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Preliminary Alternative Species PSP Review

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Executive summary

The efficacy of growth and productivity models rely on abundant and geographically well-distributed data. Scion has produced productivity surfaces for a range of exotic species, including *Pinus radiata*, *Sequoia sempervirens* (coast redwood), *Cupressus lusitanica*, and *Cupressus macrocarpa*. However, while 300 Index for *P. radiata* was derived from a model of 3,676 permanent sample plots (PSPs), productivity surfaces pertaining to *S. sempervirens*, *C. lusitanica*, and *C. macrocarpa* were derived from far smaller datasets of 130, 156, and 134 PSPs, respectively. In order to validate productivity estimates in areas of high and low predictions, and climatic extremities, additional plots of these underrepresented species need to be established. These models would help forest growers choose the right site for the best species based on more robust estimations of site quality. This report reviews the existing PSPs for three species: *S. sempervirens*, *C. lusitanica*, and *C. macrocarpa*, and suggests areas of New Zealand to prioritise, with the objective of improving new and existing models.

The problem

The objective was to review PSP data/plots available for 3 alternative species: *Sequoia sempervirens*, *Cupressus macrocarpa* and *Cupressus lusitanica.* The specific objectives were to identify opportunities to add plots in regions/age classes and plots where remeasurements would support/improve growth models and or productivity surfaces.

Introduction

Scion's Permanent Sample Plots (PSPs) are permanently established areas of forest that are periodically maintained and remeasured (Dean, 2000; Pilaar and Dunlop, 1989). These sample plots provide invaluable information about the growth of forests, as well as the effects of silvicultural practices and abiotic factors, such as climate, on forest state (Dean, 2000). PSPs are typically established in parts of an existing stand where conditions are approximately representative of the stand as a whole (Ellis and Hayes, 1994). Sample plots contain a minimum of 20 trees per plot, and the diameter at breast height (DBH) and height are measured for at least 12 trees. Other observations are also noted, such as felled trees, dead trees, or trees afflicted with disease. The data acquired from PSPs have been used for a range of purposes, such as monitoring stand productivity, determining optimal silvicultural practices, and for the development of growth, yield and productivity models.

Scion has installed 36,396 PSPs across Aotearoa New Zealand within 156 exotic and native species. Scion's extensive national PSP database has been used to develop a wide range of growth, productivity, and carbon surfaces for different species throughout New Zealand (Table 1). Growth models have been developed for *Eucalyptus bosistoana* (Salekin et al., 2021), *Eucalyptus fastigata (*Meason et al., 2011), *Eucalyptus globoidea* (Salekin et al., 2021), *Eucalyptus nitens* (Candy, 2003), *Eucalyptus regnans* (MacLean and van Zyl, 1997), *Sequoia sempervirens* – coast redwood (Kimberley and Watt, 2021), *Pseudotsuga menziesii* – douglas fir (Knowles and Hansen, 2004), *Cupressus lusitanica* (Kimberley and Watt, 2023), and *Cupressus macrocarpa* (Kimberley and Watt, 2023). Important tree metrics, such as DBH, have also been modelled for less commonly planted species, including *Eucalyptus nitens*, *Podocarpus totara* – totara, *Leptospermum scoparium* – manuka, *Sequoia sempervirens*, and *Cupressus spp.* (Lin et al., 2023). Additionally, national-scale productivity (300 index and Site index) and carbon surfaces have been produced for *Pinus radiata* – radiata pine (Watt et al., 2021a; Watt and Kimberley, 2022), *Sequoia sempervirens* (Watt et al., 2021b; Watt and Kimberley, 2022), *Cupressus lusitanica* (Watt et al., 2023), and *Cupressus macrocarpa* (Watt et al., 2023).

Table 1: Growth models and surfaces describing spatial variation in productivity produced for exotic plantation species in New Zealand.

Species	Model/Surface type	Reference
Cupressus lusitanica	Growth	Berrill, 2004; Kimberley & Watt, 2023
Cupressus lusitanica	Productivity	Watt et al., 2023
Cupressus macrocarpa	Growth	Berrill, 2004; Kimberley & Watt, 2023
Cupressus macrocarpa	Productivity	Watt et al., 2023
Eucalyptus bosistoana	Growth	Salekin et al., 2021
Eucalyptus fastigata	Growth	Berrill & Hay, 2005; Meason et al., 2011; van der Colff & Kimberley, 2005
Eucalyptus globoidea	Growth	Salekin et al., 2020; Salekin et al., 2021
Eucalyptus nitens	Growth	Candy, 1997; Candy, 2003
Eucalyptus regnans	Growth	Hayward 1987; MacLean & van Zyl, 1997
Pinus radiata	Growth	Kimberley et al., 2005
Pinus radiata	Productivity	Palmer et al., 2009; Watt et al., 2021a; Watt & Kimberley, 2022
Pseudotsuga menziesii	Growth	Knowles & Hansen 2004; Lee 1998; Xu, 1990
Pseudotsuga menziesii	Productivity	Meason et al., 2018
Sequoia sempervirens	Growth	Kimberley & Watt, 2021
Sequoia sempervirens	Productivity	Palmer et al., 2012; Watt et al., 2021b; Watt & Kimberley, 2022

Productivity surfaces of Site Index and 300 Index for *P. radiata* have been developed from 3,676 plots (Watt et al., 2021a) which have an extensive geographic distribution. Comparatively, while also reasonably distributed throughout the country, surfaces for 300 Index, Site Index, and carbon were developed for *S. sempervirens* using growth data from only 130 plots (Watt et al., 2021b; Watt and Kimberley, 2022). Moreover, modelling productivity and carbon for *C. lusitanica* and *C. macrocarpa* used 156 and 134 plots, respectively (Watt et al., 2023). While plots covered a wide range of environmental variables further data collection would improve the confidence in these models.

Additional plots for these species should be installed in areas without plots where growth predictions are high or low, and in areas of environmental extremities to ensure complete coverage across climatic ranges, which not only improves predictions under current climate but will greatly assist when making predictions under climate change. Plots of improved genotypes could also be established to understand whether resistance to various diseases could also influence species productivity.

Current spatial distribution of plots

The distribution of PSPs for *Cupressus lusitanica, Cupressus macrocarpa*, and *Sequoia sempervirens* are shown in Figure 1. The PSPs for all species have a wide geographic distribution, particularly in the North Island of New Zealand. The latitudinal range of *C. lusitanica* extends from 43.6°S in the south to 35°S in the north, and longitudinally from 178.3°E in the east to 170.5°E in the west. Plots of *C. macrocarpa* extend latitudinally from 46.2°S in the south to 34.8°S in the north, and longitudinally from 177.9°E in the east to 167.7°E in the west. The southernmost PSP for *S. sempervirens* is located at 46.2°S and most northerly at 35.1°S. Plots for this species extend longitudinally from 178.3°E in the east to 168.7°E in the west.

While the PSPs for these species extend across a wide geographic range and cover various environmental variables, none of the species are found in all the regional districts of New Zealand. The Waikato, Gisborne, Canterbury, Otago and Bay of Plenty were regions with the most abundant PSPs. However, there are no PSPs for any of the three species in the Marlborough or Nelson regions, and only five plots containing *C. lusitanica* are found in Tasman (Fig. 1).

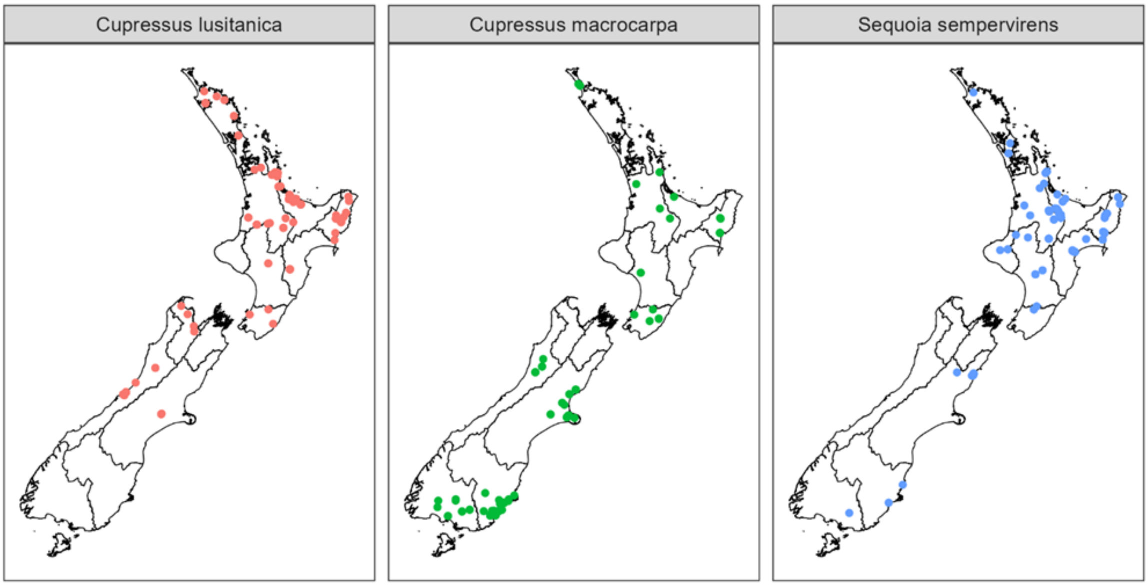

Figure 1: Maps of New Zealand, including the regional districts, showing the current spatial distribution of PSPs for *Cupressus lusitanica*, *Cupressus macrocarpa*, and *Sequoia sempervirens.*

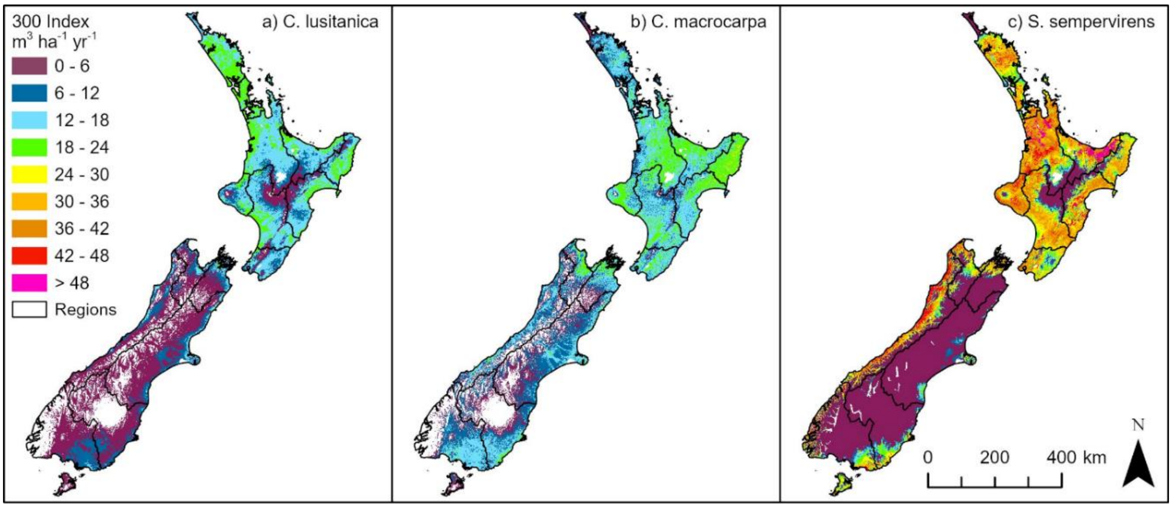

Figure 2: Spatial variation in 300 Index for a) *Cupressus lusitanica*, b) *Cupressus macrocarpa*, and c) *Sequoia sempervirens*.

Permanent sample plot data for *S. sempervirens* has the largest geographical range in the North Island, occupying every region. However, plots containing this species span a very limited geographical area in the South Island, being found only in Canterbury, Otago and Southland, with 76% of South Island PSPs located in Canterbury alone (Table 2). Approximately 75% of PSPs containing *C. macrocarpa* are located in the South Island (Fig. 1). PSPs containing *C. macrocarpa* are reasonably well distributed in the North Island, however, are missing throughout Auckland, Hawkes Bay and Taranaki, and only one plot is found in Bay of Plenty (Fig. 1; Table 2).

Table 2: Number of PSPs for Cupressus lusitanica, Cupressus macrocarpa, and Sequoia sempervirens per region in New Zealand. Cells that are coloured orange denote regions without PSPs.

	Number of PSPs			
Region	*C. lusitanica*	*C. macrocarpa*	*S. sempervirens*	Total
Northland	33	3	1	37
Auckland	3	0	3	6
Waikato	38	21	35	94
Bay of Plenty	31	1	12	44
Gisborne	19	5	47	71
Hawke's Bay	8	0	26	34
Taranaki	0	0	8	8
Manawatū-Whanganui	3	2	9	14
Wellington	3	5	2	10
Marlborough	0	0	0	0
Nelson	0	0	0	0
Tasman	5	0	0	5
West Coast	13	7	0	20
Canterbury	3	38	28	69
Otago	0	52	8	60
Southland	0	12	1	13
Total	159	146	180	485

Conversely, PSPs containing *C. lusitanica* are predominantly found in the North Island, within which nearly 87% of PSPs occur. In the South Island, plots of *C. lusitanica* are mainly located in the north, including the Canterbury, West Coast, and Tasman regions. These spatial patterns are largely reflective of the species preference for warmer climates.

Species productivity

Scion's PSP database consists of an extensive number of plots situated across a range of environments. This database has been used to produce productivity surfaces to predict carbon sequestration potential. Historically, the Site Index has been used as a proxy for site quality and predicted in a range of plantation species in New Zealand (Palmer et al., 2009; Palmer et al., 2012; Watt et al., 2009). Site Index is the height of the dominant trees at age 20 years, towards the end of the rotation period (Skovsgaard and Vanclay, 2008). It was postulated that height and volume in even-aged stands were well correlated, regardless of the site conditions and stocking (Eichhorn, 1904). However, research has shown environmental conditions have a differential influence on both height and volume (Hock et al., 1993; Kimberley and Watt, 2021; Vanclay et al., 1995; West et al., 1982). The variation in volume for stands at a given height can reach up to 30% (Skovsgaard and Vanclay, 2008). As a result, a number of studies have since produced productivity models for volume, typically by normalising growth to a certain age, stocking, and silvicultural regime.

One such productivity measure is the 300 Index, which is defined as the stem volume mean annual increment age 30 years for stands with a stem density of 300 stems ha^{-1} (Kimberley et al., 2005). The 300 Index overcomes the limitations of the Site Index in that it provides a direct measure of volume growth at a standardised age and stocking, and thus provides a more reliable estimate of site quality than the former. Surfaces of 300 Index have been developed for *P. radiata* (Watt et al., 2021a), *S. sempervirens* (Watt et al., 2021b), *C. lusitanica* (Watt et al., 2023), and *C. macrocarpa* (Watt et al., 2023). However, while 300 Index for *P. radiata* was developed using 3,676 PSPs, far fewer plots were used to develop volume surfaces for *S. sempervirens*, *C. lusitanica*, and *C. macrocarpa*, at 130, 134 and 156, respectively (Watt et al., 2021a; Watt et al., 2021b; Watt et al., 2023). In order to verify predictions in areas under-represented by the PSP dataset or in climatic extremities, additional PSPs consisting of these three species need to be established. In addition, the development of the 300 Index for *S. sempervirens*, indicated that the species was 8.1% more productive than *P. radiata* in the North Island of New Zealand (Watt et al., 2021b). Using derivatives of the 300 Index, such as surfaces pertaining to carbon sequestration, *S. sempervirens* accumulated more carbon than *P. radiata* at 650 stems ha^{-1} and 40 years old in the North Island (Watt and Kimberley, 2022). Establishing more PSPs in areas where carbon sequestration potential is higher, could be of considerable value for verifying these estimates. Furthermore, with calls to move the forestry industry away from *P. radiata*, further research needs to be undertaken to understand the productivity of alternative species (Jones et al., 2023).

The spatial variation in volume productivity (300 Index) for *C. lusitanica*, *C. macrocarpa*, and *S. sempervirens* are shown in Figure 2 and all three of these geo-spatial surfaces are free to download at https://koordinates.com/. Spatial variation in 300 Index for all species are strongly influenced by the environmental variables included in the modelling. Spatial predictions of *C. lusitanica* 300 Index reflects the strong influence of air temperature, rainfall and soil water balance on productivity. Values of 300 Index were highest in warm coastal areas of the North Island, which experience moderate rainfall and soil water balance. Values continued to increase further into the northern regions, with the exception of the far north, where the low water retention capacity of the sandy soils restricts available water. Values were markedly lower in the South Island, due to a combination of environmental factors, such as insufficient water, waterlogging and or cold air temperatures. The highest productivity values were in the northernmost areas of the South Island where precipitation and air temperatures were moderate.

Predictions indicated that *C. macrocarpa* was more productive than *C. lusitanica* within 62% of the North Island and 96% of the South Island. Predictions indicated *C. macrocarpa* prefers moderate temperatures, thus, 300 Index was higher within the central latitudes of the North Island, and within warm areas of the east coast with moderate to high rainfall. In the South Island, values were highest in Marlborough and Nelson, where temperatures were moderate with high rainfall throughout the year. *C. macrocarpa* appears to have a greater tolerance to cold temperatures and low rainfall than *C. lusitanica*, with low-moderate productivity throughout the eastern and southern regions of the South Island.

Spatial variation in the predictions of *S. sempervirens* productivity were strongly influenced by air temperature, soil moisture and relative humidity. Values of 300 Index were highest in the western and north-eastern areas, characterised by moderate air temperature, low seasonal water deficit and low vapour pressure deficit. In the northern areas of New Zealand, values of 300 Index were lower due to higher air temperatures, as well as annual water deficits, especially in the far north. On the east coast of the North Island, where seasonal water deficits are more pronounced, values were generally lower. Values were low around the central North Island due to high elevation. 300 Index for *S. sempervirens* shows low productivity throughout most of the South Island, except for the very northern and southern regions. These regions have low seasonal water and vapour pressure deficits. Values for *S. sempervirens* are low within the east coast, which is characterized by its dry and cold climate. Values of 300 Index within the west coast of the South Island were relatively high.

Recommendations for new sites

New plots of *C. lusitanica, C. macrocarpa*, and *S. sempervirens* should be established in areas not represented by the existing PSP dataset, areas characterised by climatic extremes, and areas without plots, where predictions were markedly high or low. For *C. lusitanica*, plots could be established in the South Island in areas where the climate is cold or dry. Currently, there are only 21 plots consisting of *C. lusitanica* in the South Island, which represents approximately 13% of the total established plots for this species (Table 2). Predictions of 300 Index for this species are also low throughout most of the South Island (Figure 2a). Establishing additional plots in the South Island would greatly assist understanding of how air temperature and water availability influence species productivity.

Predictions of 300 Index for *C. macrocarpa* are relatively high along the east coast of the North Island compared to other areas of the country, particularly in the Gisborne and Bay of Plenty regions. However, there are few PSPs established in these regions, with five installed in Gisborne and one in the Bay of Plenty. Additional plots should be established in these regions to verify estimates from the model. Taranaki is also underrepresented by the PSP dataset for this species and additional PSPs should be established in this region to verify high predicted values of 300 Index.

Cypress canker disease caused by *Seridium cardinale* inflicts serious damage to *Cupressus* species, often leading to mortality, and is particularly infectious in *C. macrocarpa* (Hood et al., 2009). Research is underway to develop genetically improved *C. macrocarpa* stock that is resistant to cypress canker (Aimers-Halliday et al., 2002; Gea and Low, 1997). Establishing PSPs within newly planted stands with resistant genotypes presents an opportunity to understand how deployment of canker resistant genotypes influences productivity. These installations should target areas, shown by the surfaces to have high productivity, to determine if higher rates of productivity can be achieved in these warmer areas, susceptible to canker, through use of improved genetic material.

Plots of *S. sempervirens* are generally well distributed throughout the North Island of New Zealand. However, values of 300 Index were markedly higher in regions that are under-represented by the PSP dataset, such as the Bay of Plenty. Establishment of PSPs in the eastern Bay of Plenty would help verify estimates that suggest *S. sempervirens* would be very productive in this region. In contrast, estimates of 300 Index in the Gisborne region were relatively low compared to the North Island. As redwood has considerable potential for mitigating erosion within Gisborne, particularly when managed under continuous cover forest regimes (Bown and Watt, 2024), it would be useful to establish more PSPs in this region. *S. sempervirens* is also highly productive along the west coast of the South Island, yet there are no PSPs located in this region. It is imperative that PSPs consisting of *S. sempervirens* are established to verify the estimates of 300 Index in this region.

The establishment of PSPs in the Nelson, Marlborough, and Tasman regions for where there are very few, would be advantageous. The climate and soils in these regions are quite unique, for instance the soils in Nelson, and the low annual rainfall in Marlborough, thus the installation of further plots here provides an opportunity to extend generality of the model to account for this climatic and edaphic variation.

Post-2022 update to Scion's Permanent Sample Plots

A number of PSPs were either remeasured or established in 2022 and 2023 but are not present in the current PSP database. Scion is in the process of updating the database with these new measurements as they arrive. These new measurements were funded by The Forestry and Wood Processing and Industry Transformation Plan (ITP) and Forest Growers Research (FGR), and the dataset is summarized in Table 3. The dataset includes PSPs that have been re-measured, newly established, as well as plots that have been allocated for establishment or re-measurement. The allocated plots are tentative and subject to change, and so the figures in Table 3 may not be precise.

The dataset is also yet to be updated with specific information pertaining to the age of established plots and their specific location. The age of established PSPs is important, as modelling can only occur using plots greater than 10 years of age. Currently, the majority of the PSPs in this dataset lack precise coordinates, as only the region is provided. Therefore, caution needs to be exercised when using this data in its current form.

Table 3: Summary of PSP measurements and establishments post-2022 funded by ITP and FGR.

	C. lusitanica		*C. macrocarpa*		*S. sempervirens*	
Region	New	Re-measured	New	Re-measured	New	Re-measured
Northland	1	0	0	0	1	1
Auckland	0	0	0	0	2	0
Waikato	0	0	0	0	1	5
Bay of Plenty	0	14	0	0	1	8
Gisborne	0	2	0	2	12	25
Hawkes Bay	0	0	0	0	0	28
Taranaki	0	0	0	0	0	2
Manawatū-Whanganui	2	0	0	0	0	2
Wellington	0	0	0	0	0	1
Marlborough	0	0	0	0	0	0
Nelson	2	0	0	0	0	0
Tasman	0	0	0	0	0	0
West Coast	0	0	0	0	1	0
Canterbury	0	0	0	1	0	15
Otago	1	0	19	5	3	7
Southland	0	0	0	0	0	1
Total	6	16	19	8	21	95

Since 2022, a total of 119 existing PSPs have been or are expected to be remeasured, and 46 new plots have been or are in the process of being installed for all three species. Of these, 16 existing plots containing *C. lusitanica*, 8 existing plots containing *C. macrocarpa*, and 95 redwood plots, have been or are expected to be re-measured. New plots have also been or are expected to be established, for which 6 consist of *C. lusitanica*, 19 consist of *C. macrocarpa*, and 21 consist of redwood.

An additional 20 plots have been or are in the process of being established for Cypress in the Otago region. Of these, 19 plots consist of *C. macrocarpa* and 1 plot consists of *C. lusitanica*. The plot consisting of *C. lusitanica* has yet to be installed but has been designated for installation in the future. It is important that plots containing *C. lusitanica* are installed in the South Island, as there is a paucity of plots here, particularly in the southernmost regions. Plots containing *C. lusitanica* have also been established in Northland (1), and Manawatū-Whanganui (2). Crucially, 2 plots have been established in Nelson, for which there had been none previously. This new data will help to develop more robust models and improve the accuracy of productivity estimates in the upper South Island where data is severely lacking.

Redwood is represented in 3 new plots that have been or are in the process of being established in the Otago region. Plots have also been established in several under-represented regions including Northland, Auckland, and the West Coast. Many plots were established in Gisborne to verify the relatively low values of 300 Index predicted from the model in this region. An additional plot was also established in the Bay of Plenty, which could help to verify the high values of 300 Index shown there.

A table that includes the location of current and these additional plots is shown below as Table 4.

Table 4: Location of current and additional PSPs

Region	Existing	New	Total
Northland	37	2	39
Auckland	6	2	8
Waikato	94	1	95
Bay of Plenty	44	1	45
Gisborne	71	12	83
Hawkes Bay	34	0	34
Taranaki	8	0	8
Manawatū-Whanganui	14	2	16
Wellington	10	0	10
Marlborough	0	0	0
Nelson	0	2	2
Tasman	5	0	5
West Coast	20	1	21
Canterbury	69	0	69
Otago	60	23	83
Southland	13	0	13
Total	485	46	531

Conclusion

This report reviewed the existing PSP dataset for *C. lusitanica*, *C. macrocarpa* and *S. sempervirens*, and suggests areas of New Zealand where new PSPs could be installed. The reliability of growth and productivity models is contingent on a high quantity and well distributed dataset of PSPs. To improve estimates of these surfaces for these three species, the following suggestions were made (refer to **Recommendations for new sites**):

- Plots containing *C. lusitanica* could be installed in the southern regions of the South Island, within which there are few PSPs. This includes Otago and Southland. The 300 Index predictions are very low here, particularly in Otago.
- Plots containing *C. macrocarpa* could be installed in Bay of Plenty and Gisborne, where few PSPs are present, and 300 Index estimates are very high. Additionally, plots containing genotypes with enhanced resistance to cypress canker should also be installed, particularly in areas of high productivity, to see whether higher productivity can be achieved in areas susceptible to canker.
- Plots of *S. sempervirens* should be installed in areas shown by 300 Index to be highly productive. This includes the Eastern Bay of Plenty, and the West Coast of the South Island where few PSPs currently exist and 300 Index is very high.
- There are currently no plots present in Nelson (2 plots containing *C. lusitanica* have since been established) or Marlborough for all species. These regions present unique edaphic and climatic conditions for productivity modelling and should therefore be represented within the PSP dataset for these three species.

References

Aimers-Halliday, J., Dibley, M., Faulds, T., Low, C., & Gea, L. D. (2002). Forest Research develops superior macrocarpa and lusitanica. *New Zealand Tree Grower*, *23*(2), 25-27.

Berrill, J.P., & Hay, A.E. (2005). Indicative growth and yield models for even-aged Eucalyptus fastigataplantations in New Zealand. New Zealand Journal of Forestry Science, 35(2/3), 121-138.

Berrill, J. (2004). Preliminary growth and yield models for even-aged Cupressus lusitanica and C. macrocarpa plantations in New Zealand. *New Zealand Journal of Forestry Science*, *34*(3), 272.

Bown, H.E.; Watt, M.S. Financial Comparison of Continuous Cover Forestry, Rotational Forest Management and Permanent Carbon Forest Regimes for Redwood within New Zealand. Forests 2024, 15, 344.

Candy, S. G. (1997). Growth and yield models for Eucalyptus nitens plantations in Tasmania and New Zealand. *Tasforests*, *9*, 167-194.

Candy, S. G. (2003). Stand level growth models for Eucalyptus nitens plantations in New Zealand. *Confidential Eucalypt Coop Special Project report*.

Dean, M. (2000). *Permanent Sample Plots*.

Eichhorn, F. (1904). Beziehungen zwischen bestandshöhe und bestandsmasse. *Allgemeine Forst- und Jagdzeitung*, *80*, 45-49.

Ellis, J., & Hayes, J. (1994). *Field Guide for Sample Plots in New Zealand Forests*. (Forest Research Institute Bulletin; Vol. 186).

Gea, L. D., & Low, C. B. (1997). Genetic parameters for growth, form and canker resistance of Cupressus macrocarpa in New Zealand. *New Zealand Journal of Forestry Science*, *27*(3), 245-254.

Hayward, W. J. (1987). Volume and taper of Eucalyptus regnans grown in the central North Island of New Zealand. *New Zealand Journal of Forestry Science*, *17*(1), 109-120.

Hock, B. K., Payn, T. W., & Shirley, J. W. (1993). Using a geographic information system and geostatistics to estimate site index of Pinus radiata for Kaingaroa Forest, New Zealand. *New Zealand Journal of Forestry Science*, *23*(3), 264-277.

Hood, I.A., Gardner, J.F., Hood, R.J., Smith, B.M., Phillips, G.D. (2009) Pruning and cypress canker in New Zealand. *Australasian Plant Pathology*, *38*.

Jones, A., Steer, B., Salekin, S., Meason, D., & Stovold, T. (2023). Stock Take of the Commercially Viable Alternatives to Pinus Radiata.

Kimberley, M., West, G., Dean, M., & Knowles, L. (2005). The 300 index-A volume productivity index for radiata pine.

Kimberley, M.O., Watt, M.S. (2021) A Novel Approach to Modelling Stand-Level Growth of an Even-Aged Forest Using a Volume Productivity Index with Application to New Zealand-Grown Coast Redwood. *Forests*, *12*.

Kimberley, M.O., Watt, M.S. (2023) Growth Models for Even-Aged Stands of Hesperocyparis macrocarpa and Hesperocyparis lusitanica. *Forests*, *14*.

Knowles, L., & Hansen, L. (2004). Application of the New Zealand Douglas-fir silvicultural growth model (DF NAT) to data from the Pacific Northwest: NZ Douglas-fir Cooperative Report No. 41.

Lee, S. H. (1998). Modelling growth and yield of Douglas-fir using different interval lengths in the South Island of New Zealand.

Lin, Y., Salekin, S., Meason, D.F., Ducey, M. (2023) Modelling tree diameter of less commonly planted tree species in New Zealand using a machine learning approach. *Forestry: An International Journal of Forest Research 96*, 87-103.

Maclean, C. M., & van Zyl, A. (1997). "Regnans": a program to predict Eucalyptus regnans growth in New Zealand. Management of Eucalypts Cooperative Report No. 33.

Meason, D., Almeida, A., Manning, L., & Nicholas, I. (2011). DS041 Preliminary parameterisation of the hybrid model 3-PG for Eucalyptus fastigata in New Zealand.

Meason, D., Hock, B., Lin, Y., Lad, P., Heaphy, M., Andersen, C., & Dodunski, C. (2018). Development of the Douglas-fir Productivity Spatial Surface using the Process-based model 3-PG - technical report.

Palmer, D. J., Höck, B. K., Kimberley, M. O., Watt, M. S., Lowe, D. J., & Payn, T. W. (2009). Comparison of spatial prediction techniques for developing Pinus radiata productivity surfaces across New Zealand. *Forest Ecology and Management*, *258*(9), 2046-2055.

Palmer, D. J., Watt, M. S., Kimberley, M. O., & Dungey, H. S. (2012). Predicting the spatial distribution of Sequoia sempervirens productivity in New Zealand. *New Zealand Journal of Forestry Science*, *42*, 81-89.

Palmer, D.J., Höck, B.K., Kimberley, M.O., Watt, M.S., Lowe, D.J., Payn, T.W. (2009) Comparison of spatial prediction techniques for developing Pinus radiata productivity surfaces across New Zealand. *Forest Ecology and Management*, *258*, 2046-2055.

Pilaar, C., & Dunlop, J. D. (1989). *The permanent sample plot system of the New Zealand Ministry of Forestry.* Paper presented at IUFRO Conference 1989.

Salekin, S., Mason, E. G., Morgenroth, J., & Meason, D. F. (2020). A preliminary growth and yield model for Eucalyptus globoidea Blakely plantations in New Zealand.

Salekin, S., Mason, E.G., Morgenroth, J., Bloomberg, M., Meason, D.F. (2021) Hybrid height growth and survival model for juvenile Eucalyptus globoidea (Blakely) and E. bosistoana (F. Muell) in New Zealand. *Forest Ecology and Management*, *490*.

Skovsgaard, J.P., Vanclay, J.K. (2008) Forest site productivity: a review of the evolution of dendrometric concepts for even-aged stands. *Forestry*, *81*, 13-31.

van der Colff, M., & Kimberley, M. (2005). Modelling Eucalyptus fastigata growth in New Zealand. *Unpublished report. Eucalypt Cooperative*.

Vanclay, J. K., Skovsgaard, J. P., & Hansen, C. P. (1995). Assessing the quality of permanent sample plot databases for growth modelling in forest plantations. *Forest Ecology and Management*, *71*(3), 177-186.

Watt, M.S., Kimberley, M.O. (2022) Spatial comparisons of carbon sequestration for redwood and radiata pine within New Zealand. *Forest Ecology and Management*, *513*.

Watt, M.S., Kimberley, M.O., Rapley, S., Webster, R. (2021b) Comparing volume productivity of redwood and radiata pine plantations in New Zealand. *Forest Ecology and Management*, *500*.

Watt, M.S., Kimberley, M.O., Steer, B.S.C., Holdaway, A. (2023) Spatial comparisons of productivity and carbon sequestration for Cupressus lusitanica and macrocarpa within New Zealand. *Forest Ecology and Management*, *536*.

Watt, M.S., Palmer, D.J., Dungey, H., Kimberley, M.O. (2009) Predicting the spatial distribution of Cupressus lusitanica productivity in New Zealand. *Forest Ecology and Management*, 258, 217-223.

Watt, M.S., Palmer, D.J., Leonardo, E.M.C., Bombrun, M. (2021a) Use of advanced modelling methods to estimate radiata pine productivity indices. *Forest Ecology and Management*, *479*.

West, G. G., Knowles, R. L., & Koehler, A. R. (1982). *Model to predict the effects of pruning and early thinning on the growth of radiata pine*. Forest Research Institute, New Zealand Forest Service.

Xu, L. (1990). Growth and yield of Douglas fir plantations in the central North Island of New Zealand.

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