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Report information sheet

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Study summary: Short rotation bioenergy forestry

Overview

We reviewed literature on site suitability and growth characteristics for potential candidate tree species for a potential national-scale short rotation bioenergy forestry system, identifying three highly productive species; *Pinus radiata*; *Eucalyptus fastigata* and *E. regnans*, with the greatest potential for economically viable bioenergy feedstocks. We analysed the potential yields of these three species, if planted nationally using a short rotation bioenergy regime with harvest at 16 years. We also refined a national maximum potentially afforestable area for short rotation bioenergy forestry. This available land was identified according to, e.g., steep lower value land areas (land use capability (LUC) classification 5-7 land) and by deselecting land not currently forested; or areas where transport costs exceeded economic limits for access to potential processing centres. From this spatial analysis we were able to calculate a potential total bioenergy feedstock yield from short rotation bioenergy forestry if planted nationally over 16 years. We extrapolated our results to a real-world scenario, utilising an indicative 240,000 ha total land area target for bioenergy forestry in 2035, previously suggested by the Climate Change Commission in their 2021 advice to government. This comparison suggested that rapid implementation of short rotation bioenergy forestry on marginal land would meet governmental 2035 bioenergy targets, using less than 1% of the national land area.

Articulating a future short-rotation bioenergy forestry scenario

Our analysis suggests that a 16 year short rotation regime with an 833 to 1111 stocking density would be optimal for short rotation bioenergy forestry, using three highly productive tree species we identified (*P. radiata*; *E. fastigata* and *E. regnans*). Priority regions, in terms of their total productivity, are identified as Hawkes Bay, Gisborne, Central North Island, Northland, Canterbury, Otago-Southland and South North Island (Figures 1 and 3). Total biomass yields are a product of both growth rates and the total land area available. The total land area potentially available for short rotation bioenergy forestry across these high performing regions, assuming a $50 carbon price, is approximately 3.7 M hectares, against a total of 4.4 M hectares potentially available nationally for this forestry system (Figure 2). The Climate Change Commission's advice to government[1] recommends a far smaller area, of up to 240,000 hectares of dedicated bioenergy forest, would be needed to meet its stated targets.

In simplified terms, therefore, if we take our calculated averaged regional mean yield of *P. radiata* per hectare under a 16 year rotation at a $50 t carbon price, which is 564 m^3 ha^{-1}. An 'average' 240,000 hectare area of dedicated short rotation bioenergy forest would be capable of producing 46.5 M oven-dry biomass tonnes after 16 years, assuming a water content of 58%. Taking the gross energy value of 18.9 MJ kg^{-1} for *P. radiata* [2], this equates to 878 PJ after 16 years, or 55 PJ yr^{-1}, which exceeds our interpretation of the Climate Change Commission's advisory 2035 target of 37 PJ yr^{-1} for biofuel energy generation. Over 16 years, this would displace the equivalent of approximately 4.8 Mt of CO_2 emissions from oil combustion per year, or 6.4 Mt CO_2 from coal. Our extrapolation, based on modelled data, suggests that a short rotation bioenergy forestry system using less than 1% of New Zealand's land area would be capable of meeting the Climate Change Commission's target for bioenergy production, and very close to its stated 2035 timeframe. We used our modelled mean national mean productivity rate to calculate this, however, the highest productivity regions according to our analysis are capable of delivering biomass at rates 5-10% greater than the national regional average. This suggests even greater productivity could be reached with carefully targeted site selection and silvicultural optimisation in the most productive regions.

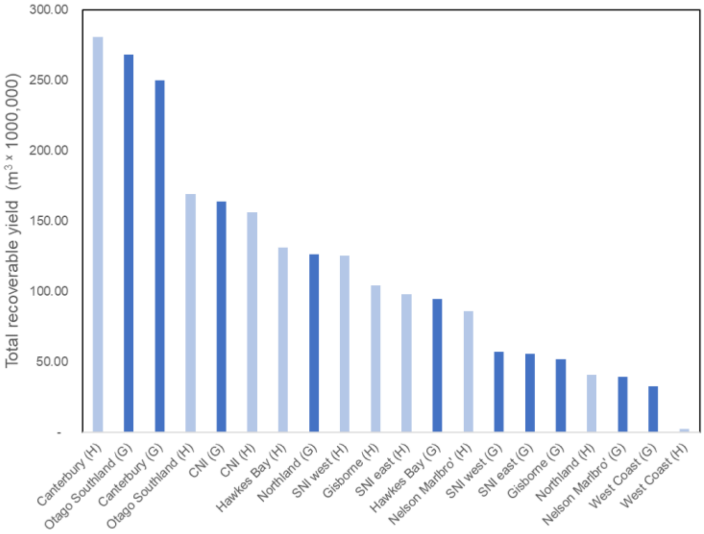

Figure 1: Summary of total potential biomass yields available per wood supply region for *P. radiata* under a \$50 tonne C^{-1} price scenario and a 16 year rotation at 833 stocking density. (G) - ground-based extraction. (H) – hauler-based extraction.

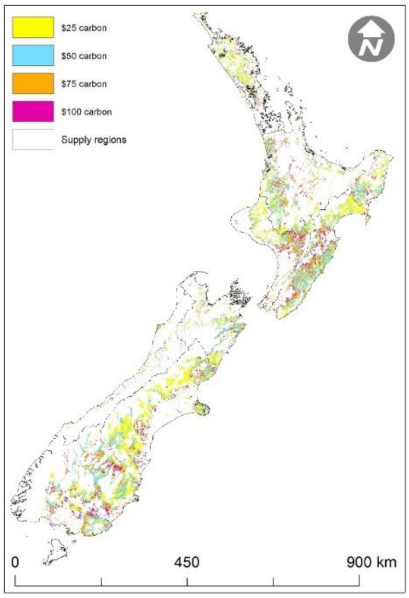

Figure 2: The 4.4 M ha total potentially afforestable land area for short rotation bioenergy forestry as identified by our analysis. Colours represent different price scenarios (\$ per tonne CO_2) for standing forest carbon under the emissions trading scheme.

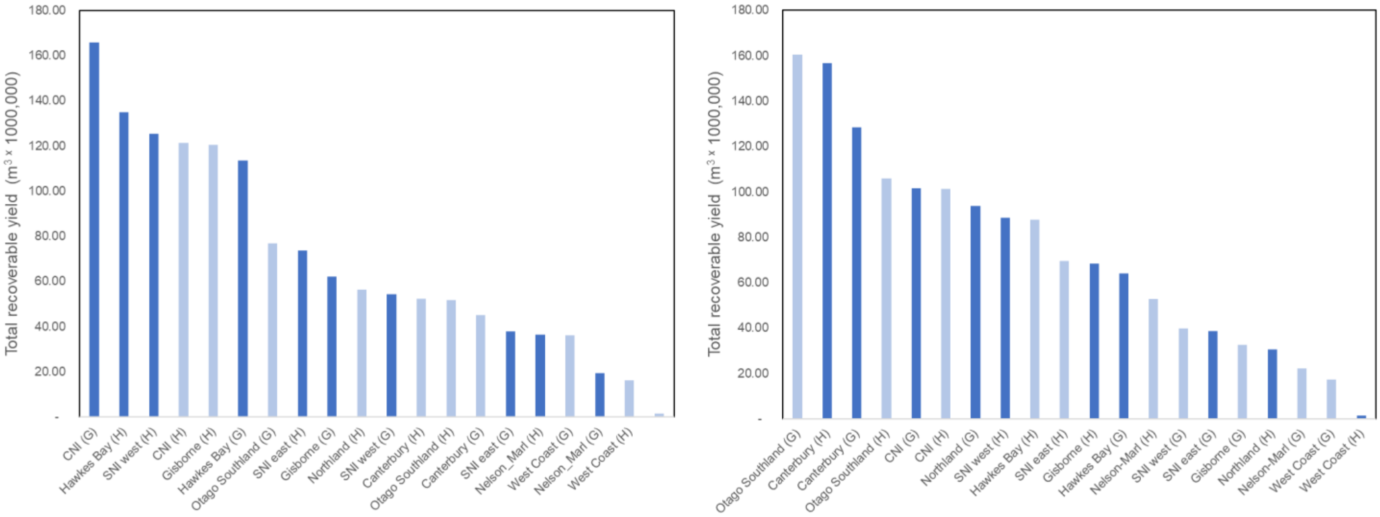

Figure 3: Summary of total potential biomass yields available per wood supply region for (a) *E. fastigata*, (b) *E. regnans* under a \$50 tonne C^{-1} price scenario and a 16 year rotation at 833 stocking density. (G) ground-based extraction. (H) hauler-based extraction.

We caution, however, that our interpretations are simplified. Many factors, both positive and negative, would influence actual yields from future bioenergy forests, greatly affecting total energy recovery. Moreover, bioenergy conversion efficiencies differ. For example, up to 50% of biomass energy would be lost if converted to liquid biofuels. Moving forward, therefore, both the pathways in which this energy will be used, together with the biophysical performance of short rotation bioenergy forests themselves will determine overall outcomes nationally. Trade-offs throughout the entire production system need to be appraised to develop this effectively.

Knowledge gaps and future research priorities

To develop a national strategy for short rotation bioenergy forestry deployed at scale on steep terrain, a range of outstanding questions and uncertainties need to be addressed. The real-world productivity of short rotation regimes will be influenced by interacting factors such as stocking density and rotation length. To increase yields in short rotation systems, stocking densities should be optimised according to, e.g., individual site characteristics. However, as stocking densities increase, pest, disease and windthrow risks, become stronger. To manage negative trade-offs, further understanding is required to evaluate and optimise the real-world performance of short rotation bioenergy forestry. Dedicated forestry trials can answer some of these questions and address some outstanding uncertainties. In combination, spatial modelling may also be used to scale up the results of biophysical assessments, while addressing further economic uncertainties also identified by this research. Future work in these areas will inform national strategies for the planting and management of short rotation bioenergy forests. Following our review, the some specific questions we identify as near-term research priorities for short rotation bioenergy forests include: (1) impact of tree stock quality and genetics; (2) impact of altitude or slope on growth and harvesting; (3) optimum stocking density and regime length; (4) site suitability soil fertility and climate impacts; (5) silvicultural management impacts; (6) costs of planting and harvesting; (7) biophysical risks including windthrow, soil erosion and pests, (8) impact of external economic conditions on profitability.

Methods

Potential productivity

Potential biomass yields for our three candidate tree species were determined using spatial modelling in ARC-GIS with base biophysical layers for terrain, soil type, landcover and climate, to derive a national productivity surface (Figure 4). Total and mean yield data were then aggregated to wood supply regions, as defined by MPI[3].

Yields for *P. radiata* were derived from “P. rad calc.”, which is an empirical productivity model based on the NZ Farm Foresters Association Radiata Pine Calculator[4]. In this analysis we specified an 833 stocking density modelled under a 16-year rotation, with no pruning. These criteria were selected because they are closest to the expected features of an ‘idealised’ short rotation regime for *P. radiata*. In particular, this stocking density may provide the ideal compromise for *P. radiata* productivity in terms of maximising short rotation yield, while minimising risks from high stocking such as increased risk of windthrow. A 16-year rotation is slightly longer than that initially identified as a priority for the two *Eucalyptus* species but may be more suitable for *P. radiata*, due to its slower initial rates of growth.

Eucalyptus growth rates were modelled using primary data from a network of permanent sample plots nationally, these data were parameterised using a physiological growth process-based model called “Physiological processes for predicting growth” (3-PG). 3-PG model outputs were then integrated with a spatial model in ARC-GIS to predict growth rates nationally according to spatial variations in climate, soil type and fertility. Outputs from this method delivered a national productivity surface for *E. fastigata*, and *E. regnans,* based on a 16 year short rotation and 1111 stocking density, which was selected because it was judged to be the highest stocking density that these species would grow optimally under with this rotation length.

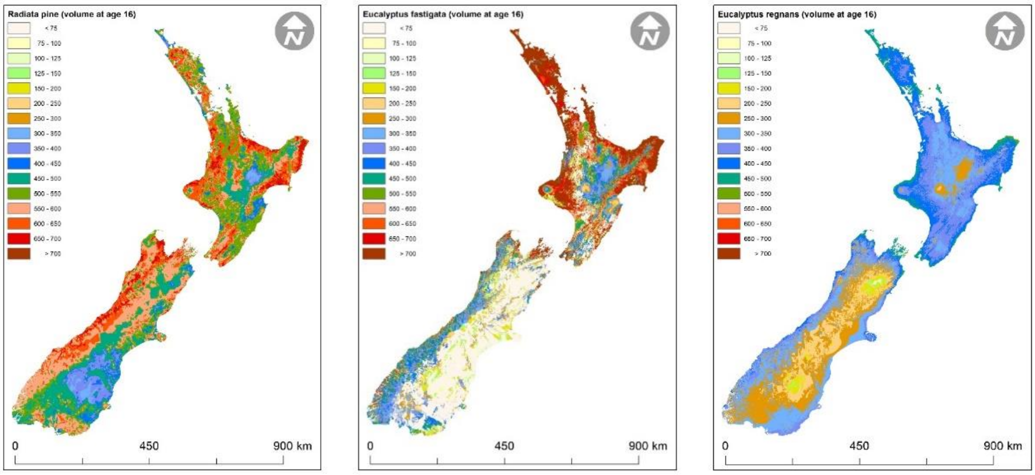

Figure 4: Productivity surfaces (total volume ha^{-1}) modelled for (a) *P. radiata*, (b) *E. fastigata*, (c) *E. regnans*

The total nationally available area for short rotation bioenergy forestry was determined according to biophysical, legislative and economic criteria. For example, afforested areas were included if based on steep terrain, or LUC 5-7 land. Areas were excluded if identified as, e.g., areas currently forested, or if under DOC estate, or if 'red zoned' for soil erosion risk. Site suitability criteria and modelled yield growth data for each species were used in combination to also predict land whether a candidate species could be grown effectively on the available land area. The potentially afforestable land area was further refined wherever our analysis suggested biophysical constraints, such as site suitability limits for the three species, would prevent successful establishment.

Land costs were incorporated into our economic analysis to determine profitability thresholds that would potentially limit the afforestable land area for short rotation bioenergy forestry. In this analysis we spatially projected data from Land Information New Zealand (LINZ) property boundaries, populated with averaged land price into a GIS layer (Figure 5). This analysis highlighted regions of primarily high-value agricultural land across Waikato, Taranaki, Wellington, Canterbury and southern Otago that would be uneconomic for short rotation bioenergy forestry, in contrast to with regions across Northland, central and eastern North Island and central Otago with the lowest land values.

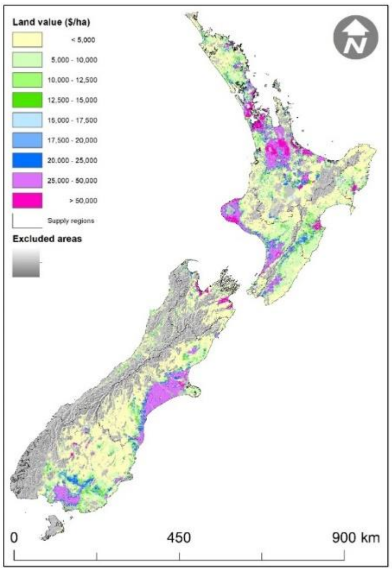

Figure 5: GIS layer derived for land values nationally

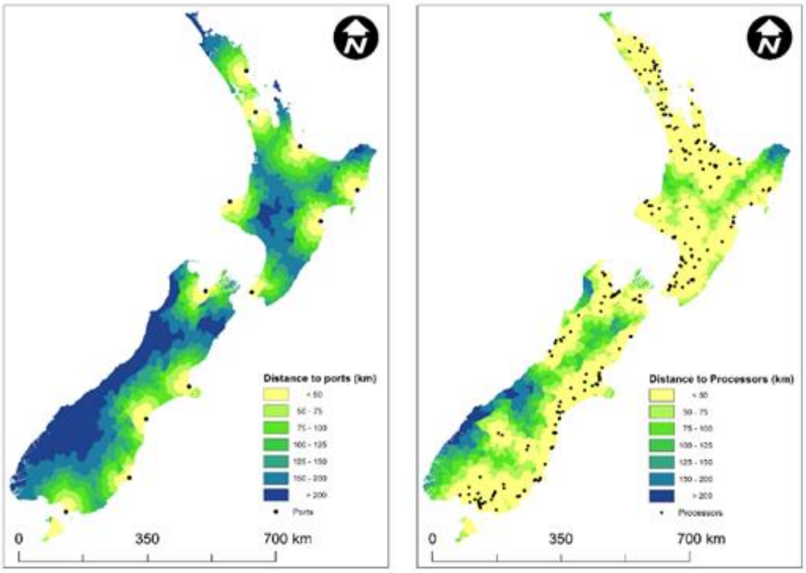

Figure 6: Distance-to-processing centres ARC-GIS layers evaluated for (a) Ports and (b) major wood processing centres

Long-distance road network transport costs were also calculated on a per kilometre basis to consider economic limitations of transport distance. In this case, we took the distance from each forest cell location in ARC-GIS to a nearest potential processing destination, developing two costing layers based on major ports or large processing facilities as feedstock destinations nationwide (Figure 6). We interpreted these as probable locations as where future bioenergy feedstocks could be processed and transported to market in near-term horizons up to 2035. This analysis was performed using the 'cost path' function in ARC-GIS with information on the New Zealand road network[5] used to generate a national transport cost layer.

The profitability assessment for short rotation forestry incorporated Scion's Forest Investment Framework (FIF)[6], which models timber production costs versus expected revenues. This framework observes costs associated with logistics, planting and harvesting and compares these with revenues from both timber and carbon. Carbon returns were evaluated at four levels ($25, $50, $75 and $100 t^{-1}), allowing a profitability assessment under carbon pricing scenarios relevant to the present and near-term. For carbon, a standard annual compliance cost of $40.00 ha^{-1} for the ETS was added to costs to cover reporting and measurements[7]. Collectively all of this information was used to derive a total potentially afforestable area for short rotation bioenergy forestry (Figure 2).

References

1. Commission, C.C., *Ināia tonu nei: a low emissions future for Aotearoa.* 2021.
2. Genless, *BIOMASS CALORIFIC VALUE CALCULATOR*. 2021.
3. Ministry of Primary Industries, *Wood Availability Forecast – New Zealand 2021 to 2060*. 2021.
4. Knowles, L., *Radiata Pine Calculator Version 4.1 Pro.* Developed for Future Forest Research e Based on NZFFA Radiata Pine Calculator, 2014.
5. Land Information New Zealand. *NZ Road Centrelines (Topo, 1:50k)*. 2021; Available from: https://data.linz.govt.nz/layer/50329-nz-road-centrelines-topo-150k/.
6. Yao, R., et al., *Forest investment framework as a support tool for the sustainable management of planted forests.* Sustainability, 2019. **11**(12): p. 3477.
7. Turner, J.A., et al., *Managing New Zealand planted forests for carbon.* A review of selected scenarios and identification of knowledge gaps. Report to the Ministry of Agriculture and Forestry 130pp, 2008.