore the opportunities for future afforestation, this study identifies land within Canterbury deemed suitable for forestry. The land deemed suitable for forestry within the Hurunui Territorial

Authority (TA) was further evaluated to identify the land where forestry is economically superior to the next best alternative land use. Results from a survey of 556 Canterbury-based rural decision-makers was used to identify the potential barriers and drivers that impact landowner's afforestation decisions. Combining the suitable land, economic analysis, drivers, and barriers of afforestation allowed inferences to be made about the Canterbury plantation forestry area's potential future size.

This study identified that there are over 1.2 million hectares of land deemed suitable for afforestation across the Canterbury region. Within the Hurunui TA, 82% of the suitable planting areas provided an economic return that exceeded the average return of the alternative land use (sheep and beef farming). None of the land identified as suitable for afforestation achieved the assumed forestry investment return requirement at the average land cost. However, if the land cost was reduced to the minimum of recent sales, 4% of the suitable land met the assumed required rate of return for forestry investment-based afforestation. The influence of land cost, log price and carbon price were observed to significantly impact the land deemed to be economically superior to the next best alternative land use, a sheep and beef farm.

Canterbury-based respondents of the 2019 Survey of Rural Decision makers identified that the main drivers for afforestation were predominately non-financial and prioritised decisions that accounted for the impact of afforestation at a farm level. These non-financial drivers lead to primarily non-commercial forestry species being identified for future planting. The primary barrier to afforestation of opportunity cost further highlighted the consideration of the broader farming system. The financial cost of undertaking tree planting was also a significant barrier to land use change. However, the One Billion Trees Programme results identified that this barrier was able to be overcome when sufficient funding was available.

Estimation of the potential future size of the Canterbury forestry area was based on the expansion of the results of the Hurunui TA study to the wider Canterbury region and combined with the drivers and barriers of afforestation. If the land can be acquired at a minimum land cost, then 50,945 hectares meet the required rate of return for forestry investment-based afforestation. A total of 1.04 million hectares exceeds the return of the next best alternative land use. However, given the barriers and drivers for afforestation, a maximum of 14% of this area is likely to be planted in commercial forestry species. This suggests that the Canterbury plantation forestry area could increase by a maximum of 197,157 hectares—15% of the hill country land in the Canterbury region. At the current rates of afforestation, this expansion would occur over a period of 92 years.

LUKETINA, IVAN (2017)

WHY DOES NEW ZEALAND EXPORT SAWN TIMBER TO SOME MARKETS AND LOGS TO OTHERS?

New Zealand's annual log harvest has increased rapidly from 2009 to 2017. This increase in harvest has been mostly exported as logs, rather than being processed in New Zealand into sawn timber and other products. Previous industry strategy studies have identified the need for the sawn timber processing sector to be internationally competitive, as it is both an important processing industry, and a supplier of residue to downstream manufacturers.

Studies that compare New Zealand's export log and sawn timber markets have shown that most markets import either sawn timber or logs, but rarely an even mix of both. However, most export logs are processed into sawn timber or plywood at the destination. This research uses econometric analysis to identify the drivers of these differences in market behavior.

A seven-country export demand panel model was used to analyse the effects that different variables had on demand for sawn timber and logs. Real GDP and real prices were used to explain demand for

log and sawn timber imports from New Zealand. Variables for tariffs and tariff wedges (the difference between the tariff for a processed good and the tariff for its raw material), non-tariff barriers (NTB), competition effects, and local resources were used to test their effects on demand.

Tariff wedges and the local harvest of softwood timber were found to have a significant negative effect on demand for sawn timber, while only a softwood harvest was found to negatively affect demand for logs. The presence of tariff wedges was found to be negatively correlated with the sawn timber demand but did not fully explain the difference in demand between logs and sawn timber. Research suggests that NTBs have a large impact, but they are difficult to measure and therefore analyse in this context. The existence of a softwood timber resource was found to be negatively correlated with demand for softwood imports. There was no significant negative effect found for competition effects.

MCDONALD, TIMOTHY M. (2009)
MAKING SENSE OF GENOTYPE X ENVIRONMENT INTERACTION OF PINUS RADIATA IN NEW ZEALAND

In New Zealand, a formal tree improvement and breeding programme for *Pinus radiata* (D.Don) commenced in 1952. A countrywide series of progeny trials was progressively established on over seventy sites, and is managed by the Radiata Pine Breeding Company (RPBC). Diameter at breast height data from the series were used to investigate genotype x environment interaction with a view to establishing the need for partitioning breeding and deployment efforts for P. radiata. Nearly 300,000 measurements made this study one of the largest for genotype x environment interaction ever done.

Bivariate analyses were conducted between all pairs of sites to determine genetic correlations between sites. Genetic correlations were used to construct a proximity matrix by subtracting each correlation from unity. The process of constructing the matrix highlighted issues of low connectivity between sites; whereby meaningful correlations between sites were established with just 5 % of the pairs. However, nearly two-thirds of these genetic correlations were between -1.0 and 0.6, indicating the presence of strong genotype x environment interactions.

A technique known as multiple regression on resemblance matrices was carried out by regressing a number of environmental correlation matrices on the diameter at breast height correlation matrix. Genotype x environment interactions were found to be driven by extreme maximum temperatures (t-statistic of 2.03 against critical t-value of 1.96 at 95 % confidence level). When tested on its own, altitude was significant with genetic correlations between sites at the 90 % confidence level (t-statistic of 1.92 against critical t-value of 1.645).

In addition, a method from Graph Theory using proximity thresholds was utilised as a form of clustering. However, this study highlighted the existence of high internal cohesion within trial series, and high external isolation between trial series. That is, grouping of sites (in terms of diameter) was observed to be a reflection of the series of trials for which each site was established. This characteristic is particularly unhelpful for partitioning sites into regions of similar propensity to genotype x environment interaction, as the genotype x environment effect is effectively over-ridden by the genotype effect.

Better cohesion between past, present and future trial series, and more accurate bioclimatic data should allow more useful groupings of sites to be extracted from the data. Given this, however, it is clear that there are a large number of interactive families contained in the RPBC dataset. It is concluded that partitioning of New Zealand's *P. radiata* breeding programme cannot be ruled out as an advantageous option.

MANSELL, JEREMY D. (2007)
DRAFT FOREST MANAGEMENT PLAN FOR CASHMERE FOREST, PORT HILLS

Cashmere Forest is currently a production forest comprised of mostly radiata pine (c. 85%), Douglas fir (c. 5%) and some non-plantation areas. The Port Hills Park Trust Board (PHPTB) is interested in purchasing Cashmere Forest for the purpose of creating a public forest park environment where forestry, indigenous biodiversity, recreation and the environment are goals of sustainable management. For this purpose this draft forest management (DFM) plan has been prepared.

The preparation of the Cashmere DFM plan comprised three main components:

1. An economic analysis of the current plantation component of Cashmere Forest;
2. Preparation of a draft forest management plan which encompasses the management of plantation and non-plantation areas; and
3. Preparation of a geographic information system (GIS) for Cashmere Forest.

Economic analysis evaluated clearfell, coupe (2 to 5 ha), and a mixture of coupe and continuous canopy management (CCM) as harvesting scenarios. The coupe CCM mix was recommended for implementation primarily as it best suited long term management goals for Cashmere Forest Park while also returning modest value (NPV $561,966). Normal cashflow analysis was also used to analyse cashflow over the first thirty years of operation from 2007.

Under coupe/CCM, accrued profit does not become permanently positive until around 2019 due to initial infrastructure costs. Accrued revenue culminates at around 4 million after 30 years. This figure may drop following implementation of high pruning, alternative growth models and indigenous restoration.

The Cashmere DFM plan begins with the 200-year vision which sees a Forest Park ecosystem that achieves production, environmental, ecological and recreational goals appropriate to its Port Hills location. Production forestry is practiced through the selective harvesting of a range of naturally regenerated exotic and restored indigenous species. Landscape, soil and water resources are sustainably managed through the retention of a mixed forest canopy. The forest park has been significantly augmented with indigenous flora and fauna typical of the Port Hills and ecologically significant areas are managed specifically for their indigenous biodiversity. Park recreational users are enjoying ongoing utilisation of a unique Canterbury landscape. Plantation forest management involves coupes of between 2 to 5 ha which will be harvested with cable or ground based systems with areas split approximately 50:50 between the two. Cable harvesting will be carried out with a swing yarder system with ground based operations carried out with track skidders. CCM will be carried out on a trial basis in three compartments. Re-establishment of plantation areas will aim towards occupying around 58% of Cashmere Forest, comprised of areas of radiata pine 65%, radiata pine/eucalypt 24%, Douglas fir/eucalypt 5% and Alternative species 6%.

Non-plantation areas are identified as either bluff, track or clearing. Within each area there may be one or more vegetation type including tussock grassland, mixed shrubland, rock association and any mixture of the three. It is proposed that the non-plantation area will eventually increase to include riparian buffers 31%, restored native 55%, bluff 10% and track 4% areas, reflecting the long term vision of increased native areas in Cashmere Forest.

Monitoring of forest operations, restoration, recreation and management progress will be integral to the successful implementation of the Cashmere DFM plan. A database of information will be created to allow periodical reviews of processes and predictions and reconciliation of costs and revenues associated with the management of Cashmere Forest. Periodical reviews will also be undertaken by an independent management advisory group who can liaise with the project manager of Cashmere Forest

Park to discuss issues and aid planning and ensure the successful establishment of this unique park resource.

O'KELLY, GLEN (2008)
FOREST-MILL INTEGRATION FROM A TRANSACTION COSTS PERSPECTIVE

Fibre sourcing is a critical strategic question for all sawmills and pulpmills, but the degree of supply integration through long-term contract sand forest ownership varies widely. The purpose of this research was to investigate the extent to which forest-mill integration patterns can be explained by the transaction cost economics (TCE) theory.

TCE theory holds that organizations will choose transaction governance forms that minimize transaction costs. The TCE factors expected to influence that choice can be grouped into three categories: transaction frequency, market uncertainty, and asset specificity. Interviews with various industry representatives suggested that factors from all three categories are relevant to the question of forest-mill integration.

A survey was conducted of mills in New Zealand and Sweden, providing data on their supply mix and various TCE factors. Of an estimated population of approximately 450 mills, 136 mills were sampled and 88 responded to the survey. Fractional logic models were developed to explore the factors that may influence the integration decision.

Considerable evidence was found for the importance of TCE factors in driving fibre supply integration. The evidence was strongest for factors related to asset specificity, including forest owner concentration and the specificity of a mill's fibre requirements. Transaction frequency appears less important; while integration was found to be significantly associated with the number of mills an organization has within the supply basin, the influence of mill capacity was found to vary. There was weak evidence for the importance of uncertainty, and perhaps only through the impact of forest owner concentration on market conduct.

Integration was found significantly higher for pulpmills than sawmills, and higher in Sweden than in New Zealand. The latter result is difficult to explain by TCE theory, and suggests that non-TCE factors play a significant role. Survey responses also indicated that non-TCE factors are important. Further research is required to enlarge the sample size and better understand the role of TCE factors in forest-mill integration.

OUNEKHAM, KHAMSENE (2009)
DEVELOPING VOLUME AND TAPER EQUATIONS FOR *STYRAX TONKINENSIS* IN LAOS

A volume equation for predicting individual tree volume, and a taper function for describing a stem profile were developed for a little known species, Styrax tonkinensis (Siam benzoin) in northern Laos. The species has high potential commercial value and can make an important contribution to the local economy. It can provide two different types of products, a non-wood product (benzoin resin) and timber. In Laos, the most important product is currently resin, and the use of timber for commercial purposes is rare. One reason is that information about the timber is not available. In Vietnam, on the other hand, the species is an import pulpwood species.

Data used in this study came from 73 trees. Trees were purposely selected to ensure coverage of a full range of tree sizes. Measurement was undertaken only on over-bark diameters due to some constraints, limitations and problems during the field data collection. However, due to the importance of under-bark volume for this species, a small available dataset was used to build a bark model as an interim

guide to the errors associated with using over-bark models for estimating under-bark volumes. From this bark model, errors in estimating under-bark volumes of trees with diameters at breast height between 10cm and 17 cm were approximately 18%.

Nineteen individual volume models, and 7 individual taper functions were compared for bias and precision. Collective names for the volume equations tested include single-entry, double-entry, logarithmic, combined variables. Most volume models had similar bias but a few were clearly biased. The models with similar bias were further evaluated by four common statistics including bias, standard error of estimates, standard deviation of residuals and mean absolute deviation. The results showed that a five parameter model was ranked first, and was the most precise model. However, the magnitudes of difference in prediction errors between this model and other models, particularly the three parameter model were not significant. For practical purposes, the simpler model was preferred.

Seven taper functions tested here belong to three different groups including single taper equations, compatible taper equations and segmented taper equations. Evaluation of taper equations used the same residual analysis procedures and criteria as those applied with volume equations. Graphical residual analysis showed that most taper models had similar precision with their errors in diameter predictions being similar in range. However, some models showed obvious bias. The most highly ranked taper model was a compatible taper model of polynomial form. It was the least biased model. The second ranked model was a single, simple model. This latter model is relatively simple to apply, but it is not compatible with the volume model, yielding slightly different estimates of volume if it is integrated and rotated around the longitudinal axis of a tree. However, if the sole purpose is to describe tree taper, it is the best model to use.

OYIER, PAUL OKANDA (2016)
FUEL CONSUMPTION OF TIMBER HARVESTING SYSTEMS IN NEW ZEALAND

Fuel is a major cost in logging and is also relied on by logging contractors in New Zealand to adjust unit logging rates in dollars per cubic metres ($/m^3). There is however, no benchmark on fuel consumption rates in litre per cubic metres (l/m^3) in New Zealand, making it difficult to optimise logging operation during planning. A study on fuel consumption of timber harvesting systems in New Zealand was conducted with the participation of 17 ground-based (GB) and 28 cable yarding (CY) logging contractors with crews working commonly on pine plantations (Pinus radiata). The logging contractors, distributed in both the North and the South Islands of New Zealand, provided data on fuel use, production, stand and terrain attributes, type and number of machines used by month or year of harvesting. This data was used to determine and set benchmark on rates of fuel use in l/m^3 and litres per kilowatt-hour (l/kWhr), and establish the proportion of unit fuel consumption costs in unit harvesting costs by type of harvesting system.

All the GB systems combined harvested approximately 1.1 million cubic meters of timber using 2.94 million litres of fuel. Similarly, all the 28 CY systems combined harvested approximately 1.5 million cubic metres by consuming 4.6 million litres of fuel. Results showed that on average, the rates of fuel use for GB systems combined was 3.04 l/m^3 and 0.15 l/kWhr, while that of CY systems was 3.18 l/m^3 and 0.09 l/kWhr. There was no clear difference in average rates of fuel use in l/m^3 between GB and CY unlike rates of use in l/kWhr. Using comparable data from GB systems in the Southern US states of Alabama, Georgia, Florida, Louisiana, and North Carolina, on average, GB systems in New Zealand use 32% more fuel per unit of production. Sensitivity analyses based on unit harvesting rates ($/m^3) from harvesting benchmarking data and average fuel (diesel) prices for 2013 in New Zealand showed that fuel costs per unit volume of wood harvested, on average, constitutes 16 and 14% for GB and CY operations, respectively per unit cost of harvesting.

The study concluded that on average, GB and CY harvesting systems use the same rates of fuel use in l/m^3. The rates of fuel use in l/m^3 were found to be dependent on total production, slope of harvesting

sites and directions of pulling during extraction. The results of the study also showed that GB and CY harvesting systems use different rates of fuel in l/kWhr. The rates of fuel use in l/kWhr were found to be dependent on the type of harvesting system used, total production, number of machines used, average power, slope, directions of pulling during extraction and surface moisture conditions during harvesting.

The results of this study will contribute significantly to the understanding of logging fuel use by providing a benchmark on rates of use in l/m^3 and l/kWhr, for harvesting planning, adjustment of logging rates, and updating the existing machine costing spreadsheet. The rates of fuel use in l/m^3 reported in this study will also be applicable in comparing operational costs between harvesting systems and machines for purposes of economic efficiency.

PARK, DAWOON (2012)

ECONOMIC WOOD AVAILABILITY AND PROFITABILITY OF SMALL-SCALE FORESTS IN WANGANUI DISTRICT

New Zealand wood availability forecasts indicate that increases in the future wood availability significantly relies on small-scale forest owners‟ resources. This “small-scale” resource is poorly understood and comprises a large number of owners. It is questionable how many of these forests are established with consideration of the cost and practicality of harvesting. An improved understanding of the likelihood of this resource ever being harvested is important for understanding future wood supply.

The main objective of this study is to answer a fundamental question on how much small scale forest area is economic to harvest. The study aims to estimate the basic stumpage value of the forests at modelled costs and different log price levels, and to analyse the profitability of the small scale forests by looking at the historic rate of return, as well as the net present value (NPV) and internal rate of return on existing and future forest land. The emission trading scheme (ETS) was also taken into account during the analyses and the effects of the ETS on the profitability, optimum age and future wood availability were investigated.

The methodology developed for this study uses a forest growth model (Radiata Pine Calculator), Geographic Information Systems, the Visser harvest cost model, and Microsoft Excel. The growth model enables the analysis to be customised to a specific region of interest, while spatial characteristics such as slope and transportation distance of individual forests were taken into account by using GIS. The cost model allows the analysis to be customised to individual forests to some extent although a number of assumptions are made generalising the forests as whole. Developing the overall framework within Excel allows easy analysis of the results and changes to the underlying assumptions.

Harvesting and transportation costs are the main drivers in determining the profitability of small scale forests. A significant increase in log prices is required for the existing forests to obtain substantial profit from log production. At current log prices 90% of small-scale forests in the Wanganui District are economically available. The other 10% small blocks on steep sites, have negative stumpage revenues because of high harvesting costs.

Additional cashflows from entering the ETS have the potential to generate significant revenue for post-89 forests. However the substantial increases in optimal rotation age are likely to delay the increase in harvest volumes forecast from the small-scale estate.

PENDLY, MELISSA (2014)
INVESTIGATING THE REGIONAL VARIATION IN RULES AND BEST MANAGEMENT PRACTICES FOR FORESTRY IN NEW ZEALAND

Under the Resource Management Act 1991, the interpretation and implementation of environmental policy is primarily the responsibility of local government. The management of forestry operations may be influenced via two written means: statutory rules published in regional and district plans, and recommended best management practices (BMPs) published in guidelines. There are concerns that inconsistency between jurisdictions' regulations have a negative impact on the forestry industry; both in terms of cost and achieving positive environmental outcomes.

This research has investigated and quantified the variation in Permitted Activity rules and BMPs between the sixteen Regional Councils of New Zealand, with a focus on culvert installation and earthworks. This research quantified variation on both a national scale and between neighbouring councils. A peer review exercise was carried out to test the possible subjectivity of results, and found that an expert panel largely agreed with the results produced.

It has been found that there is significant variation in these regional rules and BMPs. Variation in both the level of control, i.e., the number of rules and BMPs per council, and the nature of control, i.e., the proportion of rules or BMPs utilised, is considerable. Further, the rules and BMPs of one council are seldom the same as another. This variation is apparent on both a national scale and when considering only neighbouring pairs of councils.

The findings on levels of variation between councils show that the variation is high, given that the parameters of this research excluded rules and BMPs which pertained to areas of special significance or value. As only 'general' rules and BMPs were examined, one would expect variation between councils to be low. The results, however, indicate that there is only limited agreement between Regional Councils.

New Zealand's resource management rules and policies regarding plantation forestry are currently under review. By highlighting the existing regional variation, this research may help to promote the need for a more consistent and effective approach to the regulation of forestry operations.

ROBERTSON, KIMBERLY (2006)
ESTIMATING REGIONAL SUPPLY AND DELIVERED COST OF FOREST AND WOOD PROCESSING BIOMASS AVAILABLE FOR BIOENERGY

New Zealand has ratified the Kyoto Protocol and agreed to reduce greenhouse as emissions to 1990 levels by 2008. Energy generated from renewable sources, such as New Zealand plantation forests and wood processing sites, is considered greenhouse gas neutral. But the use of biomass for bioenergy in New Zealand is very small. Some of the reasons for this include a lack of information abut the future fuel supply and delivered cost.

This thesis aims to provide a methodology to estimate biomass fuel availability and the delivered cost, or a range of forest and wood processing sources within a district, and to analyse the impact of harvest age, harvesting practices, terrain, collection and chipping costs, opportunity cost and transport costs on the availability and delivered cost of biomass for bioenergy. The six biomass streams included were chiplogs, forest landing residues, cutover residues, sawdust, bark and chip.

The methodology was developed based on an area in Canterbury, and tested on an area in the Nelson/Marlborough region. It utilises forest growth models, Geographic Information Systems and Microsoft Excel. Growth models allow the analysis to be customised to a particular area or region, while the use of GIS allows the model to take spatial aspects (for example slope and transport distance)

into consideration. Developing the overall framework within Excel allows easy analysis of the results and changes to the underlying assumptions.

Opportunity costs make up a large proportion of the total cost of delivery for the chiplog, sawdust, bark and chip biomass and need to be included in any estimate of cost for these biomass streams. The logistic system chosen for collecting and chipping the forest residues has a large impact on their delivered cost as do the transport costs. However transport cost is not the most significant influence on the delivered cost of other biomass stream. The use of biomass for electricity generation only is not currently economic in either of the areas analysed. The use of biomass for heat production is currently economic if compared to the electricity purchase price.

ROTH, GOETZ

STANFORD AS A DATA SOURCE FOR FOREST MANAGEMENT: A FOREST STAND RECONCILIATION IMPLEMENTATION CASE STUDY

The New Zealand forest industry is in a state of change from motor-manual chainsaw processing towards fully mechanised harvesting operations. This is driven predominately by changes in the health and safety legislation and increased efficiency targets. Through the use of advance harvesting machinery with built in computer systems and standardised compatible data collection software (called StanForD), all mechanised processing operations are able to produce near real-time production data. This data stream enables forest management to work with datasets containing detailed information of all harvesting production. StanForD data will therefore enable the development of new ways of forest management.

The study objective was to research the use of StanForD data in a forest stand reconciliation scenario. StanForD production volumes were compared against a weight docketing system and inventory yield predictions on four harvesting sites. These studies were conducted in a clearfell harvesting crew with an experienced harvester operator over the duration of approximately one year.

The data collection included all relevant production files from the harvester; .PRI (production data), APT (harvester cutting instruction) and KTR (harvester head calibration data) files. The forest management company supplied load delivery dockets, conversion factors and inventory data. The inventory data was processed to estimate the yields of the harvested stands. PLE[1] ($p \leq 0.05$) boundaries by grade group and total volume were calculated. The estimated yields with its PLE boundaries were compared against the volume recorded by the harvester and the data retrieved via the docketing system.

The results show the harvester data, when compared with the inventory data, was within the PLE limits for seven out of 15 grade groups. Small utility was the only grade correctly predicted at all sites. Pulp wood hasn't been predicted correctly at any site in comparison to the harvester data. The docket data was for five out of 15 grade groups within the PLE limits. For the total volume the harvester data was two out three sites within the PLE limits. The docket data failed on all three sites to be within the PLE boundaries on total volume. These results show both reconciliation methods, docketing system and harvester data based system have failed to confirm the yield predictions repetitively.

Comparison of the harvester data against the docketing data, showed the harvester had lower recorded volumes for pulp, export pulp and an systematic over-measurement for the higher grades compared to the docket data at all sites. Subsequent to data collection, the reason for the lower harvester volume measurements on the lower quality grades was identified to be operators not correctly recording harvest data. As possible causes for the over measurement, missing bark function and the use of estate wide conversion factors were identified. The study showed higher grades, despite the schematic differences, were recorded more accurately than lower quality grades.

Taking all results in account, using harvester data remains a valuable data source for the future;

especially for aspects such as reconciliation. More emphasis on operator training on the harvester computers systems is likely to increase the data quality collected by the harvester.

SATCHELL, STUART DEAN (2015)
EVALUATING PROFITABILITY OF SOLID TIMBER PRODUCTION FROM 15 YEAR OLD PRUNED AND THINNED *EUCALYPTUS NITENS* (DEANE & MAIDEN) IN CANTERBURY

This case study investigated profitability of a small stand of fast-grown *Eucalyptus nitens* in Canterbury for sawn timber production. This stand was pruned and thinned and then harvested at 15 years old. An estimate of per-hectare log yields and diameters was made from the stand. Sample logs were sawn, dried and profiled, then products quantified. Log prices were estimated using the residual value method. Prices were summed for sawn products from each log, from which processing expenses and sawmill profit were deducted for an estimate of log value. In the absence of market prices for sawn *E. nitens* products empirical estimates of price were derived from market survey data. Predictive models were produced from estimated stand log yields along with predicted product revenues and processing costs from sample logs. These were used for estimating per-hectare log residual values from the case study stand trees. Financial returns to the grower were then calculated as discounted cash flows from the estimated log residual values per hectare, taking into account grower costs along with harvesting and transport costs. Best-practice processing methods were identified from the literature and applied as a productivity benchmark. Methods were developed with the view to standardising data across research efforts that seek to improve grade recoveries for *E. nitens*. A range of factors were investigated that potentially influenced *E. nitens* log residual value in this case study, including log diameter and log position. Outcomes included a reasonably favourable return on investment for the grower. However, this depended on a number of factors such as land price, distance from processor, product prices, grading methods, drying methods and level of sawmill profit. The application of contemporary best practice small-scale processing methods indicates that *E. nitens* has potential as a profitable plantation species for solid timber production.

SAU, ANDI ADRIANA WE TENRI (2013)
QUANTIFYING FOREST DEGRADATION AND EFORESTATION USING GEOGRAPHIC INFORMATION SYSTEM (GIS): A CASE STUDY IN THE THREE PROVINCES, SOUTH KAILIMANTAN, EAST KALIMANTAN AND SOUTH-EAST SULAWESI, INDONESIA

Forest degradation and deforestation have been pervasive problems in Indonesia and the country is placed second in terms of a high rate of tropical deforestation. Different definitions and different techniques have been used to quantify forest degradation and deforestation in Indonesia, and different factors have been detected as direct and underlying causes. However, almost no quantitative studies have been conducted to relate deforestation and forest degradation to the causes. This study quantifies the rate of forest degradation and deforestation between 2000 and 2009 in three provinces of Indonesia, South Kalimantan, East Kalimantan and South East Sulawesi, as a case study.

A geographic information system (GIS) was used to generate geographic datasets to allow quantification; accompanied by a descriptive statistical analysis. Land cover in 2000 and 2009 was used as the basis of analysis. A national land use classification was aggregated into 10 different land use classes. Changes in land use between 2000 and 2009 allowed quantification of the rates of forest degradation and deforestation as well as the association between degradation and deforestation and potential causes.

Overall, 95% of primary forest degradation in South Kalimantan, 65% in East Kalimantan, and 46% in SE Sulawesi were associated with direct causes such as forest concessions, mining activities and the government-sponsored transmigration program. The selected direct causes explain 56% of secondary forest deforestation in South Kalimantan, 44% in East Kalimantan and 55% in SE Sulawesi.

Results of this study also show that forest degradation and deforestation occurred across the official forest areas. Almost 40% of forest degradation in South Kalimantan and East Kalimantan occurred in conservation forests and production forests respectively; while 57% of forest degradation in SE Sulawesi occurred in protected forests. Deforestation occurred 29% and 34% in the production forests of South Kalimantan and East Kalimantan respectively. In SE Sulawesi, 34% of deforestation occurred in watershed protection forests.

This study suggests that current practice in the forest resources management in Indonesia is not effective and efficient enough to mitigate and to halt forest degradation and deforestation. This is due to the lack of consistency in implementing forest land use policy, mistaken policy interventions, and non-synchronised policy between central and local governments. Policy reform is needed to conserve the remaining forest resources and mega-diversity of Indonesia.

STEWARD, GREGORY A. (2011)
GROWTH AND YIELD OF NEW ZEALAND KAURI (*AGATHIS AUSTRALIS* (D. DON) LINDL.)

The growth and productivity of kauri (*Agathis australis* (D. Don) Lindl.) in even-aged single-species planted stands and mixed-aged second-growth natural stands has been studied. Stand-level models of height, basal area and whole-tree volume were developed. Kauri growth and productivity in planted stands up to 83 years old were compared to that of natural stands that were up to 196 years of age. Within natural stands, the effect of thinning treatments on growth and productivity was also assessed.

Models of growth and productivity were initially developed for each of the three different kauri stand types independently (planted, second-growth unthinned and thinned). Combined data sets allowed for the development of single models that were able to fit all stands. A Schumacher equation with local slope parameter and asymptote bounded at 45 m gave the best fit for height growth, while a von Bertalanffy-Richards equation in difference form with local slope parameter gave the best fit for basal area growth. Kauri in all stand types were found to be slow to establish with little height growth in planted stands for the first five years after planting, and for the first 25 years in natural stands. Similar trends were observed for basal area and whole-tree volume development. Models developed in this study are relevant only to kauri in the “ricker” or monopodial form irrespective of age, and for stands from 320-2000 stems/ha.

Kauri growth and productivity in planted stands was substantively better than that in second- growth stands. Planted kauri had height increment of 0.4 m/yr for periods of up to 30 years. At age 50, planted kauri was predicted to be 20 m in height, over twice the height of kauri in natural stands, and to be 28.1 m by 100 years. Basal area at age 50 averaged 64.9 m^2/ha for all planted stands, and was predicted to be 98.2 m^2/ha at age 100. Whole-tree volume was predicted to increase by 11.7 m^3/ha/annum for all stands, but was as high as 20.6 m^3/ha/yr in one 70 year old stand. The maximum productivity of kauri was observed in one high-performing young kauri planted stand where whole-tree volume increment in excess of 30 m^3/ha/yr were predicted for a period from age 15-30. Carbon sequestration was calculated from the volume model and predicted to be 316 t C/ha and 1168 t CO_2/ha at age 100.

Mortality of kauri in planted stands was as high as 3.9%/yr for individual stands, over their entire rotation to date. For all stands, mortality averaged 0.56%/yr. The highest mortality occurred in the years before the first assessment and averaged 0.64%/yr for all stands. From the first to the last assessment mortality averaged 0.30%/yr. Where mortality in individual stands was above the average rate the dominant cause was drought.

The growth and productivity of kauri in second-growth stands was only marginally improved by thinning to reduce competition. The volume removed in thinning operations had not been replaced in the (up to) 50 years since thinning treatments were applied. At age 150, the predicted height of kauri in unthinned control and thinned stands were identical at 25.9 m. Basal area at age 150 was 64.5 m^2/ha in unthinned stands and 52.6 m^2/ha in thinned stands. Whole-tree volume was predicted to be 681 m3/ha in unthinned and 549 m^3/ha in thinned stands. Volume increment peaked at 5.2 m^3/ha/yr in unthinned stands and 4.7 m^3/ha/yr in thinned stands.

This study has shown that the worst growth and productivity of kauri in planted stands was better than that of the best natural stands. The difference in performance between plantation and second- growth kauri was most likely a result of a combination of lower site quality characteristics (soil type and fertility), stand structure and within-stand competition of natural stands.

The data for planted kauri came from 31 permanent sample plots located in 25 planted stands. These stands ranged in age from 14-83 years at the last assessment, and ranged in stand density from 218-1800 stems/ha. The overall number of planted stands and plots from which data was available to develop models was small in comparison to many exotic forest species datasets. The majority of the planted stands were not silviculturally treated after planting, and considerable variation in establishment methods was recorded. The results of productivity from the models developed for planted kauri should therefore be considered to be conservative.

The results of this study indicate an opportunity to grow kauri in plantations on good quality sites for the production of high quality sapwood timber over rotations of 60 years or less. They also indicate that second-growth stands will produce usable volumes of timber, but only over extended periods of time.

To ensure that kauri in planted stands can meet the potential observed during the development of these models, a series of well-managed stands on a range of sites is urgently required where the effects of timely silviculture, including initial stand density, can be assessed, quantified and reported on. Further research on selection and breeding for the species would improve the early establishment and growth of planted kauri resulting in a reduced rotation length. Research on long- term management strategies that include continuous cover forestry may make the species an attractive proposition for carbon forestry and/or for the production of high quality, naturally durable heartwood. The dataset compiled for this study was the best data available. While it cannot as yet be used to develop prescriptions for the establishment and maintenance of planted kauri stands, it does provide clues and directions that should be pursued in further research, however.

TOLAN, ALEX (2014)

THE EFFECT OF THE NUMBER OF LOG SORTS ON MECHANISED LOG PROCESSING PRODUCTIVITY AND VALUE RECOVERY IN LANDING-BASED CABLE YARDER HARVESTING OPERATIONS

The New Zealand forest industry produces a diverse range of log grades and sorts to meet domestic and export market demands and to maximise returns to the forest grower. An implication for the supply chain is the number of log grades and sorts a harvesting operation is expected to produce from one species, radiata pine (Pinus *radiata).* The number of log grades and sorts can impact on landing size and layout requirements, value recovery, log- making complexity, machine utilisation and quality control requirements.

A study was conducted to investigate if the number of log sorts affects mechanised log processing productivity and value recovery. This would determine if any gross value gains derived from producing a higher number of sorts are offset by losses in log processing productivity. Two landing-based mechanised log processors at cable yarder harvesting operations were studied using different

cutting scenarios producing five, nine, twelve and fifteen log sorts. The study collected data from over 26 hours of mechanised processing which included the processing of 578 stems at an average piece size of approximately 1.6 m3. Machine utilisation results showed processors spending 84% of total time on productive tasks and that 49% of total time was spent on the primary productive tasks of log processing.

Quadratic regressions were used to model log processing productivity trends which showed piece size and cutting scenario as significant predictor variables (p-value <0.01). There was a significant difference between cutting scenario with five log sorts and the cutting scenarios with twelve and fifteen log sorts (p-values <0.05), as well as a significant difference between the nine and fifteen log sort cutting scenarios (p-value <0.01). There was not enough evidence to suggest productivity was different between cutting scenarios producing five and nine log sorts. Based on this analysis, it was likely that the null hypothesis that the number of log sorts does not affect log processing productivity should be rejected. At a piece size of 2 m3, the productivity model estimated processing productivity was 10% higher producing nine log sorts compared to producing fifteen log sorts.

A linear regression model showed a strong relationship between gross value recovery, piece size and cutting scenario (p-value <0.01). Gross value recovery increased as the number of log sorts increased. A significant model suggested it is likely null hypothesis 2, that the number of log sorts does not affect gross value recovery, should be rejected. There were only some differences in variances between cutting scenarios which were statistically significant. Both the average results and regression estimates showed the five log sort cutting scenario recovering 94% of the value of the cutting scenario with fifteen log sorts. Incremental gains in value recovery as the number of log sorts increased were marginal, which appeared to be due to log prices for many major log grades trading in a close range in relation to historic price trends.

Regression trends for productivity and gross value recovery indicated that the most optimal cutting scenario, in terms of processing value outturn per productive machine hour, was the cutting scenario producing nine log sorts. This suggests that declines in processor productivity offset gains in gross value recovery when producing twelve and fifteen log sorts. Market sensitivity analysis suggested that differentials in log prices impact on the number of log sorts which optimise the value outturn per productive machine hour from log processing.

WAGHORN, MATTHEW J. (2006)

EFFECT OF INITIAL STAND SPACING AND BREED ON DYNAMIC MODULUS OF ELASTICITY OF *PINUS RADIATA*

Wood stiffness or modulus of elasticity (MOE) is one of the most important wood properties for solid timber applications, and as such, the efficacy of wood use, especially for structural timber is strongly related to MOE. MOE in *Pinus radiata* is highly variable and poorly understood. In this study, the effect of initial stand spacing and breed on outerwood MOE and the vertical distribution of MOE of *Pinus radiata* was assessed. Understanding positive or negative influences of growth caused by initial stand spacing and genetic material on MOE is appealing because it could enable us to better comprehend how forest growers could adapt silvicultural operations to the demand of wood processing.

Physical characteristics of different breeds and propagation methods of *Pinus radiata* were assessed at a variety of initial stand spacings. Stem diameter, crown height, stem slenderness and branch size were all heavily influenced by stand spacing. Breed had a marginally significant influence on diameter and stem slenderness. Internode length was not affected by stand spacing, but showed sizeable differences, especially between the long internode 870 breed and the remaining growth and form (GF) breeds.

Outerwood MOE was significantly (P<0.0001) influenced by stand spacing and breed, but not their interaction (P>0.05). MOE scaled positively with stand spacing. MOE increased by 39% from 5.4 GPa at 209 stems ha^{-1} to 7.5 GPa at 2551 stems ha^{-1}. The majority of this increase (33%) occurred between 209 and 835 stems ha^{-1}. Physiologically aged cuttings of greater maturation status exhibited greater MOE, with the three-year-old cuttings being stiffer than the one-year-old cuttings, seedlings from the 870, 268 and 850 series, by 15, 17, 22 and 27% respectively. Stem slenderness exhibited the strongest significant (P<0.0001) relationship with MOE (r^2=0.49), followed by green crown height (r^2=0.46) and diameter r^2=0.44). Stem slenderness and green crown height had a direct influence on MOE that explained 53% of the variance in MOE.

MOE was also significantly (P<0.0001) influenced by spacing and breed when using the resonance technique to assess whole stem MOE. The vertical distribution of MOE showed that the lowest portion of the stem (bolt 1) was approximately 30% less stiff than bolts 2 and 3. After the greatest MOE value had been obtained at bolt 3, MOE gently declined to the top of the measured stem. Variation of MOE within trees was significant (58%) at the high stockings of 1457 and 2551 stems ha^{-1}, but somewhat lower (36%) at the lower stockings. The 870 breed was approximately 8% and 16% stiffer than the 268 and 850 breeding series respectively, across all stockings, with the three-year-old cuttings being 7% stiffer than the one-year-old cuttings. At stockings of 481 stems ha^{-1} and less, the proportional height at which MOE was greatest within a tree was between 25% and 50% of stem height. At stockings above 481 stems ha^{-1} the proportional height at which maximum MOE was obtained was between 15% and 40% of stem height. Bolt slenderness was found to be the most significant factor impacting on MOE of the bolt.

Regression of critical buckling height against diameter at ground level yielded a scaling exponent of 0.55, which was lower than the scaling exponent of 0.67 predicted with constant density-specific stiffness. There was a tendency for some bolts with lower mean diameter to display significantly higher safety margins than bolts with higher mean diameter, suggesting that the largest bolts, which occur at the base of tree, are the point of most likely critical failure.

WAKELIN, HEATHER (2010)

IGNITION THRESHOLDS FOR GRASSLAND FUELS AND IMPLICATIONS FOR ACTIVITY CONTROLS ON PUBLIC CONSERVATION LAND IN CANTERBURY

Grassland fuels quickly respond to moisture changes in the environment, and successfully ignite more readily compared with other wildland fuel types. In recent years in New Zealand grasslands, wildfire ignitions have increased due to recreational activities on public conservation land. Ignition sources have included off-road vehicles, sparks from machinery, and campfires, cooking stoves, etc. This research investigated ignition thresholds for fully cured tussock (*Festuca novae-zelandiae*) and exotic (*Agrostis capillaris*) grasses, with the aim of providing a scientific basis for wildfire prevention through decision-support tools for activity controls.

Five ignition sources of concern to the Department of Conservation were tested in the laboratory, and results were validated against field experiments. Experiments were innovative, and were designed to simulate ignitions from: hot exhaust systems on off-road vehicles (hot metal); sparks from vehicle exhausts (carbon emissions); grinding operations (metal sparks); smouldering debris dropped onto grass fuels from hot vehicle parts (organic embers); and ordinary cigarette lighters (open flame). Fuel moisture content (MC), and wind speed were varied, but ambient temperature and relative humidity were kept relatively constant in the laboratory.

Logistic regression was used to analyse data for each ignition source, except organic embers because no ignitions occurred. Ignition thresholds were determined for a probability of ignition success of 50%, and all models were statistically significant. The thresholds are listed in terms of model accuracy for each experiment: open flame was 28% MC without wind, and 55% MC with light wind (1 m/s); metal

sparks was 37% MC; hot metal, with a wind speed of 2 m/s and MC of 1%, was 398ºC hot metal temperature; and carbon emissions was 65% MC.

The results represent a significant contribution to knowledge of the ignition behaviour of grassland fuels. Further research is required to verify and extend the results; but, initial findings provide a scientific basis for management, investigations of wildfire causes, and decisions around controls on recreational activities to protect highly sensitive ecosystems and natural areas from damaging wildfires.

WEKESA, ANNE (2013)
USING GIS TO ASSESS THE POTENTIAL OF CROP RESIDUES FOR ENERGY GENERATION IN KENYA

Crop residues can make a significant contribution to the energy sector in Kenya. The purpose of this study was to identify the availability and spatial distribution of crop residues and their energy potential through the creation of a Geographical Information System (GIS) model. This information is important to the successful utilisation of these residues. In addition, a GIS tool was created that automates the resource estimation process for the purpose of identifying potential biomass energy plant sites.

This study was conducted considering six provinces: Rift Valley, Western, Nyanza, Eastern, Central and Coast. The Rift Valley Province was selected as the case study for model tool creation and the crops considered in the study were maize, wheat, rice and sugarcane. The study was a quantitative one entailing the collection of secondary data in the form of crop production statistics and spatial data which comprised population, land use and road shape files and analysis using GIS. Residues to Product Ratios were used to estimate the amount of crop residues while Lower Heating Values assessed the energy potential. Moreover, ArcGIS Model Builder was used to create the GIS model tool for the feasibility of a potential biomass energy plant.

The results of this study indicated the amount of crop residues that can be generated in Kenya to be about 7,384,600 tonnes with an energy potential of approximately 124,300 TJ/year. Rift Valley Province was found to have the highest residue generation of about 3,866,000 tonnes with a corresponding energy potential of about 64,800 TJ/year. The GIS model showed that the Rift Valley Province and Uasin Gishu, Trans Nzoia, and Nandi districts all had the potential for high residue generation resulting from their high agricultural production and high yields. The modelling tool was also able to demonstrate the increase in the amount of crop residues that can be collected using different radii around a potential biomass plant.

The main conclusion was that crop residues have a high potential for energy generation in Kenya. In addition, a GIS model tool was created for Rift Valley Province which can be transferred to any other region, in order for the local energy planners to supply the model with their own parameters to obtain locally based results.

WHITELEY, YANNINA (2020)
EMPIRICAL MODELS OF TREE TOP BREAKAGE AND SCATTERED WIND-THROW IN A *PINUS RADIATA* AND *PSEUDOTSUGA MENZIESII* PLANTATION FOREST IN NEW ZEALAND

In this thesis, attritional damage to trees attributed to wind and snow was studied in *Pinus radiata* (radiata pine) and *Pseudotsuga menziesii* (Douglas-fir) at Geraldine Forest, a 5,500 hectare forest in the South Island of New Zealand, based on tree damage descriptions from forest sample plot data. This damage largely comprises the breakage of live stems, and also a smaller number of windthrown trees.

The mean levels of damage were compared by species, and it was established that the damage levels are significantly different, with Douglas-fir exhibiting higher broken heights, lower proportion of trees damaged, and lower proportions of trees alive than radiata pine.

With these results established, damage was modelled for each species separately, using both mixed-effects linear (or generalised linear) regression and random forests to create empirical models. The three response variables were the mean height of broken trees per plot (*P_tree_ht_mean_BRKN*); the proportion of trees with damaged tops per plot (*Tops_prpn_DAM*); and the proportion of live trees per plot (*Prpn_LIVE*). None of the models created were suitable for re-use with new data, due to bias in the model results and the reliance of the models on mixed-effects.

Three models had sufficient explanatory power to demonstrate that some particular tree and topographic variables correlate with damage levels. These models, all at the plot level, were 1) radiata pine *P_tree_ht_mean_BRKN* by linear regression with mixed-effects, 2) radiata pine *P_tree_ht_mean_BRKN* by random forest, and 3) radiata pine *Tops_prpn_DAM* by logistic regression with mixed-effects, using only data where the top of every tree had been assessed.

For the model of radiata pine *P_tree_ht_mean_BRKN* by linear regression with mixed-effects, the age of the trees, the proportion of trees pruned, and the aspect correlated with the height at which trees break, with the stand identity as a mixed effect. For the model of radiata *P_tree_ht_mean_BRKN* by random forests, the year of establishment, the per-hectare equivalent basal area, the age of the trees, the height of the unbroken trees, the pruned proportion, the mean pruned height, and a group of weather variables correlated with the height at which trees break. For the model of radiata pine *Tops_prpn_DAM* by generalised linear model with mixed-effects, the per-hectare equivalent stocking, the mean diameter of unbroken trees, and the proportion of live trees correlated with the proportion of trees damaged, with the stand identity and the plot number as mixed effects.

From these results, and by comparison with previous research into empirical models of damage to trees by wind and snow, some management recommendations have been made to reduce future damage by wind and snow at Geraldine Forest. The first is that if low levels of damage are highly desired, then Douglas-fir is the better species to plant. To reduce the levels of damage in radiata pine, any or all of the following measures apply. The first is to avoid growing radiata pine on slopes with north-east and or south-east aspects, and/or in areas of low topographic shelter, both of which positively correlate with higher proportion damaged. The second is to choose a low stocking for radiata pine, as high stocking is correlated with higher proportion damaged, but without implementing very heavy or very late thinning. The third recommendation is short rotations for radiata pine, as the age of trees is a strong predictor of damage levels. The fourth recommendation is to plant radiata pine at low elevations; height growth is faster at lower elevations and so trees will attain a desirable size in a shorter rotation; also, taller trees have higher broken heights, leaving a longer salvageable portion of stem below any breaks. The fifth recommendation (which runs somewhat counter to the third) is to prune the radiata pine crop, because pruned radiata pine breaks at higher heights, again leaving more salvageable stem.

YARUR THYS, PAULA (2022)
CARBON SEQUESTERED BY NATIVE RESTORATION PLANTINGS, SOUTHERN PORT HILLS AND QUAIL ISLAND, CANTERBURY

Restoration plantings are typically planned with a multi-goal framework. Carbon sequestration has been a common component of these since the early nineties, but we know little about how plantings in different locations achieve this goal and what improvements can be made. This study investigated the above-ground biomass (AGB) held at five native restoration sites on the southern Port Hills and Quail Island. Date of planting was key to locate randomised sampling sites in satellite imagery using GIS. Temporary plots were set out in the field to measure all AGB and two allometric equations were

applied to the measured data to estimate carbon expressed as CO_2 equivalents. Data analysis was undertaken using R statistical software. A comparison was made between the primary allometric equation used in New Zealand's national carbon accounting system (which is based mainly on mature trees) and an allometric equation based on shrubs. Results showed an average 9% increase in the total CO_2 equivalent for all plots when using the mature tree equation for plantings less than 60 years old. A revision of the allometric equations used may improve the accuracy of the carbon accounting system if time and costs are not a limitation. Plot species-composition variables and environmental variables were not found to have a significant influence on CO2 equivalent in the restoration plantings. However, the CO_2 equivalent amounts differed from those of the MPI native species look-up tables at 30 years post planting. The values suggest that a restoration planting with biodiversity objectives can reach higher carbon content the older they are and up to at least 59 years with no indication of an abatement in this. It was also found that Podocarpus totara can be used as an enhancement species to increase CO2 equivalent levels in restored areas. To enhance CO_2 equivalent levels in tōtara plantings, proper management is necessary including elimination or at least reduction of ungulates and for trees to be planted on the forest's edge. Attention to management, species composition, and use of enrichment species for current restorations would improve carbon content and hence to efficiently achieve our carbon goals.

ZORIC, BRANISLAV (2008)

MODELLING THE INFLUENCE OF STOCKING ON LONGITUDINAL AND RADIAL VARIATION IN WOOD PROPERTIES OF *PINUS RADIATA* ON A WARM NORTHLAND SITE

The objective of this study was to determine how final stocking influences tree growth and radial and longitudinal variation in wood properties at a *Pinus radiata* D. Don plantation located at one of the warmest forest sites in New Zealand, Forsyth Downs forest in Northland. This thesis addressed both the effect of stocking on stand basal area, height, diameter and branch diameter and the effect of stocking on wood properties microfibril angle (MFA), module of elasticity and density. Finally, how ring width influences wood properties and whether this variable accounts for the treatment effects was investigated.

Stocking, height and ring number and all interactions between these variables significantly affected ring width. Ring width by itself was significant as a predictor of density, but when it was combined with other class level variables it was insignificant (i.e. does not account for treatment effects), and it did not add anything to a model with only class effects. There was a significant impact of ring number on density while ring width was insignificant in the same model.

MFA was significantly affected by ring width, height and ring number in the tree, and all interactions, apart from the three way interaction, but not by stocking. Ring width was significant in the MFA model both by itself and when it was combined with other variables. Ring width accounted for the stocking effect.

The best model of MOE included the class level effects of stocking, height and ring number within the tree, and all interactions between these variables, and ring width, as a continuous variable. While there was a significant effect between stockings this was relatively weak compared to the other main effects. Ring width largely accounted for the effect of stocking, but not that of ring number, or height.

MFORSC REPORT ABSTRACTS

ARIHAFA, ARISON (2008)
THE USE OF A GEOGRAPHIC INFORMATION SYSTEM (GIS) IN DETERMINING THE PAST AND PRESENT VEGETATION PATTERN OF TIROMOANA BUSH, NORTHERN CANTERBURY, 1950-2005

A GIS (geographic information system) database was created to quantify and spatially distinguish historical changes in vegetation cover in the 423 ha of Tiromoana Bush in New Zealand. Four main land cover types (forest, shrubland, pasture and wetland) were classified in this study. In Part A of the study, I conducted a field survey to produce the 2008 vegetation map (FMD2008) in order to compare it with the Land Cover Database (LCDB2) map of the same area created from remotely sensed satellite data. Overestimation and underestimation of vegetation classes were evident in LCDB2 map. 30% of the total land cover was incorrectly represented in LCDB2, while there were more patches of each vegetation type identified by field mapping than by the use of LCDB2. These data suggest caution in using LCDB alone to accurately map vegetation pattern, especially at the scale of my study. In Part B, four land cover aerial photographs from 1950-2005 were imported, registered and rectified into the GIS under a common legend. The total area of shrubland and native forest increased, while that of pasture decreased over the study period in a 99 ha portion of Tiromoana Bush. More areas of pasture and grassland covers were lost to forest while less forest cover was lost to other vegetation types during this period. There was an increase in the forest growth rate from 0.15 ha/yr in the period 1950-1985 to 0.74 ha/yr in the period 1985-2005. Furthermore, the total number of forest patches increased from 1950-1985, but it decreased from 1985-2005. Unlike that of the pre-1985 period, the increase in the forest cover in the post-1985 period is likely an effect of the government's removal of agricultural subsidies and therefore fewer disturbances. The data presented in this report provides an excellent basis for mapping longer-term vegetation change that result from the restoration project at Tiromoana Bush.

BIERLIN, TIMO R. (2007)
HARE'S AND RABBIT'S HABITAT UTLIZATION: A REVIEW AND PRONENESS MODEL

The European rabbit (*Oryctolagus cuniculus* L.) was, and in some areas still is, a significant pest in arid and semi-arid parts of New Zealand. High rabbit densities can cause great financial and ecological losses. In contrast, in most parts of Europe and especially in its area of origin, the Iberian Peninsula, the European rabbit is considered to be a game animal rather than a pest. It is also, not only for endangered species, one of the most important vertebrate prey species and its decline in numbers is worrying. In many areas where the European rabbit is present, the brown hare (*Lepus europaeus* Pallas) can also be found. Both species show a certain habitat and diet overlap and its interaction is discussed controversially. The first part of this report gives an overview of both species' biology, focusing on habitat and diet requirements. The overview is based on a wide literature review on Lagomorphs, including European, as well as Australian and New Zealand studies and reports.

In the second part of this report, the results of the literature view, historical kill data of European rabbits and brown hares from 1991 to 2006 recorded during pest control operations at the Otematata Station, and digital data sets of vegetation cover and soil types, are used to create a rabbit proneness model. To evaluate rabbit density, the data set of 'rabbit kills per hour' is used. The kill data have been statistically analysed and a regression has been performed on rabbit kills per hour and n the characteristics of soil type and vegetation cover. The regression does not show statistical significance between these data and consequently were excluded from the further modelling process. To analyse interactions between European rabbit and brown hare numbers, a regression with dummy variables was performed on the total number of annually killed rabbits and the total number of annual killed hares. The result indicates

a statistical significance of the parameter and explains the increase in hare numbers after rabbit numbers have dropped sharply in 1997. Spatial analysis of the data sets was applied to form the 'Otematata Station rabbit proneness model'. Under this model, areas where rabbit proneness is most likely are determined primarily by the availability of certain soil types suitable for building warrens and the availability of preferred feeding grounds. It is also suggested that the factors altitude, aspect, and slope affect the suitability of certain areas for rabbit abundance.

BULAI, TEVITA (2016)
IMPACT OF IMPLEMENTING THE NEW DIAMETER LIMIT TABLE (DLT) ON NATIVE WOOD SUPPLIES IN VANUA LEVU, THE NORTHERN DIVISION OF FIJI

The aim of this research is to assess and quantify the potential impact of implementing the proposed new diameter limit table (DLT) on wood supply, in terms of log volume delivered to saw-mills from native forests in Vanua Levu, the northern division of Fiji. Currently in Fiji the diameter limit for harvesting of all native species is 35 centimetres at breast height.

In 2013 a new diameter limit table (DLT) was endorsed by the Department of Forestry in Fiji together with a new revised Fiji Forest Harvesting Code of Practice (FFHCOP). The new diameter limit table (DLT) provides new diameter limits for different native species which range from 40 to 105 centimetres.

Log production data was extracted from the Timber Revenue System (TRS) of the Department of Forestry in Vanua Levu from January to December for the year 2015. Data collected was organised in Microsoft excel for analysis. The top ten species which collectively comprised more than 85 percent of the total volume of logs harvested in 2015 were selected for analysis. These species were analysed to determine and quantify the difference in log volume by applying the current diameter limit of 35 centimetres and the new diameter limit table (DLT).

Results of this study indicated a huge reduction in log volume supplied to saw-mills if the new diameter limit table is applied in 2015. The reduction in volume was recorded for the month of January through to December for all the top ten species analysed. It ranges from 55 to 98 percent reduction in log volume. Annual reduction in log volume recorded at 85 percent of the total volume for the top ten species. This mean that only 15 percent of the total volume extracted in 2015 qualifies under the new diameter limit table (DLT). Analysis was also carried out to determine the impact on exported wood commodities in the form of sawn timber, veneer and plywood, focussing on the three major sawmills and the only exporters from Vanua Levu in 2015.

DAUGHERTY, JAMIELYN (2007)
THE STYX RIVER: A REVIEW

The Styx 40-year Vision is a comprehensive management programme geared towards the ultimate restoration of natural areas from the source of the river to the sea. The vision requires a detailed understanding of the many ecological aspects within the system as well as human activity throughout the catchment. Human activity can be measured through development or recreation. This gives rise to a large selection of potential research projects from environmental engineering to community volunteering. This report will take a brief look at the five key visions in the plan. An overview of the primary aspects of the Styx River and surrounding catchment will then be looked at. Tributaries, reserves and wildlife communities a well as recreational use will be outlined to help gain a better understanding of the issues needed to fulfil the 40-year Vision.

DEBRAH, DANIEL (2017)
TERRESTRIAL INVERTEBRATE AS AN INDICATOR OF RESTORATION SUCCESS AT TIROMOANA BUSH, NEW ZEALAND

The use of invertebrates as bio-indicator in monitoring restoration project is gradually gaining attention worldwide .Their composition and distribution is able to indicate changes in the ecosystem. Invertebrate can be used as a tool to measure restoration success due to their ability to detect small changes in in the environment. This study was undertaken at Tiromoana Bush, New Zealand with the aim to determine invertebrate abundance, diversity and their relationship with the plant growth patterns. Invertebrate samples were collected from two restoration sites, rank grassland and two naturally regenerating forest (kanuka and mixed shrubland) using pitfall and malaise traps. A three 10 x 10m plot was demarcated in each forest type around malaise trap to estimate the plant cover. In all, 18 malaise and 54 pitfall traps were deployed to the sites. The invertebrate specimens were sorted and identified to recognisable taxonomic unit (RTUs). A total of 3291 specimens representing 11 orders and 273 RTUs were discovered. Of 273 the RTUs, 44% were found in restoration site (R2S), 38.5% in the rank grassland with the sparse kanuka having the lowest (2.12%). Out of the total number of specimens, the rank grassland (39.9%) had the highest abundance with 15% and 11% coming from the restoration sites R2S and R1S respectively. The ordination and cluster analysis of malaise samples revealed presence of invertebrate composition at the kanuka natural regenerating forest. This is an indicative of both sites serving as suitable habitat for some species. Although diptera RTUs was significantly abundance across the vegetation types, its diversity was significant. This particular coleoptera RTUs (coleoptera 019) increase in abundance from the grassland through the restoration sites to the natural forest. This explains habitat preference for some species. On the other, overall ordination pattern of plant samples was strong and had better groupings. Plant diversity and abundance was highly significant. The presence of regenerated species like *Melicytus ramiflorus* and Coprosma spp at the restoration sites and similarities of invertebrate composition at both restoration sites and kanuka forest shows a positive progressing of restoration the success state. It is therefore recommended that similar studies should be undertaken in different season to determine seasonal influence on invertebrate diversity and abundance.

HAYNES, PIUS (2011)
MODELLING BASAL AREA GROWTH OF STAND ELEMENTS IN RADIATA PINE (*PINUS RADIATA* D. DON) PLANTATIONS

Basal area growth (dG) of stand elements was modelled as a function of crown length per hectare (CL ha^{-1}) and leaf area (LA) in a 15 year old *Pinus radiata* genotype by grass competition experiment in the South Island of New Zealand. A comparison between the two modelling approaches revealed that basal area growth was better correlated to LA ha^{-1} than to CL ha^{-1}. The coefficient of correlation for LA ha^{-1} (0.840) was almost twice that of CL ha^{-1} which was 0.479.

Using a linear mixed-effects modelling (lme) approach to build models, the results indicated that LA ha^{-1} was significantly superior to CL ha^{-1}. Additionally, the leaf area model suggested that the significant effects on dG were the main effect of 9 year old trees ($p = 0.0148$) and a significant leaf area by age interaction at both age 9 ($p = 0.0127$) and age 10 ($p = 0.044$) respectively. The residuals were adequately distributed and there was no major evidence of bias. In contrast, the only significant effect on dG for the CL ha^{-1} model was an interaction ($p = 0.0236$) between CL ha^{-1} and trees at age nine. Overall, the residuals were better distributed in the LA model, with a p-value from the Shapiro-Wilk normality test, of 0.355 compared to that of CL ha^{-1} which was $p = 0.2829$. Therefore, it was concluded that LA was a better predictor of basal area growth of stand elements in *Pinus radiata* plantations than was CL per hectare.

Furthermore, an analysis of covariance (ANCOVA) revealed significant variable growth among all three stand elements during the pruning period (i.e. age 6 to age 10). Apart from the growth delays which typical happen after pruning, another major contributing factor to the high level of variability in dG was weed competition. The initial negative effects of weeds on the site seemed to have persisted until age 10. However, dG was generally more productive in the weed-free environments offered by the weed control treatments. This study thus serves as a good guide to radiata pine modellers and plantation managers who are always seeking innovative ways of improving model accuracy and efficiency, especially at the stand element level.

KLEIN, NORBERT (2007)
HABITAT SELECTION MODEL FOR FERAL GOATS (*CAPRA HIRCUS*) AT ISOLATED HILL SCENIC RESERVE: REPRESENTED BY A GEOGRAPHIC INFORMATION SYSTEM

The introduced feral goat (*Capra hircus*) occupies approximately 14% of New Zealand and about half of this land is administered for conservation purposes. Feral goats have a well-documented history of being one of the most destructive animal pests found in forests. Therefore, organised government control has been an ongoing issue since the mid-1930s. Conservation managers could benefit from a robust method of estimating the spatial attributes of the target, the simple but vital information of where feral goats live in a certain area.

A literature review about animal-habitat relationships followed by an overview of different modelling approaches provided useful aspects for the main task of this report: the development of a habitat selection model for Isolated Hill Scenic Reserve. The Reserve is approximately 2850 ha in size and is one of the largest forest remnant areas in Southern Marlborough on the South Island of New Zealand. The data for the habitat selection model is mainly based on an earlier study by Cochrane (1999) and was supplemented by relevant key environmental variables that were identified through an extensive literature review. In the model building process, the GIS ArcView 3.2a was used for analysing the data and a graphical representation. Patches throughout the Reserve, totalling 446 ha (15%), that have the utmost probability of high goat densities were determined. The validation of the habitat selection model was carried out by digitising and analysing numerousness kill data. More than 50% of the kill locations that were found exactly within the predicted area and 94% within a 300 m perimeter or 98.7% in a 500 perimeter provided a very high accuracy for the model.

The resulting topographical map assists hunters to increase their encounter-rates, as well as their hourly kill-rates. Furthermore, the incorporation of the habitat selection model on a strategic level would provide a surveillance tool and a post-operational monitoring tool for both the pest and biodiversity. Further research to extend the habitat selection model on a broader scale for regions with known feral goat distribution areas and the development of a goat index linked to the Land Cover Database 2 is advisable.

LARASATIE, PIPIET (2013)
TEAK FURNITURE INDUSTRY: A CASE STUDY IN JEPARA, INDONESIA

As the second largest producer of teak wood in the world, Indonesia has used teak as the main raw material for its furniture industry. In 2009, the furniture industry reportedly achieved total sales of US $ 135 billion or approximately 1% of the global furniture trade, and contributed 17% to the Indonesian income from 2000 to 2005. One of the well-known furniture making regions in Indonesia is Jepara. The industry is labour intensive, comprising 27% of Jepara's economy and providing 176 thousand jobs in 2005 and the livelihood for approximately 4-5 million Indonesians. Unfortunately, previous research has shown a decline in the Jepara‟s furniture industry with only 80% of the furniture enterprises survived.

The main purpose of this research is to propose the scenarios to improve the overall economics of Jepara's teak furniture industry and review the trend hypotheses. With a survey of 210 furniture makers in Jepara and in-depth interviews with key personnel of Jepara's teak furniture industry stakeholders, this research showed that total teak wood consumption for furniture raw material decreased from 2007 to 2011, indicating a corresponding reduction in teak furniture production. The condition also was aggravated by the furniture industry culture of utilising marketing intermediaries in their marketing channel which reduced profit margins.

Regarding the market proportion of teak furniture sales, there were slight increases in the domestic market while the export market was decreasing which was a new phenomenon in Jepara. The other important result from the survey was that the profitability trends have started to change, as the respondents who are small-scale enterprises had larger profit margins in the domestic market than in export. This situation happened due to the inequitable distribution of profitability within the value chain that reduces the returns for small-scale producers.

Overall, this research study concluded that green furniture labelling and building the capacity of the small-scale producers were the preferred solutions to improve the overall economics Jepara's teak furniture industry and support the small-scale industry as the back- bone of this historic industry.

LI, ANG (HARRY) (2017)

SEEDLING QUALITY ASSESSMENT FOR *EUCALYPTUS GLOBODIEA* – COMPARISON OF BAREROOT AND CONTAINERIZED SEEDLINGS FROM TWO NURSERIES

This research project overall aims to compare the performance (mortality and early growth) of the containerized seedlings and bareroot seedlings supplied by two nurseries in New Zealand. It also considered the influence of water availability and seedling morphological characteristics (initial seedling height and diameter) on the seedling mortality and growth were considered in this experiment.

The seedlings were tested in two growth chambers at the University of Canterbury for two month, and they were treated with three watering regimes during the period. The result shows the containerized seedling stock was inferior as a 100% mortality occurred within one week after planting. The containerized seedlings, their mortality was significantly influenced by watering treatments (χ^2=12.22, df=2, P=0.002) and initial seedling diameter (χ^2=5.445, df=1, P=0.019). The seedling height, diameter and basal area growth were all significantly influenced by the watering treatments, and the diameter growth was significantly influenced by the initial seedling diameter (χ^2 = 7.581, df = 1, p= 0.006). The initial seedling diameter also had a wee influence on seedling height growth (χ^2=3.095, df=1, p = 0.079).

The stomatal conductance of the *E. globodiea* containerized seedlings decreased with the volumetric water content in the seedling pots, and a volumetric water content of 7.6% that gives zero stomatal conductance was predicted.

The two seedling stocks had distinctly different seedling morphological characteristics, the containerized seeding stock overall had less foliage and more fibrous root system than the bareroot seedlings, and also a more consistent seedling morphology (smaller standard deviation). The allometric relationships developed for the containerized seedling stock indicated the seedling diameter had significant correlations with seedling height (p=0.017, R^2 = 0.528), stem dry biomass (p = 0.002, R^2=0.716) and foliage dry biomass (p = 0.015, R^2 = 0.545). Those allometric relationships suggested the mortality of containerized seedlings with smaller initial diameters might be due to their less leaf area, initial height, smaller stem size and slower height growth as those factors might have led to an overall slower root growth and a higher chance of being overtopped by the adjacent seedlings with larger diameters and lower moisture stress.

MAKROSIMNOK, LUCAS B. (2008)
ESTABLISHMENT AND GROWTH OF FOREST SEEDLINGS IN REGENERATING FOREST, TIROMOANA BUSH, NORTH CANTERBURY

Many years of consistent sheep and cattle grazing had drastically deteriorated the ecosystem and biodiversity in much of the Canterbury region. Thirteen permanent natural seedling regeneration plots were established within Tiromoana Bush, North Canterbury. The aim of the Tiromoana Restoration Project is to monitor and assess the dynamics of the native forest regeneration that may result in the restoration of an example of lowland forest so that the ecosystem and biodiversity can be restored in the future.

The data analysis was undertaken to examine the relationship between a number of dependent variables and independent factors. Dependent variables examined were: total seedling density present in 2008, total tree seedling density present in 2008, average change in height of tree species seedlings between 2007 and 2008 measurements, percentage change in height of tree species seedlings between 2007 and 2008, and density of new seedlings that were measured for the first time in 2008. Four independent variables that were measured for each vegetation monitoring plot and used to predict the seedling variables include: canopy openness, soil pH, aspect expressed on north-south gradient, and distance from plots to the potential seed sources, expressed in 3-point scale.

Significant correlations ($P \leq 0.05$) occurred between tree seedling density and density of new seedlings and distance from potential seed sources, and between percentage change in tree seedling height and aspect. All other correlations were not significant ($P > 0.05$). Despite developing significant regression models for above key predator variables, the variance explained in the regression models was low, suggesting that the relationship was not that strong. This vegetation monitoring study showed that more tree species would establish under the open canopy with potential seed sources within close proximity. Fast growth of tree seedlings was occurring in gully and slopes facing South direction with rich environmental resources (water, soil nutrient, light).

NORIA, ANDREW (2008)
ASSESSING THE SUCCESS OF RESTORATION PLANTINGS AT CAPE FOULWIND, BULLER, NEW ZEALAND

The success of restoration plantings in restoring farmland adjacent to the Cape Foulwind limestone quarry was assessed at two sites. The results obtained in this study suggest that restoration plantings at the nursery site are facilitating the recolonisation of new species such as *Dacrycarpus dacrydiodies* and *Melicytus ramiflorus*, while those at the beach site are failing. Seedlings regenerating at the nursery site are progressing well with a wide range of indigenous species establishing under the canopy species. The presence of novel seedlings at the study sites indicates that seed dispersal agents are present. However, the restoration plantings at the beach site have failed. The restoration failure at the beach site is due to the high mortality rate of the initial plantings. Sunlight has penetrated through the open canopies causing an influx of weeds and exotic grass. The grass swards have dominated the planting site and smothered the seedlings. Selection of species for the restoration plantings that are inappropriate to the site have also contributed to the restoration failure. The difference between the nursery site and the beach site suggest that weed control and species choice had a major impact on the regeneration, succession and overall success of restoration plantings at these sites.

PAY, MICHAEL (2017)
QUANTIFYING AN INTEGRATED PRODUCTION/CONSERVATION MODEL FOR SMALL-SCALE FORESTRY IN NEW ZEALAND

An estate model has been constructed for Woodside Forest; a 121 ha property managed for integrated production and conservation forestry in North Canterbury. Three revenue streams were modelled; black beech (*Fuscospora solandri*) forestry, radiata pine (*Pinus radiata*) forestry (managed under a continuous cover system); and honey produced from beech honeydew (sugary excretions of coccid scale insects from the *Ultracoelostroma* genus). Revenue from Woodside's beech forests can be either from logs sold to a local sawmill, or from the landowner's contract sawmilling, and seasoning the timber on site. Revenue from the honey operations can either be from renting out "hive rights" to contractors, or Woodside staff managing honey production and sales.

Mapping the Woodside property in ArcMap™ software using a combination of empirical knowledge from the landowners and field checks using handheld GPS identified the areas (ha) occupied by each land use. Silviculturally tended areas versus untended areas in Woodside's beech forests were also quantified using these methods, which formed the basis for an area-weighted average annual growth rate (AGR) that was used for the beech diameter growth increment in subsequent growth modelling.

Beech forest development (for each of Woodside's six beech management blocks) was modelled based on a variant of a commercially used stand table projection model for New Zealand beech forests. The model contained 5 cm wide diameter classes from 12.5 cm to > 80 cm, and 6 five-year long modelling projections to give a total modelling period of thirty years. Key model inputs included: stocking densities for each diameter class, derived from historical inventory sampling in Woodside's beech forests between 2011 and 2016, and diameter growth increments determined by an area-weighted average AGR. Initial stocking densities from the six blocks (all diameter classes) ranged from 265 to 1041 stems/ha. Area-weighted average AGR values from the six blocks ranged from 0.30 to 0.35 cm/year.

Harvest removals from the beech forests were modelled using three approaches; diameter-based (45 to 60 cm DBH), increment-based (volume growth in 45 to 60 cm DBH range), and a combination of diameter (45 to 60 cm DBH) and increment-based (volume growth in all diameter classes) removals. Combination-based harvesting (70% removal of stems 45 to 60 cm DBH) was found to produce the greatest removal volumes of the three approaches, while also maintaining the greatest number of stems in larger diameter classes (> 45 cm) (beneficial for ecological value). The initial size class distribution of stems was found to be critical in determining what level of removals could be sustained (under a combination-based approach) without depleting the target diameter classes to a non-recoverable level. The initial size class distribution varies across Woodside's six beech blocks, and each block's distribution is irregular (imperfect reverse J curve) (mean Q-factor values range from 1.76 to 2.40), suggesting that some beech blocks will sustain higher removal levels (> 70%).

Historical data (2002 to 2016) from Woodside's radiata pine forests (six PSPs located in five different planting blocks) was used to quantify historical harvest volumes, and estimate site productivity (using an estimate of MAI) to determine a sustainable harvest level that Woodside's radiata pine forests may support in a steady-state. MAI was estimated using DBH measurements from PSPs, combined with a tree height equation (Petterson) and volume equation (all NZ 182 for "young crop" pruned and thinned stands), as an estimate of calculated volume production divided by tree age. Historical harvest volumes (average of 13.42 m^3/ha between 2002 and 2016) were less than the estimated MAI (25.11 m^3/ha). The estimated MAI was used as a sustainable harvest level for the estate model.

Estimated land areas from forest mapping and the sustainable harvest levels from the beech and radiata pine forests were used as inputs in an Excel-based estate model. Thirty-year cash flows and NPVs were modelled based on price and quantity assumptions from the actual Woodside operation. On a per hectare basis, producing beech sawn timber is the most profitable land use, followed by radiata logs,

beech logs, honey sales and hive rights. The combination of beech timber, radiata logs, and honey sales (Combination 2) is the most profitable combination, with total annual net returns starting at $129,000 and increasing to $218,000 by year 30 (as the beech forests continue to develop). NPV (using $5000/ha land cost and an 8% discount rate) is greatest for Combination 2 ($929,000) and negative for Combination 3 (beech logs, radiata logs, hive rights) (-$177,000).

Cash flows from the Woodside operation can support outsourced labour ($100,000 manager's salary) if activity combinations are chosen that include revenue from beech sawn timber (other activity combinations cannot support the additional expense). However, the NPV for the most profitable combination (2) is negative when outsourced labour is included (-$197,000), suggesting at $5000/ha land cost, this operation cannot achieve an 8% return.

The Woodside operation (Combination 2) was found to be most sensitive to shifts in beech sawn timber prices, followed by honey prices and hive numbers. There is significant importance therefore for Woodside maintaining (or increasing) the prices achieved for beech and honey. Woodside's beehive numbers are restricted for ecological reasons under a QEII covenant to 350 (though the carrying capacity of the property is higher), suggesting that an opportunity cost occurs for Woodside by including viodiversity as a management objective.

SEALEY, COURTENEY (2010)
EFFECT OF CANOPY TREATMENTS ON INTER-PLANTING LOWLAND TOTARA INTO REGENERATING KANUKA FOREST, TIROMOANA BUSH, KATE VALLEY, NORTH CANTERBURY

Podocarpus totara was once widespread through Canterbury as it was a key species in the podocarp forests which covered the landscape. However human arrival saw the loss of vast areas of forest and this species became sparse. Today restoration of ecosystems to approximations of their natural pre-human condition is gaining recognition. For regeneration of totara to occur in lowland Canterbury it is important to reintroduce a seed source which can be facilitated by restoration planting. However to be successful in restoration plantings it is important to recreate the effect of disturbance in pre-existing vegetation by canopy clearance as totara is a light demanding species and by creating gaps in the canopy seedling establishment and survival is optimal. The comparative growth and survival of *Podocarpus totara* seedlings were investigated under various canopy cover conditions. Five treatments were created under different canopy vegetation types in regenerating kanuka forest in Tiromoana Bush, Kate Valley North Canterbury. These treatments consisted of: Gap (trees cut down), Gradual light (Ring-barked canopy trees), Control (Closed Canopy), Forest Edge, and Open. Survival and relative height growth were measured over a 7 month period over starting November 2009 commencing in May 2010. The only significant effect was that of treatment on relative height growth which was found to be significantly higher for the gap treatment compared to the kanuka and ringbark treatments, but not significantly different from the edge and open treatments.

TAMANIKAIVAVALAGI, SAIMONI S.R. (2007)
"FIJI MAHOGANY" – ADDING VALUE AND MAXIMISING OPPORTUNITIES FOR EXPORT TO THE UNITED STATES OF AMERICA AND ITS FUTURE ON FIJI'S ECONOMY

Fiji Mahogany, *Swietenia macrophylla*, King, commonly known world-wide as the big-leaf mahogany, is a medium density hardwood species which originated from Belize in the early 1900s. With similar characteristics, wood properties and growth conditions as the Brazilian mahogany, the species has been plantation grown for more than forty (40) years in the Republic of the Fiji Islands. Fiji Mahogany were originally planted as avenue trees but later converted by the Fiji Forestry

Department to be a reforestation species on logged-over native forest areas. Plantations now reach more than 40 000 hectares (ha). Regarded as being a luxury timber with a reputation as the most valuable commercial timber, mahogany has prompted the Fiji Government to establish the Fiji Hardwood Corporation Limited to manage all mahogany plantations and oversee the commercial undertakings of Fiji Mahogany.

The restrictions placed on the mahogany trade through the listing of the species on the Appendix II of the Convention on International Trade in Endangered Species (CITES) by most Southern American mahogany suppliers, has presented the Fiji Government with an opportunity to benefit immensely from the sale of Fiji Mahogany products. The harvesting of mahogany is now in its initial stage of operation. The Fiji Hardwood Corporation Limited in cooperation with the Fiji Mahogany Trust who is responsible for the welfare of landowners whose land is leased by Fiji Hardwood Corporation for mahogany plantations are involved in the harvesting operation. Before harvesting commenced, the actual value of Fiji Mahogany plantations is the subject of debate with conflicting monetary values put forward by various forest consultant companies. This has brought about a sense of uncertainty among the major mahogany stakeholders.

In reality, to attain the "true" value of the species is to formulate a marketing strategy on how to fully maximise the utilisation of Fiji Mahogany logs for value-added products, with a defined market for Fiji Hardwood Corporation Limited. Currently, sawn timber has been the sole major product from Fiji Mahogany. The Fiji Hardwood Corporation Limited ought to put more focus into producing value-added products such as moulding parts, furniture, flooring, decking, lining and slice veneer. Furthermore, mahogany residues can also be utilised for the production of electricity through combustion by generated steam turbines. Although the technology for down streaming processing of value-added products is to some extent lacking in Fiji at the moment, the Fiji Government, Fiji Forestry Department, Fiji Hardwood Corporation and the Fiji Mahogany Trust must work together to find ways for training of personnel, create a partnership of investment for capital funding, and assist in the purchasing and installation of value-added machinery. Emphasis must be placed on creativity in the nature of design for value-added machinery. Emphasis must be placed on creativity in the nature of design for value-added products that can compete with what is on offer on the current market. Only then can the full utilisation of mahogany logs from the first branch sawlog to the upper branch logs accomplish for the production of value-added products.

The mahogany markets in the United States of America have been recommended for the marketing of Fiji Mahogany value-added products. Although there are other mahogany markets around the world that the Fiji Hardwood Corporation Limited can choose from, the American market is more valuable for such mahogany products. First and foremost, the American market is currently the largest importer of mahogany products, contribution approximately US$60 million in revenues annually which is part of the US$13 billion in total timber imports for the whole country per year. This mahogany consumption simply implies the high demand of the species corresponding to a large population with a vast number of buyers spread out geographically, demographically and psychographically with variations in needs, tastes, specifics and demands. Hence, with an available mahogany resource of 40 000 ha it is simply not enough to satisfy the demands of the whole American market.

The second important criteria of the American market are that prices paid for mahogany products are quite high as compared to other mahogany importing countries. Hence, for Fiji Mahogany value-added products to achieve these price premiums is to implement an efficient market research that will focus on narrowing the market to target a niche which Fiji Mahogany can use to satisfy customer needs and maximise market profitably. It would seem logical to find an initial target niche market which is located within the state of California, the urban and metropolitan areas of the two major cities of Los Angeles (one of the 5 most populous cities in the United States of America) and Sacramento before diverting into the other states or Canada. Furthermore, the assistance of the Fiji Trade Commission based in Los Angeles and other Fiji Government representatives (Fiji Embassy, Honorary Consuls and Fiji Mission to the United Nations) having professional background knowledge of the United States

trading regulations, standards and mahogany traders on the American market, is an advantage in finding a suitable market for Fiji Mahogany value-added products.

Working in collaboration with the Fiji Trade Commission in Los Angeles will be a market representative appointed by Fiji Hardwood Corporation Limited to oversee the negotiations and market research on the marketing of Fiji Mahogany. Having an office in Los Angeles (may be within the Fiji Trade Commission) is vital; the major task of the marketing representative is to identify who are the end-users of the product, the type of mahogany products used by the end-users and the price premiums paid for such products. Information gathered by the marketing representative is relayed back to Fiji Hardwood Corporation Limited in Fiji, which will assist in the decision-making and approval for the manufacture of value-added products. The results of this market research are the most critical aspects for Fiji Hardwood Corporation Limited in determining the capabilities of Fiji Mahogany as a value-added product on the American market.

One of the marketing principles include the market positioning of Fiji Mahogany on the American market where it must have a competitive edge on other mahogany suppliers and distinguish itself in terms of high quality product, wood characteristics and wood properties to enhance its marketing abilities. The advantage of having a few similarities n physical characteristics and wood properties with naturally grown mahoganies from South American countries solidifies the image of Fiji Mahogany on the market. This would build up its reputation as to what it promises it can deliver for that specific need which strengthens customer relationships, builds-up customer trust, loyalty and influences customer confidence to trade on the species in the long term. It has to produce a value-added product that has an end-user and with its high demand strengthens the product's position on the market.

The detail formulation of a marketing mix (product, place, price and promotion) would allow Fiji Mahogany value-added products to portray the highest standard of quality to meet the American quality standards that would compete well and perhaps do better in terms of price than other mahogany suppliers in the same market. Value-added products from mahogany such as mouldings, furniture, decking and flooring are now attracting very high prices on the American market from antique dealers, DIY (Do It Yourself) stores, retailers and wholesalers. Hence, Fiji Mahogany must keep a competitive edge to ensure that it stays ahead of other competitors in terms of high quality products. The dwindling supply of mahogany world-wide and the increase in demand for the species product are now the main factors influencing the price hike.

Finding a customer (end-user) for direct trading within the state of California that offers the best possible price (same or better than prices paid to South American value-added products) would result in effective and efficient communication for produce confirmation, one-dealing negotiation would incur maximum premium price paid for the product, less inconsistency in produce paperwork clearance, specific arrangement of product distribution channels and logistics to reach the customer. The three sea ports of Los Angeles is the ideal distribution channel since the majority of the shipping lines from the Pacific rim use these ports for their cargo distribution. Again, the presence of the Fiji Trades Commission in Los Angeles is a huge benefit for effective communication in product marketing and assistance for any bureaucratic discrepancy that may arise from American customs or trade personnel on product clearance and distribution.

Promoting this criterion of high quality product through the internet, ales promotion expositions, media advertising or even presenting a sample of the product during market research will give potential customers a glimpse of the quality standards that Fiji Mahogany offers as a product. In addition, correct profiling, packaging and wrapping and labelling of the products is a necessity and an incentive for the promotion of Fiji Mahogany. The brand name itself should distinguish Fiji Mahogany from other mahogany producers indicating its origin and identity. The stamping of a certification logo on the wrapper will indicate to the importing authorities that the product comes from a sustainable forest, hence, confirming to CITES regulation for mahogany importation on the American market.

Fiji Mahogany is unique in that 50% of the estimated 40 000 ha plantations are planned for harvesting in the next five to ten years. It has taken more than forty years for the first mahogany to be harvested and without any form of forest certification and sustainable forest management, the effect on the fundamentals of the marketing principles for the marketing of Fiji Mahogany will be severely hampered. The main consequence of the above undertaking will fall heavily on the Fiji Government and Fiji Hardwood Corporation, where customer relationship, trust and confidence are severely affected. It is an expensive exercise to implement a market research, but the benefits in the long term for the marketability of Fiji Mahogany is quite enormous; it outweighs the cost of its implementation. However, the cost of breaking a customer relationship from not fulfilling customer needs due to lack of resource supply is the one critical issue that outweighs all the costs involved in the marketing of Fiji Mahogany. In other words, the customer has the option to choose another mahogany producer where it can get a continuous supply or an alternative product species. To re-negotiate with the customer or find a new customer (the non-supply issue is communicated around the customers quite easily), costs a lot more than the initial negotiation to get customer confidence and trust for trading. Forest certification is unavoidable in the current world mahogany trade markets. This is one criterion that is required under the United States of America mahogany trade import laws that Fiji Mahogany value-added product must be compliant with. Hence, without forest certification, direct dealing with customers on the American market would be impossible.

What does the future hold for Fiji Mahogany? Currently, the Fiji Government is focussing its attention on the marketing of Fiji Mahogany through Fiji Hardwood Corporation Limited for much needed revenue to boost the shrinking economy of Fiji after the December 6th 2007 military coup. The Government must show its credibility to all mahogany stakeholders and the people of Fiji and uphold the reputation of the species as a highly valuable commercial timber. This credibility must be founded on the implementation of a well-defined marketing strategy to ensure the species is marketed efficiently and effectively. To accomplish this, the Fiji Government and its subsidiary organizations, Fiji Hardwood Corporation, Fiji Mahogany Trust and the Fiji Forestry Department must devise a working framework that will be effective and responsible for the improvements of Fiji Mahogany from its current establishment to the marketing of its products.

This working framework would involve integrating the roles of the Fiji Forestry Department and Fiji Hardwood Corporation limited for the establishment of forest genetic research programs, finding alternative species to Fiji Mahogany that are commercially viable for quicker revenues and the establishment of down-streaming industry for value-added products. The long-term benefits of forest genetic research are quite enormous not only for Fiji Mahogany but for other potential forest commercial species. As for Fiji Mahogany, it provides a more in-depth knowledge for the establishment of tree breeding programs for superior trees that are disease resistant, has good wood quality attributes and growth form far more improved than the current trees. It is also an incentive to further improve the current forest research laboratories in terms of modern computerised equipment and advanced knowledge through training programs for research personnel.

The result of this integrating in responsibilities based on research will also inform the Fiji Government of an alternative species to Fiji Mahogany that would provide revenues in the medium term before mahoganies are mature. Since Fiji Mahogany takes more than 40 years to mature, it is an opportunity for the Fiji Mahogany Trust, other interested landowners or investors to implement the planting of species that take a lot quicker to mature and harvested for quick returns. Species such as Sandalwood, Teak, Eucalyptus and lesser-known Bamboo are now more established on the market with premium prices paid for its products. The critical factor to comprehend with these species is that it can be plantation grown quite easily in the Republic of Fiji Islands.

Production of value-added products requires modern machinery and expertise. Again the result of this integrating role allows the implementation of training programs on the different ways for producing value-added products. Having this knowledge would provide incentives for Fiji Mahogany Trust to

attract investors for the purpose of capital funding, machine installation, advance training in the production of value-added products and assist in the establishment of markets for these products. The potential benefit to Fiji Mahogany landowners in the long term will be quite enormous.

The organizational structure within Fiji Hardwood Corporation Limited must distinguish between the production and the marketing divisions. This is to ensure that there is a two-way definite line of communication on what value-added products recommended by the marketing division that are on demand which needs to produced for sales. On the other hand, information relayed back to the marketing division if the product desired cannot be produced for some unforeseen problems as lack of resources of equipment unavailability. It is vital that these two major divisions are given priority by the Fiji Hardwood Corporation Management to ensure Fiji Mahogany's reputation to supply and meet market demands.

Lastly, the way forward for Fiji Mahogany right now is to maximise its utilization. The Fiji Hardwood Corporation Limited must be given the opportunity to function as a commercial entity to the terms it was initially formalised in 1998 without political interference from the Fiji Government of the day, landowners and other mahogany stakeholders. The people of Fiji would like to see the reality in the value of Fiji Mahogany right now. After the past mistakes from its management, the time is "ripe" for the people of Fiji and future generations to enjoy the benefits of this valuable resource.

TITIULU, TERENCE (2009)

OPPORTUNITIES FOR PLANTATION FORESTRY AS AN ALTERNATIVE TO UNSUSTAINABLE COMMERCIAL LOGGING IN THE SOLOMON ISLANDS

Log exports remain the major foreign exchange earner for Solomon Islands, but the current level of harvest is unsustainable. Log exports from natural forests have been the major export earner for the Solomon Islands since 2000, currently accounting for over two thirds of total exports by value. The current harvest volume is estimated to be four times the sustainable rate. There remains a significant gap in understanding about alternatives for future development of the remaining natural forest and an enhanced plantation forest industry to assure a sustainable economic return from forestry in the future.

Small-scale processing may be competitive in domestic niche markets, but is unlikely to be competitive internationally. There are a number of plantations that have been successfully established on customary land with local community involvement. The support of, and leadership by, the local community has been critical in successful plantation establishment.
Current forest policies do not encourage sustainable management of forest resources. Current policies aimed at reducing natural forest harvesting and attaining sustainability does not offer alternative income-generating options for local landowners. Effective policies need to take account of the diversity in language, culture, geography, government interests and customary systems of land tenure. This study will propose solutions that are consistent with the principles of sustainability, and compatible with the existing customary land tenure system. The main objective of these policies should be to allow fundamental features of customary ownership to remain intact while allowing some new types of land use to occur.

The study approach uses both qualitative and quantitative methods of analysis using national level economic data and a review of literature to identify lessons from the experiences of other comparable Pacific countries faced with similar problems. Strategic analysis was used to identify options for creating a sustainable Solomon Island forestry sector. Plantation forestry was identified as the primary means of improving sustainability, with an assumption that customary land would form a major component of the land required for future forest industry development. The role of increased marketing effort and "value-added" manufacturing were also considered.

Reducing the merchantable volume for natural forest harvest from 60cm dbh so that the amount of wood flow available increases was considered. This will enable higher wood flow from natural forest and maturing plantations to cover the anticipated economic downfall gap. Customary land registration will give greater investment opportunities for large plantation establishment.

DPS price scheduled for quarterly changes occur only infrequently, and therefore may not reflect actual international price changes. It is recommended for that an alternative mechanism be in place to include CIF price changes considered for the DPS. Direct entry of local producers of sawn timber into the export niche markets will give producers opportunities to understand market requirements and maximize revenue.

WANG, DI (2018)

THE FORECAST OF CHINA'S DEMAND FOR SAWNWOOD, WOOD-BASED PANELS AND PAPER PRODUCTS

This study forecasts China's future demand for sawnwood, major wood-based panels and paper products. The drivers of demand are identified to establish the models for projection. The key variables that influence the consumption of sawnwood and wood-based panels are GDP, construction activities and furniture-making while GDP is also selected as the crucial predictor variable for the projection of paper products consumption. Based on the inspection of data, the linear model is established for the forecast of solid wood products and reconstituted wood panels consumption while a non-linear model is selected for the forecast of paper products consumption. The prediction for each product has been made till year 2030.

The analysis of historical data shows that China's demand for wood products is largely satisfied by domestic production. However, the lack of suitable forest resources in China results in a high dependence on the import of raw materials (e.g. logs and pulp) and primary wood products (e.g. sawnwood) to meet domestic processing requirements. The demand for wood-based panels has developed rapidly in China with a current consumption (m^3) far greater than that of sawnwood. The demand for sawnwood is primarily driven by construction activities in China, and is expected to grow to 230 million m^3 in 2030. The consumption of plywood and particle board is mostly driven by GDP, and is projected to reach 269 million m^3 and 55 million m^3, respectively. The consumption of MDF is significantly influenced by both construction activities and furniture-making, and is anticipated to increase to 118 million m^3, by 2030. For paper products, wrapping and packaging paper and paperboard has maintained its position as the principal paper products for long time. As China's economy grows, the consumption for printing and writing papers, household and sanitary papers, and wrapping and packaging paper and paperboard will increase to 20.4 t/000 capita, 8.8 t/000 capita, and 62.7 t/000 capita. The model selected in this research is not suitable for the prediction of newsprint consumption. Further work should focus on establishing a more appropriate model for the consumption of printing papers. The consumption of both of these products has been significantly affected by disruptive technological change, and the future impact of this change needs further investigation.

China still has a relatively low income per capita compared with developed countries. Although China's consumption per capita of sanitary and packaging paper products is growing very quickly, it still has a long way to go to reach the consumption level in developed countries.

WILLIAM, HEIDI (2018)
A CASE STUDY ON MOSAIC RESTORATION PLANTING IN SABAH, MALAYSIA

With the rapid decline of natural forests, the establishment of forest plantation estate is important to supply continuous resources to timber-based industries in perpetuity. Sabah, which is one of the thirteen states in Malaysia, had started establishing forest plantation since the 1970s. In recent years, given the importance of timber plantations, the scarcity of land, as well as addressing the adverse image of converting forests into Industrial Tree Plantation (ITP), a new system called mosaic restoration planting was introduced and later adopted by the State Government of Sabah. This is a system that combines planting of fast growing species and retention of natural forests in an area having either patches of good forests and degraded forests together, or sporadic forests, or mixed stands of both within the licensed areas. This approach is considered to be an alternative means to gain quicker economic returns to the State, through a common 60:40 ratio (ITP/NFM) management or conversely. In this approach, about 60% of the areas will be clear-cut for the planting of selected fast growing species, while the remaining 40% will be under the retention of natural forest patches, or vice versa, depending on the site condition.

The objective of the study is to compare the implementation of mosaic restoration planting on three (3) different sites in Sabah. A comparison between companies in terms of costs and benefits for 3 'what-ifs' scenarios, i.e. a combination of both (mosaic planting) versus 100% NFM versus 100% ITP was assessed through NPV analysis at 15% discount rate. The results showed that while all companies do not benefit from 100% NFM management at all, there was a clear distinction in terms of benefits when implementing mosaic planting or 100% ITP. The base case NPV for Empayar Kejora was RM 90.6 million (mosaic planting) and RM 170.8 million (100% ITP); RM 7.6 million (mosaic planting) and RM 8.1 million (ITP) for Maxland Sdn Bhd; and finally RM 28.2 million (mosaic planting) and RM 37.6 million (ITP) for KTS Plantation.

When the sensitivity analysis for log prices were performed, in all cases, even the increase of log prices by 86% failed to lift the NPV for NFM management to a positive state for all companies. However, all companies enjoyed a significant increase in NPV for mosaic planting and ITP when the log prices increase. It was observed that Maxland and KTS Plantation were more vulnerable to the log prices change, whereby Maxland will suffer a negative NPV of – RM2.6 million if the log prices reduced by 86% when implementing 100% ITP, while KTS will suffer similar fate when implementing mosaic planting with –RM 3.2 million following massive price drop.

The sensitivity analysis on timber yield was performed at +10%, +20%, -10% and - 20%. The results showed that despite the 20% increase in timber yield, every company still do not benefit from 100% NFM, with negative NPVs ranging from – RM27 million (Empayar Kejora); – RM3.5 million (Maxland), to –RM 99.8 million (KTS Plantation). However, with the increase from timber yield, 100% ITP performed better than mosaic planting for every company. For instance, Empayar Kejora experienced 81% increase in NPV for implementing 100% ITP as compared to mosaic planting when the timber yield increased by 20%. This pattern was also observed in Maxland with 74% increase in NPV for implementing 100% ITP as compared to mosaic planting, and 22% in the case of KTS Plantation in the same condition. This trend was expected, given that 100% ITP has more areas allocated for tree plantation than mosaic planting. The sensitivity analysis also revealed that a reduction of timber yield by 20% will not put any company in an unprofitable position, if they chose to implement either mosaic planting or 100% ITP.

Both sensitivity analysis suggested that log prices had a bigger effect on the NPV of these companies than timber yield, and the viability of 100% NFM is highly dependent on the condition of the forests prior to plantation establishment.

In conclusion, based on the initial NPV assessments and sensitivity analysis on log prices and yield, 100% ITP yield better outcomes than mosaic planting. It was also found that while the feasibility of 100% NFM is highly dependent on the condition of the forests, mosaic planting can be designed in such a way that protects a proportion of the forest remnants while still making profits, which is better than the image commonly associated with ITP.

Therefore, mosaic planting should be considered as an alternative to move away from traditional ITP in future since this regime show potential in managing forest resources in a sustainable manner, while also sustaining the business of the forest companies.

XIAN, ZHUO (WENDY) (2009)
THE CURRENT SITUATION OF FURNITURE MARKET IN SHANGHAI AND BEIJING

This study was focus on the current situation of Chinese furniture and interior decoration material market. Observation and in-depth interviews were chosen as main research methods to collect the first hand information and data. Beijing and Shanghai were the objectives of this study, and several furniture and decoration material retail stores were visited. 11 experienced sales staffs were picked up from these stores as the responders to undertake the respondent-interviews. Guanrong Xu, the secretary-general of Shanghai Furniture Association and Liying Ma, the section chief of Beijing Furniture Association were interviewed for the informant-interview.

Based on the information gathered from these research methods, it seems there is a big potential market for New Zealand high value products in DIY home improvement materials market and high grade furniture market. Several marketing strategies were discussed in this report.

MSc (Environmental Science or Biological Science) Thesis Abstracts

Bloor, Marcus (2009) (ENVR)
Review of current vegetation monitoring on privately protected land under ongoing economic use (grazing)

There has been a noticeable shift in focus in biodiversity research in New Zealand over recent decades. Research has traditionally focused on biodiversity protection on the public estate, which was comprised primarily of ecosystems with lower productive potential (generally over 500m asl). Private lands generally have higher production potential and are often used for intensive cultivation and agricultural practices. They still however have significant potential for protecting biodiversity values. One of the key tools for protecting biodiversity values on privately owned lands in the Canterbury region are through legally binding QEII open space covenants and there is significant potential through industry certifications.

QEII covenants are placed on the land in perpetuity and provide legally binding protection for biodiversity or landscape values within the covenant. This protection is voluntary and allows the land owner to continue to use the land for economic benefit providing it does not prove detrimental to biodiversity through monitoring outcomes. Case studies of QEII covenants that contain grazing clauses in the Canterbury region were used to determine what values are present and what monitoring is occurring in the field within these ecosystems. Photopoints and informal visual monitoring were the primary methods used by the QEII representatives to monitor vegetation in all of the covenants.

Monitoring forms a critical feedback for all biodiversity protection. It is especially important to have an accurate feedback on vegetation condition and change from monitoring on properties that are grazed. Monitoring needs to be capable of providing sufficient information on vegetation change on these sites so that the most suitable grazing levels can be obtained by land managers. This thesis focuses on monitoring methods to ensure that this feedback is suitable and that the methods are cost effective.

Current vegetation monitoring techniques were reviewed to determine which methods would be most suited to monitoring in these ecosystems where resources are tightly restricted and observers may not have existing skills and experience in monitoring these ecosystems. Methods reviewed were quadrats, transects, height-frequencies, photopoints, needle point, biomass, tagged plants, visual rank and remote sensing. Each method is described and then assessed on its suitability for monitoring tussock shrublands, with cost effectiveness being an important criterion. Of these methods quadrats, transects and height-frequencies were the most robust but also the most intensive and least cost effective methods. Visual rank, needle point and photopoints were the most cost effective, but are generally suited to monitoring single objectives. In most cases a combination of methods would be ideal to suit the objectives of the monitoring. QEII photopoint monitoring should follow guidelines more closely and include more complimentary information with their photographs. Clear monitoring objectives should be developed for every covenant that is grazed and these need to be determined before it is possible to accurately select appropriate monitoring methods. These objectives will also provide the monitoring program with more structure and direction. If possible a detailed management plan for each grazed covenant would be beneficial for values present. QEII are in a unique position, where they have the potential to develop a database of biodiversity information for private land and contribute to other projects like the National Vegetation Survey (NVS).

DICKINSON, YVETTE L. (2008) (ENVR)

THE SPATIAL PATTERNING OF *HIERACIUM PILOSELLA* INVADED SHORT TUSSOCK GRASSLANDS

Hieracium pilosella is an invasive weed of New Zealand's short tussock grasslands. Since the 1960s, the abundance of *I. pilosella* has dramatically increased; it is now thought to occur in 6 million hectares of New Zealand (Espie, 2001), predominantly in grasslands. It is at least common in 42% of this area (Espie, 2001).

Ecology is inherently spatial and as plants closely interact with their direct neighbours, the spatial arrangement of plants is vital to their functioning. A handful of recently published articles have implicated spatial structure of plant communities in theories of plant competition, resource use and the invasion of plant communities. The aims of this thesis were to: 1) determine if there are consistent spatial patterns in New Zealand's short tussock grasslands at relatively small scales (i.e. spatial relationships between individuals); 2) investigate how the invasion of *H. pilosella* may be altering these spatial patterns; and 3) establish if the spatial patterns of species, life-forms and root systems are being altered in different ways.

Spatial patterns of both tussock and inter-tussock species, life-forms and root functional groups were evaluated at a range of short tussock grassland sites across a gradient of *H. pilosella* invasion levels in Canterbury, suing both join-count statistics and Ripley's K-function. A classification system for the root functional groups of vascular species in these communities was developed and applied. It was found that species, life-forms and root functional groups in short tussock grasslands had generally consistent spatial patterns across sites both within and between species. These patterns were variable between significantly different levels of *H. pilosella* ground cover. The type of spatial pattern exhibited, and the way it was altered differed between species, life-form and root functional groups. For example, tussocks exhibited increased regularity up to scale of 160 cm and increasing aggregation at scales up to 500 cm, with increases in *H. pilosella* abundance. In contrast, both *Agrostis capillaris* and herbaceous chamaephytes had increased aggregation across scales up to 160 cm. These differences in spatial patterns along the gradient of invasion are a strong indication that *H. pilosella* is structurally fragmenting New Zealand's short tussock grasslands. This fragmentation is likely to have far reaching effects including the disturbance of invertebrate communities and the disruption of ecosystem services including pollination, vegetation regeneration, and nutrient cycling.

DIJKSTRA, STEPHANIE (2020) (BIOL)

INVESTIGATING THE MECHANISMS OF THE FORMATION OF SPIRAL GRAIN AND INTERLOCKED GRAIN IN WOOD

Spiral grain is the deviation of grain angle away from the stem axis, where the grain forms a helical array around the pith. In radiata pine, trees are initially straight- grained but develop a left-handed twist in the first year of growth that increases in severity in the several subsequent growth rings until reaching a maximum angle that is often above 5° from vertical. After this, grain angles slowly decrease and sometimes shift to right-handed (Cown et al., 1991; Harris, 1989). Most northern hemisphere gymnosperms follow this pattern in which grain is initially left-handed (Harris, 1989), and they retain this left-to-right pattern when grown in the southern hemisphere suggesting that spiral grain formation is under genetic control. Genetic control of grain direction is also supported by the partial heritability of grain angle severity in radiata pine (Gapare et al., 2007).Suggestions have, however, been made that southern hemisphere gymnosperms develop an initially right-handed twist before shifting back towards the left (Edwards et al., 2007; Kubler, 1991; Ohkura, 1958), although these suggestions are based on observation of only two Australian species, and none that are indigenous to New Zealand. It has been further suggested that any difference in spiralling direction between trees originating in

different hemispheres might be caused by an interaction between predominant wind directions, and growth of the young trees towards the sun (Gapare et al., 2007).

While serial sectioning approaches are traditionally used to observe cell development, they are time consuming in both technique and data analysis and can generally only be applied to smaller samples. Additionally, 3D reconstructions can be confounded by section distortion, misalignment or tearing, severely reducing the accuracy of the model generated. A novel method for measuring grain in whole stems of young trees that utilises X-ray microtomography (μCT) has been developed. This technique allows whole stem sections of young trees to be imaged and reconstructed, thereby allowing *in-situ* tracheid angle measurements. Using this technique, several northern hemisphere species grown in New Zealand were analysed and no changes were observed in the grain patterns from the change in hemisphere suggesting that spiral grain is under strong genetic control. Additionally, the analysis of southern hemisphere gymnosperms with this technique demonstrated that the left-handed to right-handed pattern is common among all coniferous species regardless of hemisphere.

GLOGOSKI, DAVID (2017) (BIOL)

VEGETATION RECOVERY FOLLOWING THE 2015 FLOCK HILL FIRE, CANTERBURY HIGH COUNTRY

This study presents the results of the investigation into the vegetation recovery following the 2015 fire at Flock Hill Station.

In 2015 a large fire burnt an area of approximately 300 hectares at Flock Hill Station. This area was largely dominated by the invasive wilding conifer *Pinus contorta* and exotic pasture grasses such as *Agrostis capillaris* and *Anthoxanthum odoratum*. The fires also burnt areas of native shrubland, consisting largely of *Leptospermum scoparium* and *Discaria toumatou*, and mountain beech forest (*Fuscospora cliffortioides*).

The strongest post-fire recovery was shown by exotic pasture grasses and herbaceous weeds. The native vegetation showed very little recovery following the fire. *Discaria toumatou* was the only native woody species to show an ability to re-sprout following fire whilst *Viola cunninghamii* and *Wahlenbergia albmarginata* showed the highest levels of recovery of native herbaceous species.

Pinus contorta showed very little ability to recover following the fire. *Pinus contorta* showed very little germination after the fire and tests carried out on seeds extracted from burnt cones showed very low viability.

This research could have important implications for future wilding pine control and also for the management of native vegetation in the Canterbury high country as the risk of fire increases in this area with climate change.

HU, QINGLIN (2006) (ENVR)

TEMPORAL VARIATION AND INTER-RELATIONSHIP OF MOVEMENT AND RESOURCE SELECTION OF RED DEER (*CERVUS ELAPHUS*) WITH RESPECT TO CLIMATE: A CASE STUDY

Red deer (*Cervus elaphus*) is one of at least 31 herbivorous exotic mammals existing in New Zealand. All of these species have the potential to affect environmental and production values. Reducing their impacts on their values, strengthening effective managements are important issues to a variety of agencies within New Zealand including the Department of Conservation (DOC), Ministry of Agriculture and Forestry (MAF), local and regional governments.

This research studied animal movement pattern and habitat use of 2 GPS-collared red deer in the Canterbury high country and found (1) deer movement was affected by climatic variables such as rainfall and temperature, which had positive or negative effect on it, and had seasonal variation; (2) deer had dominant landcover use categories, depending on climate, season, and individual characteristics; and (3) deer had different movement patterns in terms of hourly distances.

The purpose of the study is to draw accurate inferences from spatially explicit data for biosecurity managers and policy-makers through: (1) using global positioning system (GPS) as a tool to elucidate the application of GPS on red deer in wildlife management; (2) animal movement analysis Arc View® 3.2 Extension under Arc View® Geographic Information System (GIS); and (3) animal movement analysis which used Generalized Additive Models (GAMs) to show how the movement of red deer was affected by different periods of time, seasons, months and climatic variables (for example, rainfall and temperature).

LAGERSTEDT, M. AMY (2007)
DIDYMOSPHENIA GEMINATA; AN EXAMPLE OF A BIOSECURITY LEAK IN NEW ZEALAND

Didymosphenia geminata is a diatom that has been accidentally introduced to New Zealand's South Island rivers. It has grown to bloom conditions in all rivers it inhabits, which ha caused impacts to the river systems, loss in recreation value, and economic losses. The pathways and vectors of dispersal are difficult to control and hence it continues to spread throughout the South Island. Laboratory experiments assessed the survivability of *D. geminata* in different environmental conditions, a range of combinations of light availability, temperature and moisture. Experiments in the field were based in the Waitaki River to determine growth rates of *D. geminata*.

D. geminata is growing in a greater range of temperature and light conditions than previously recognised. In cool to cold conditions with a little water this diatom can survive up to 1500h, the colder temperatures also increase survivability in the dark. However, *D. geminata* has reduced survivability in warm, damp conditions, up to 60h. In the Waitaki River *D. geminata* is attaining biomass of 2.51mg mm^{-2} over six weeks during summer. This high biomass is causing a change in biotic and abiotic conditions. Longevity of survival and the range of conditions in which it can survive increases the risk of spread throughout New Zealand and the world.

There are considerable problems with invasive species and international trade. Policies aiming to reduce international invasions due to trade are becoming more prevalent as the consequences of invasion are more obvious and costly. New Zealand has been able to implement policies in the last decade that has reduced the number and variety of incursions. However these policies did not stop *D. geminata* arriving. This shows that even with the best policies species can invade fragile ecosystems. Central and local government policies surrounding management of invasive aquatic species were reviewed. Central and local government policies were developed to reduce the spread of *D. geminata*, however they are not effective as the diatom is still dispersing. Further research is required to elucidate means of dispersal in New Zealand, in particular the importance of dispersal by animals compared with that by humans, and the importance of continuing international dispersal.

SKURUPEY, JAMES (2012) (ENVR)
A SENSITIVITY A NALYSIS OF UNCERTAINTY IN THE SPATIAL RESOLUTION OF THE UNDERLYING DATA USED FOR ESTIMATING SOIL EROSION SUSCEPTIBILITY IN NEW ZEALAND

This study investigates the effect of changes in map scale on the error in the development of areal map units and their associated erosion severity measurements of New Zealand's (NZ) Land Use Capability (LUC) surveying system. A map scale of 1:50,000 was used in the underlying data (i.e., a LUC survey)

of an Erosion Susceptibility Classification (ESC) system, which was developed by Bloomberg and others (2011) of the University of Canterbury for the Ministry for the Environment's (MFE) 2010 proposed National Environmental Standard for Plantation Forestry. The ESC was intended for local erosion management decisions, yet most literature would classify the map scale of 1:50,000 as more appropriate for regional management issues. Thus, this study will test two finer 1:10,000 scale datasets against the current 1:50,000 national LUC areal map units and their erosion severity measurements of the underlying data for the ESC system, to quantify the level of agreement.

This study first attempted to identify a unique discriminating parameter of high erosion severity. A case study was conducted in the Sherry River catchment, located in the Tasman District of the South Island, NZ. The Sherry River Case Study had two aims; the first was to investigate the correlation between the Melton ratio and LUC erosion severity. This was accomplished by calculating the Melton ratio, a tested morphometric factor that describes basin (watershed) ruggedness, using Irvine's (2011) Geographic Information Systems (GIS) debris- flow model. The product of this GIS debris-flow model, a calculated Melton ratio ≥ 0.50 with the areal extent outlined by a River Environment Classification (REC) order one polygon, were designated the areas of interest (AOIs). The Melton ratio was then tested against LUC erosion severity using the Spearman's Ranked Correlation Coefficient, within the designated AOIs. A field investigation was conducted to verify debris-flow in GIS identified AOIs. Only five of the thirteen AOIs identified showed evidence of debris-flow. Two were un-checked due to accessibility and the others had a high degree of fluvial activity, which indicates a high probability that surface evidence of alluvial erosion deposition was erased. Nominal association between the two measurements of erosion (Melton ratio and LUC erosion severity) was found at the map scales of 1:50,000 or 1:10,000. Therefore the Melton ratio was not recommended as an independent parameter of erosion severity.

The second aim of the Sherry River Catchment study was to assess the sensitivity of empirically generalised LUC areal map units and their erosion severity measurements to spatial resolution, that is, what is the effect of agreement between the smallest measurable value when looking at LUC map units and their erosion severity measurements recorded at two different map scales. A hard classification accuracy assessment was chosen to accomplish this objective. An accuracy assessment is a statistical model, which provides a probability of error (uncertainty), in essence a goodness-of-fit measurement, and quantified the agreement between a sample and reference dataset. This was accomplished by the calculation of an Overall accuracy (i.e., overall thematic agreement), Producer's accuracy, and a User's accuracy analytical statistics. The Producer's accuracy refers to the probability that an area of sampled erosion severity category in the sample map is classified as such according to the reference map, while the user's accuracy refers to the probability that a point labelled as a certain erosion severity in the sample map has that severity rating in reality (i.e., according to the reference map). An accuracy assessment also includes a second goodness-of-fit test, the Kappa statistic (K), which measures the agreement between the sample and references map as well as chance agreement. An accuracy assessment of the AOIs within the Sherry Catchment Study area using an 85% significance criterion was conducted. This accuracy assessment investigated a sample LUC survey measured at the map scale of 1:10,000, as compared to the referenced underlying data of the ESC (1:50,000 map scale). Overall accuracy was marginal (69%) with equally marginal levels of Producer's and User's accuracy. The Kappa statistic showed a marginal level of significance according to Landis and Koch (1977) (K = 44%). The disagreement seen between the two LUC surveys, which were empirically developed using different map scales, provides evidence of high spatial resolution sensitivity, when comparing areal map units and erosion severity measurements.

To further investigate evidence of spatial resolution sensitivity in LUC surveying, a second case study was conducted using a LUC survey across a broad geographical area of the Manawatu-Wanganui Region of the North Island, NZ. A sample dataset from the LUC survey, empirically generalised at 1:10,000 map scale by the Horizons Regional Council, was compared to the referenced underlying data of the ESC. There was a moderately-strong consistency found between the assessors of each LUC survey using Spearman's Ranked Correlation Coefficient. This provides evidence of limited surveyor

bias, as each map was made using empirical judgment. The accuracy assessment's overall agreement was 63% and as for the previous case study, had equally low Producer's and User's accuracy levels. The Kappa statistic for this case study was K = 46%, a moderate chance agreement. This evidence, along with the evidence provided by the Sherry River Catchment Case study, suggested that the MFE's ESC system is sensitive to changes in map scale and that any decision based on it will have different results when its underlying data is produced at different spatial resolutions. It is therefore recommended that MFE reassess the map scales and resolutions of its underlying data, given that the ESC's purpose is for local level environmental management, before imposing the system as a regulatory requirement in the National Environmental Standards for Plantation Forestry.

SQUIRES (NÉE WOOD), CAROLYN (2007) (ENVR)
AN ASSESSMENT OF TRAMPLING IMPACT ON ALPINE VEGETATION, FIORDLAND AND MOUNT ASPIRING NATIONAL PARKS, NEW ZEALAND

The objectives of this study were two-fold. The first was to quantify the nature and extent of current levels of human impact in alpine areas at four sites within Fiordland and Mount Aspiring National Parks along walking tracks at Key Summit, Gertrude Saddle, Borland Saddle and Sugarloaf Pass. In order to do so, a survey was carried out with transects placed perpendicular to the track, and distributed among different vegetation types. In each transect, plant structural and compositional aspects, and soil and environmental parameters were measured. Transects were divided into track, transition, undisturbed and control zones, and changes to dependent variables were compared with distance from the track centre. Damage from visitor impact was largely restricted to within 1m from the track centre. The most significant impacts were to structural aspects of plant and soil properties with significant reductions in plant height, total vegetation cover and bryophyte cover, and increases in bareground and erosion on tracks. Erosion was more prevalent on slopes greater than 25°, while tracks on peat soils contained greater bareground exposure, particularly of organic soil.

The second study objective was to investigate the relationship between specific levels of impact and the resulting damage to two key alpine vegetation types, tussock herbfield and cushion bog. This was undertaken by carrying out controlled trampling experiments, measuring changes to plant structural and compositional aspects four weeks and one year after treatment. Both vegetation types saw dramatic reductions in total vegetation cover and height immediately after trampling, however overall composition and species richness varied little. These two alpine vegetation types showed moderate-low resistance to initial impact and low resilience, with very little recovery evident one year later.

Research into these two areas is important for managing visitor use within alpine areas in order to meet conservation and recreation goals. The survey indicates that alpine community types are very sensitive to visitor use, showing significant structural damage, however the spatial extent of impact is limited within the broader landscape. Instead, visitor impacts associated with tracks are likely to be more visually and aesthetically significant, influencing the visitor experience. The trampling experiments indicate that use levels over 25-75 passes per year within tussock herbfield and cushion bog vegetation on peat soils will result in ongoing damage to previously undisturbed sites. Methods for minimising impacts include limiting visitor numbers, public education in low impact practices, redirection of tracks and use to areas that are less sensitive, the dispersal of visitor activity at very low use intensities (less than 75 direct passes per year) and the concentration of activity on tracks above this level.

STEER, ZUNI (MARGARET) (2012) (ENVR)
MERINO SHEEP HABITAT USE IN CANTERBURY HIGH COUNTRY TALL TUSSOCK GRASSLANDS

1. The goals of this thesis were to determine whether Merino sheep use habitat at random. Specifically, this research was undertaken to identify areas of intensive use, determine daily

activity patterns, explore habitat use between activities, between sheep, define home ranges and to explore the influence of weather on habitat use.

2. Sixteen Merino ewes were monitored using GPS collars recording locations every 15 minutes. A weather station was set up at 1380 m a.s.l. to record weather variables at the study site.
3. Merino ewes do not select and utilise habitat in proportion to its availability. Short tussock grassland was preferentially selected for despite having a low occurrence. Overall, ewes selected habitat that was within 400 metres of a water source, on slopes less than 30° and preferred easterly habitat.
4. Merino ewes utilised different habitat for different activities. The day was divided into grazing, resting and night camping, as determined from hourly movement, backed up by 10 days of visual observations. Grazing occurred mostly on flat to low slopes in short tussock grassland. Resting occurred mostly on the riverbed or on surrounding short tussock grassland. Night camping occurred at higher altitudes (~ 100 m higher) than the resting sites and was on steeper slopes, partly due to the U-shaped nature of the valley. Night camping occurred in tall tussock grassland and native mix habitat. Several night camps were used while a smaller number of grazing sites were used.
5. Sheep differed in their individual habitat use. Two sheep were explorers, one crossing the river to occupy adjacent land, and one sheep moved out of the original study area, passing through a narrow rocky gap. Some sheep stayed close to the main mobs, while others spread out in small groups.
6. Home ranges were affected by the presence of large mobs; those sheep in the main mob had smaller home ranges than those in smaller groups. Home ranges were also smaller in areas of higher quality forage.
7. Weather variables did affect sheep habitat use with rain having the most influence. One cold, wet, windy day resulted in sheep being less active while occupying the middle of the fan, so displayed a preference for grazing and resting at higher altitude than normal. Temperatures and wind had little effect on sheep habitat use.

ZHAO, HAOTIAN (JOE) (2018)
MONITORING LAND COVER CHANGE WITH LIDAR AND AERIAL IMAGERY IN CHRISTCHURCH, NEW ZEALAND

Land cover change information in urban areas supports decision makers in dealing with public policy planning and resource management. Remote sensing has been demonstrated as an efficient and accurate way to monitor land cover change over large extents. The Canterbury Earthquake Sequence (CES) caused massive damage in Christchurch, New Zealand and resulted in significant land cover change over a short time period. This study combined two types of remote sensing data, aerial imagery (RGB) and LiDAR, as the basis for quantifying land cover change in Christchurch between 2011 – 2015, a period corresponding to the five years immediately following the 22 February 2011 earthquake, which was part of the CES.

An object based image analysis (OBIA) approach was adopted to classify the aerial imagery and LiDAR data into seven land cover types (bare land, building, grass, shadow, tree and water). The OBIA approach consisted of two steps, image segmentation and object classification. For the first step, this study used multi-level segmentation to better segment objects. For the second step, the random forest (RF) classifier was used to assign a land cover type to each object defined by the segmentation.

Overall classification accuracies for 2011 and 2015 were 94.0% and 94.32%, respectively. Based on the classification result, land cover changes between 2011 and 2015 were then analysed. Significant increases were found in road and tree cover, while the land cover types that decreased were bare land, grass, roof, water. To better understand the reasons for those changes, land cover transitions were calculated. Canopy growth, seasonal differences and forest plantation establishment were the main reasons for tree cover increase. Redevelopment after the earthquake was the main reason for road area growth. By comparing the spatial distribution of these transitions, this study also identified Halswell and Wigram as the fastest developing suburbs in Christchurch. These results provided quantitative information for the effects of CES, with respect to land cover change. They allow for a better understanding for the current land cover status of Christchurch.

Among those land cover changes, the significant increase in tree cover aroused particularly interest as urban forests benefit citizens via ecosystem services, including health, social, economic, and environmental benefits. Therefore, this study firstly calculated the percentages of tree cover in Christchurch's fifteen wards in order to provide a general idea of tree cover change in the city extent. Following this, an automatic individual tree detection and crown delineation (ITCD) was undertaken to determine the feasibility of automated tree counting. The accuracies of the proposed approach ranged between 56.47% and 92.11% in thirty different sample plots, with an overall accuracy of 75.60%. Such varied accuracies were later found to be caused by the fixed tree detection window size and misclassifications from the land cover classification that affected the boundary of the CHM. Due to the large variability in accuracy, tree counting was not undertaken city-wide for both time periods. However, directions for further study for ITCD in Christchurch could be exploring ITCD approaches with variable window size or optimizing the classification approach to focus more on producing highly accurate CHMs.