NZDFI assessment of eucalyptus species for Right Tree Right Place deployment

Executive Summary

The NZDFI is a public/private tree breeding and research partnership that is developing genetically improved nursery stock, management systems and wood processing options for eucalypt species that produce naturally durable hardwood. These species are well-adapted to New Zealand's dryland eastern regions, *with existing plantings of these species dating back to 1890s, showing suitability of these species for many NZ sites.*

The NZDFI partners established this research and development project to ensure the supply of improved nursery stock sufficient to meet our vision of planting 100,000 hectares of durable eucalypt forests in east coast regions by 2030; the aim being to create a multi-regional sustainable durable hardwood products value chain. This value chain could be worth $2 billion and employ 1700 people by 2050.

Established in Marlborough in 2008, the NZDFI partners are Proseed Ltd (Ngai Tahu subsidiary), Vineyard Timbers Ltd, Marlborough Research Centre Trust-Te Rito o Hiranga (MRCT) and University of Canterbury's School of Forestry- Te Kura Ngahere (UC SoF). NZDFI's trial-site management and communications are managed by MRCT in Blenheim with an extensive research programme led by UC SoF in Christchurch. Thirty landowners host over 80 hectares of research trials from the Bay of Plenty to North Canterbury.

Durable eucalypt species could offer a viable, sustainable alternative land-use on summer-dry, marginal grazing land in Hawkes Bay. This is because the dryland eucalypts have been selected for the following attributes:

- fast-growing, and tolerant of the summer-dry conditions which are challenging to other species
- produce naturally durable timber – a real alternative to environmentally damaging copper-chrome-arsenic (CCA)-treated radiata pine and to unsustainably harvested tropical hardwoods
- store more carbon, more rapidly, than almost any other forest species grown in New Zealand
- coppice readily (regrow from a cut stump which stays alive, along with its root system after harvest), thereby reducing the potential for erosion in the years following harvest.
- can be managed under a continuous cover regime.
- produce nectar and pollen at times of year when other species are not flowering, so add bio-diversity by supporting bees and native birds and insects.

Applicability to Hawke's Bay Hill Country

Hawkes Bay already has an established forest industry with 142,000 hectares of plantations from which an estimated 1.8 million cubic metres were harvested in 2017. This supports many thousands of jobs. It is well serviced with both timber processors and a vibrant export port. While containing only 8% of the national estate, Hawkes Bay's climate and soils produce some of the highest forest productivity in the country.

As with the rest of NZ, Hawkes Bay forest growers rely heavily on a single species, radiata pine, leaving the industry vulnerable to fluctuations in market demand and the threat of pests and diseases. However, the same soils and climate have huge potential to reap the benefits offered by NZDFI's unique research focus on durable eucalypts by diversifying the region's plantation estate.

NZDFI's first regional value chain is most likely in Hawkes Bay/Gisborne regions based on short rotation forests that will commence in 2035 to supply small peeler logs to produce super stiff LVL. This has already been recognized by several Hawkes Bay forest growers (including Juken NZ and Landcorp Farming), HBRC, as well as a number of farm foresters that have been collaborating in NZDFI research. They have already started planting durable eucalypts so as to be first to market with NZ grown high strength LVL and durable hardwood products.

NZDFI are promoting a rapid expansion of a sustained planting programme in Hawkes Bay so as to establish a resource that can provide sufficient log supply on the basis for a new hardwood industry. Their vision is for a mosaic of forests so rather than only large scale plantations, there could be a woodlot on every farm in Hawkes Bay.

- NZDFI's investment in research has led to the development of these ground-durable eucalypt species using rapid selection and novel propagation to produce high-performing genetic nursery stock that we plan to release from 2020.
- NZDFI has brought together a well organised team of skilled people who are the foundation for our proposal to establish New Zealand Dryland Forests Innovation as a centre of excellence at the University of Canterbury.

In 2014, HBRC committed to a management scale trial of durable eucalypts being a 5 hectare plantation established at Waihapua near Lake Tutira with the intention of assessing the adaptability and productivity of these species and to understand the challenges and risks associated with growing these species.

Species suitable for Hawkes Bay regional afforestation

Principal or primary commercial species to include:

Durable eucalypts
E. globoidea
E. bosistoana
E. quadrangulata

Non durable eucalypts
E. fastigata
E. regnans

Secondary species for erosion control on dry tough sites; for shelter; bee forage, nectar for birds, permanent carbon forests; etc.
E. cladocalyx
E. macrorhyncha
E. tricarpa

Site requirements

1. Topography – suitable for flat to medium steep slopes with species to be selected to match site conditions.
2. Climate – can withstand drought and survive in low rainfall areas (600-800mm). Some species can also survive minus 5 degree frosts. Optimal commercial productivity in warm, sheltered high rainfall sites i.e. over 1,000 mm per annum.
3. Soils – Some species are best sited on deep soils with moderate to high fertility. Other species are able to grow on skeletal soils by rapidly recycling soil organic matter. Some can withstand flooding and inundation being suitable for planting in periodically damp riparian sites.
4. Access and infrastructure-similar requirements to management and harvest of commercial radiata pine plantations.
5. Alternatively, farm wood lots on easy slopes with good access could be managed under a continuous cover regime with portable sawmilling for off farm timber sales and on farm use.
6. It is wise to locate eucalypt plantations and woodlots with due consideration to fire risk and outside peri-urban areas.

Attributes

7. Erosion control attributes – rapid growth and large root system with lignotuber that can coppice following felling. Some species maybe suitable for planting permanent forests to stabilise eroding slopes.
8. Durable eucalypt forests will mitigate the market and environmental risks associated with New Zealand's current radiata pine monoculture (around 90% of plantation forests in New Zealand are radiata pine).
9. Produce naturally durable timber – a real alternative to environmentally damaging copper-chrome-arsenic (CCA)-treated radiata pine and to unsustainably harvested tropical hardwoods
10. Replace some of NZ's $50 million of timber imports for e.g. cross arms, decking and rail sleepers, and allow NZ to become an exporter of high quality durable hardwood
11. Process into high strength engineered wood products (for example, laminated veneer lumber) for the construction of sustainable multi-storey wooden buildings.
12. Store more carbon, more rapidly, than almost any other forest species grown in New Zealand
13. Can be planted on farms in shelterbelts, for shade and amenity.
14. A mix of species can produce nectar and pollen at times of year when other species are not flowering that can support bees and native birds and insects.
15. Legacy effects – durable eucalypts can live hundreds of years so could also be established as permanent forests on steep unproductive land for erosion control and to sequester carbon. The trees could be spaced widely to allow under-planting of native species, or natural regeneration, with the eucalypts providing shade and a protective canopy for native plants to develop. Once a native understorey is established the eucalypts could be poisoned and allowed to decay.
16. Nutrient interception (nitrogen and phosphorus) - Eucalypts have been proven to work well when spray-irrigated in waste-water remediation systems. They could also have the potential to strip nitrates from ground water if planted and harvested with care in riparian margins.

Risks

17. There is limited potential for wilding tree problems as these species have seed which does not disperse widely. They also require specific sites and a high level of care for successful establishment.
18. There can be a major hazard in a wild fire so wood lots and plantations should be located to minimize this hazard. Landowners and fire services need to plan to mitigate fire risk and be prepared for more intense fire behaviour relative to pine forest should fire occur.
19. There is concern about possible risks eucalypts plantations may pose to water quality and human health, and to reducing water catchment yield. This will require further investigation relative to HB conditions.

Establishment and early growth

20. Land preparation requirements – are similar to P.radiata sites for cut over sites with desiccant spraying to kill regen and a withholding period after application of some dessication chemicals. For new forest sites on farmland pre plant spot spraying is recommended 4-6 weeks prior to planting in spring. Fertilising at planting can be beneficial on cut over sites and low fertility sites.
21. Planting stock types, availability and costs – container stock priced from $1.15 - $2.00 with only limited numbers produced annually dependent on demand. Good potential for existing nurseries to scale up production.
22. Research and development is underway into large-scale clonal propagation of elite plants of NZDFI species as commercial state clonal propagation has driven large-scale planting of other eucalypt species in several countries.
23. NZDFI have submitted a PGF application to fast-track research and development of genetically improved planting stock and make it available and easy to source for growers from 2020.
24. Initial stocking rates are determined by the three regimes possible for durable eucalypts shown below.
25. Growers may expect 90% survival provided that they have effective weed control; high quality seedlings in sound condition and good planting technique. Seedling losses can occur if; the climate and soil are unsuitable for the species chosen for a particular planting site, there is poor cultivation or poor handling of nursery stock during establishment, and incorrect timing of planting.
26. Despite genetic improvement some young eucalypt seedlings can develop poor form and will be damaged by insect pests.

Silviculture and management

27. Form pruning (to create a single, straight stem) may be necessary to ensure an optimal selection of crop trees. With successive breeding efforts this is intended to be a reducing requirement.
28. Good weed control is required for a minimum of 12 months to ensure high survival and rapid early growth. There are a range of selective chemicals that can be successfully applied.
29. Animal pest control is required particularly of rabbits and hares when trees are young. If goats or deer are present then these need to be reduced and maintained at minimal numbers as they can significantly damage young eucalypt trees.
30. Newly planted eucalypt seedlings will benefit from fertiliser particularly if planted on cut over sites and in low fertility soils.
31. Durable eucalypts have the potential to provide a highly complementary and sustainable forestry option to the matrix of land uses in dryland regions such as livestock grazing, conventional forestry, and mānuka/honey ventures.

32. Growers can benefit from one or two income streams by production thinning or harvesting at different ages.
33. These species can also be managed as a continuous cover forest, by conducting ongoing thinning operations, with reduced erosion risk.
34. On flat-to-easy sites with good road access and short transport distances, roundwood thinnings or clear felling will be possible from around age 12 onwards, with potential for an early return on investment. These logs will be suitable for preservative-free posts and poles for vineyards, horticulture and organic enterprises, and potentially for rotary peeling veneers.
35. On less accessible sites, the best option is a sawlog harvest at around age 25 onwards. These logs will be suitable for producing timber for cross-arms, sleepers and poles, rails and outdoor landscaping, also for use in wharves and marinas, including decking, exterior furniture and fittings and for engineered wood products.
36. Forest growing costs will be highly sensitive to regime choice and accessibility of the forest site.

Productivity

37. Growth models will be built as growth and yield data becomes available form NZDFI sites and Permanent Sample Plots (PSPs).
38. Optimal rotation ages are likely to range from late teens to late twenties dependent on product targeted by the grower and local market opportunities.
39. Growth and yield expectations (modelled) are represented in the project by Eucalyptus globoidea, with these species chosen as an apprently ubiquitous species for HB conditions, according to early indications from the HB trial series for NZDFI.

Log production

40. Harvest considerations are similar for radiata pine given likely regime scenarios.
41. Log markets and downstream processing capacity will be the subject of ongoing research within the NZDFI strategy and project activity.
42. Erosion risks will likely be somewhat reduced in the event coppicing species are chosen and allowed to develop into a subsequent crop.
43. Residue management will be lrgely dependent on markets for residues as pulplogs or biomass, will be the subject of ongoing research within the NZDFI strategy and project activity.
44. Risks may apply to increased flammability of some of these species during summer logging operations, and additional fire management precautions may be warranted, subject to local fire plans.

Carbon forestry

45. ETS eligibility is subject to usual area, survival and spacing requirements.
46. Carbon sequestration rates will track with productivity and subject to wood density of individual species, in projects where field measurement applies (projects over 100ha) and otherwise subject to generic exotic hardwood tables.
47. Expected costs, revenues, risks

Other or complimentary income streams and biodiversity benefits

48. Many types of Eucalyptus honey are sought after in Australia so large scale plantations could present the opportunity for an additional export honey crop in time.

49. Benefits may apply to local biodiversity, thorugh provision of bird fodder, flowering calendar, and existing native mix. This would require individual site assessment and expert knowledge and no claim is made as to quality or quantity of such benefits.
50. Likely erosion mitigation effects compared with other land uses or forest types will depend on rotation length, choice of coppicing species, subsequent site management.

Natives as an afforestation option in the Hawke’s Bay region: a preliminary economic analysis for planted kauri and totara

Report for the Hawke’s Bay Regional Investment Company

Gerard Horgan, Mark Kimberley and David Bergin
Tāne’s Tree Trust
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Introduction

The Hawke’s Bay Regional Investment Company (HBRIC) has commissioned the Right Tree Right Place project to look at afforestation investment options in financial, erosion reduction and ecosystem service terms, in the region.

As part of this, native regeneration is of interest, insofar as it may offer carbon returns and timber returns in time. Forestry consultant PF Olsen is populating a model with 10 forest species/forest systems including native forest options. Spatial analysis will be conducted for a shorter list across eroding Hawke’s Bay hill country, as identified through the initial stages of the project.

James Powrie, RedAxe Forestry Intelligence, contracted to HBRIC, has requested indicative cashflows for tōtara and kauri as part of these restoration mixes. In particular, a brief indication of conservative to optimistic returns for these species is required for a rotation of 60 years (these may require reference to longer rotations), including links/citations to relevant material and key references. PF Olsen will incorporate this into the modelling.

Establishment costs of native forest

Establishment costs from various sources for native forest vary from as low as less than $5000 per ha (e.g. manuka planted for honey) to over ten times that at $30,000 per ha (e.g. Davis et al. 2009). This huge difference is due to what is included in the cost of establishment and wide range of other factors including:

- the objectives of planting, both short and long term,
- the scale of planting,
- the species and grade of nursery stock planted,
- the density of planting per hectare,
- the characteristics and current vegetation cover of the proposed planting site,
- the on-site costs of site preparation and planting, and
- the post-plant monitoring and maintenance.

Care is therefore required in comparing costs for establishment of native forest to ensure similar planting scenarios, objectives and sites are being evaluated.

A range of published and on-line sources provide establishment costs for planting and early management of native forest. Approximate costs for planting natives at a range of scenarios are provided in Bergin and Gea (2007). These are summarised in Table 1 for the most commonly used planting densities for native forest programmes including various proportions of trees and shrubs used. Establishment costs range from $20-30,000 per hectare at a plant spacing of 1.5m apart (4444 stems/ha) to $6-8,000 per ha at spacing of 3m (1100 stems/ha).

These costs are at the upper end compared to other published figures reflecting the inclusion of the following planting and early management costs:

- Cost of $2 per seedling for shrubs and $4 per seedling for tree species based on PB2 or PB3 stock provided at bulk rates (Note - current 2017 seedlings costs are likely to be greater for shrubs at $3 each).
- Planting based on recently retired grassland sites - cost may be greater where woody scrub species need clearing or lines cutting.
- Includes site preparation for grass sites such as spot spraying with herbicide.
- Includes releasing of seedlings from grass using herbicide for up to 3 years after planting and control of scattered woody weed invasion for up to 5 years after planting, but not the more intensive woody weed control required for difficult weedy sites.
- Cost of fencing, animal pest control, blanking and clearing of dense exotic woody vegetation is not included.

The level of stocking clearly has the greatest impact on cost of establishment. While the lower density of planting at 1100 stems per ha is less costly, it will take an estimated 4 years for shrubs and 8 years for tree species to provide canopy cover to suppress weeds (Table 1). The lower stocking options on difficult sites will require an extended period of vigilance with site inspections to plan timely weed control where required.

Table 1: Approximate cost per ha of planting and early management of nursery-raised seedlings on a grass site at three different plant densities. Note dollar values are not converted to NPV. Modified from Bergin and Gea (2007).

Plant spacing	**1.5x1.5m**	**2x2m**	**3x3m**
Stocking (stems per ha)	**4444**	**2500**	**1100***
Expected time to canopy closure For shrubs For trees	 3 years 6 years	 4 years 8 years	 6 years 12 years
Site preparation - includes herbicide spraying of grass, some woody weed clearance @$0.50 per plant	$2,222	$1,250	$550
Seedling cost (based on 3:1 shrub:tree mix for higher stockings, and 1:1 for lowest stocking)+	3333 shrubs = $6,666 1111 trees = $4,444 **Total = $7,777**	1875 shrubs = $2,750 625 trees = $2,500 **Total = $5,250**	550 shrubs = $1,100 550 trees = $2,200 **Total = $3,300**
Delivery and planting cost @ $0.50 per unit	$4,444	$2,500	$1,100
Grass control for up to 2 years* @ $0.50 per plant annually	$4,444	$2,500	$1,100
Woody weed inspection/control annually @ $300 until canopy closure or up to 5 years For shrubs For trees	 $900 $1,500	 $1,200 $1,500	 $1,500 $1,500
Total For shrubs For trees	 $20,898 $30,386	 $12,450 $17,750	 $6,450 $8,650

+ Based on shrubs @ $2 per unit, and trees @ $4 per unit. Note that at least 500 trees should be planted per ha so the 1100 stems per ha scenario is based on a 1:1 mix of shrubs and trees.

*This allows for a minimum of two spray releasing per year; lower density options may need extra years of weed control.

Merits of using a nurse crop

Use of a high proportion of the faster growing shrub hardwood species, as listed in Bergin and Gea (2007), is recommended as a nurse crop to shelter a lower density of inter-planted native tree species and suppress weed growth. Depending on the site and early performance, early successional shrub species will likely give canopy cover in about 3 years if planted at 1.5m plant spacing or double that if planted at 3m spacing.

In a survey of 5-year-old native shrub plantings carried out for the Bay of Plenty Regional Council, the ratio of crown height to crown breadth was found to average 1.5 (Bergin and Gea 2007). This mean ratio of 1.5 suggests that crown closure begins to occur in a mixed species shrub planting when the mean height is about 50% greater than the plant spacing. Therefore, at a spacing of 1.5 m, canopy closure will occur at a mean height of about 2.25 m achieved after 3 years on a good site and 4 years on an average site, but will take 7 years on a poor site (Table 2). At a closer spacing of 1 m the height at crown closure is estimated to be 1.5 m. For good, average, and poor sites, this will be achieved at about ages 2, 3 and 4 years respectively. However, at a wider spacing of 2 m the height at crown closure of about 3 m will likely take 10 years for slow growing sites.

Planting native forest usually involves planting a mix of native shrub and tree species at a proportion of up to 75-80% shrubs to 20-25% trees but this can vary depending on site and objectives. Shrubs are cheaper to propagate as most generally take less than one year to raise in the nursery whereas many native tree species are slower growing and take at least 2 years in the nursery.

Table 2: Time in years for mixed-species plantings of native shrubs and small trees to achieve canopy closure target heights for a range of plant spacings on slow growing, average, and fast-growing sites.

Plant spacing (m)	Time in years to reach canopy closure		
	Slow growing site	Average site	Fast growing site
1	4.3	2.6	1.7
1.5	7.0	4.3	3.1
2	10.0	6.1	4.4

Growth rates of native forest

Tāne’s Tree Trust plantation database

Tāne’s Tree Trust has various resources that can be useful in evaluating planted and regenerating native trees and shrubs. In particular, the Trust has a nationwide database of tree measurements from native plantations where some 15,000 planted native trees and shrubs ranging in age from 10 to 100 years have been assessed. Using this database, Tāne’s Tree Trust has developed growth models for predicting growth rates for heights and DBH (stem diameter at 1.4 m breast height) by age for different planted native shrubs and trees (Bergin and Kimberley 2012a; 2012b; 2012c).

These growth models can be used with existing tree volume functions and carbon models to predict yield tables of stem volumes and CO_2 sequestration by age for native tree and shrub plantings and naturally regenerating stands. In this report, we used the kauri pole volume function of Ellis (1979), and the allometric carbon models of Beets et al. (2012).

Growth predictions for native tree plantations in the Hawke's Bay

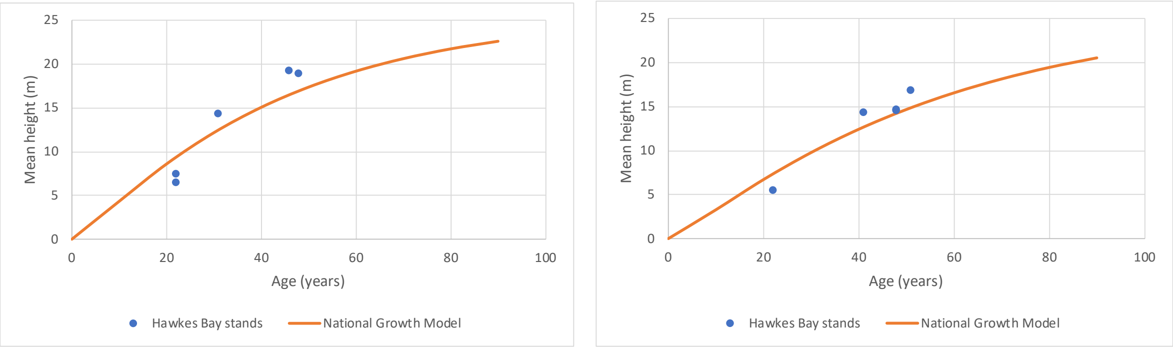
To evaluate the growth rates of native trees in the Hawke's Bay, we firstly extracted Hawke's Bay data from the Tāne's Tree Trust Plantation Database for four native tree species, namely kauri, rimu, kahikatea and tōtara. Most of these data were from small stands in the Holt Forest Trust arboretum. A summary is presented in Table 3.

Table 3: Details of plantings of native trees in the Hawke's Bay

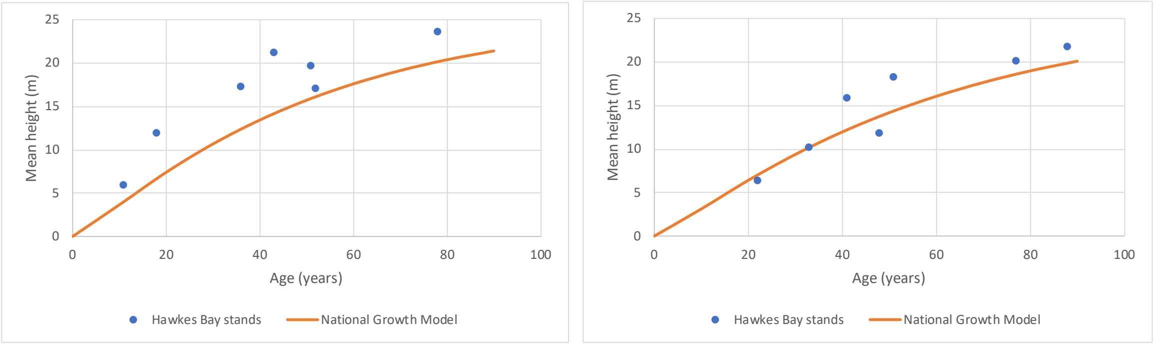
Site	**Species**	**Age (years)**	**Stocking (stems/ha)**	**Height (m)**	**DBH[1] (cm)**	**Stem Volume (m^3/ha)**	**CO_2 (t/ha)**
Holt Forest Trust	Kauri	22	2000	6.4	11.6	67	115
Holt Forest Trust	Kauri	46	2000	19.2	27.3	969	1,339
Holt Forest Trust	Kauri	22	2500	7.5	14.6	151	248
Holt Forest Trust	Kauri	48	2000	18.9	25.3	817	1,137
Holt Forest Trust	Kauri	31	2500	14.3	20.1	502	728
Holt Forest Trust	Rimu	22	3835	5.5	8.3	55	100
Holt Forest Trust	Rimu	48	3835	14.6	20.3	799	1,151
Holt Forest Trust	Rimu	48	3835	14.5	17.3	571	833
Holt Forest Trust	Rimu	51	816	16.8	31.8	486	667
Holt Forest Trust	Rimu	41	2500	14.3	22.0	606	868
Holt Forest Trust	Kahikatea	11	1975	5.9	7.5	25	40
Holt Forest Trust	Kahikatea	36	1975	17.3	21.0	508	612
Holt Forest Trust	Kahikatea	18	1600	11.9	16.8	190	245
Holt Forest Trust	Kahikatea	43	1600	21.2	28.4	916	1,058
Holt Forest Trust	Kahikatea	52	1111	17.0	22.9	339	407
Holt Forest Trust	Kahikatea	78	1111	23.6	29.2	736	842
Holt Forest Trust	Kahikatea	51	816	19.7	43.0	1,036	1,168
Holt Forest Trust	Tōtara	22	1975	6.4	11.3	61	96
Holt Forest Trust	Tōtara	33	1975	10.2	15.5	176	242
Holt Forest Trust	Tōtara	48	1975	11.8	18.6	288	382
Holt Forest Trust	Tōtara	51	816	18.2	40.6	864	1,026
Holt Forest Trust	Tōtara	41	816	15.9	30.2	418	515
Prior Park	Tōtara	77	1000	20.1	37.5	974	1,152
Prior Park	Tōtara	88	1000	21.7	40.4	1,211	1,415

[1] DBH is diameter of stem at breast height (1.4 m)

We next compared these measurements of height and diameter from Hawke's Bay stands with predictions from the Tāne's Tree Trust national growth models to determine whether growth rates in the Hawke's Bay were comparable with other parts of the country. In general, the Hawke's Bay stands showed height growth rates very similar to predictions from the national growth models as shown in Figure 1. The exception was kahikatea with the Hawke's Bay stands showing faster height growth than the national average for this species.



Kauri **Rimu**

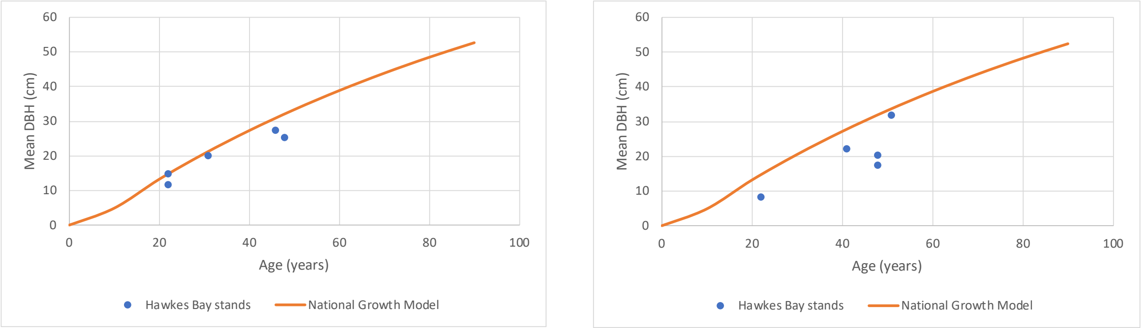


Kahikatea **Tōtara**

Figure 1: Height of Hawke's Bay kauri stands (blue dots) compared with the national growth model (orange line) for the four most commonly planted native conifers - kauri, rimu, kahikatea, tōtara.

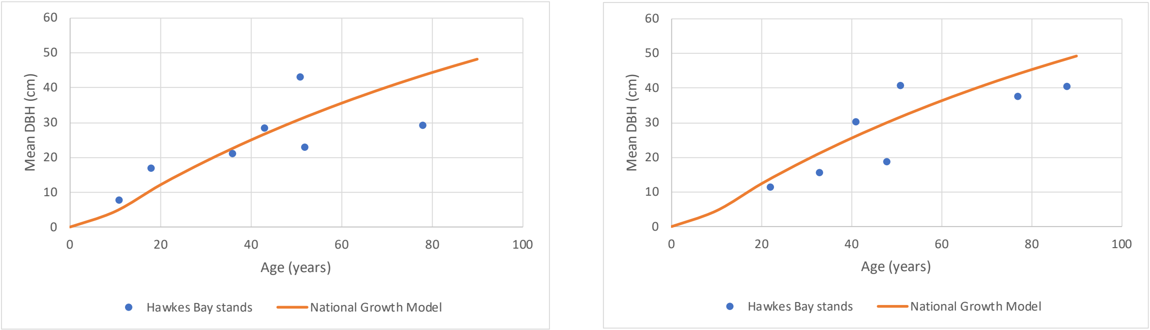
Diameter growth of the Hawke's Bay stands (Figure 2) was generally similar to or slightly slower than predictions from the national models. However, the slower DBH growth can be attributed to the high stockings of many of the Hawke's Bay stands, some of which are at stockings of 2000 stems/ha or more. At such high stockings, competition between trees would be intense, slowing the tree diameter growth although not greatly affecting the height growth.

Overall, we can conclude that growth rates of planted native trees in the Hawke's Bay are similar to those in other parts of the country. This means that we can use our national growth models to predict stems volumes and carbon sequestration likely to be achieved by native tree plantations in the Hawke's Bay.



Kauri

Rimu



Kahikatea

Tōtara

Figure 2: Height of Hawke's Bay kauri stands (blue dots) compared with the national growth model (orange line) for the four most commonly planted native conifers - kauri, rimu, kahikatea, tōtara.

Volume and carbon for native tree plantations in the Hawke's Bay

Predictions of stem volume and CO_2 sequestration from the national growth models for various native plantings are shown in Table 4. We assumed a mix at planting of 50% shrub and 50% tree species planted at a stocking of 2,500 stems/ha (i.e., 1250 stems/ha trees and 1250 stems/ha shrubs). The shrubs are planted as a nurse crop to assist tree establishment. We modelled two tree species namely kauri and tōtara, and also modelled the CO_2 sequestration for a pure planting of shrubs (e.g., manuka) at 2,500 stems/ha. The latter could also be used as an estimate of the likely CO_2 sequestration that would be obtained in a naturally regenerating native shrub stand.

Table 4: Predictions of stem volume and CO_2 sequestration using Tāne's Tree Trust national growth models.

Species	**Age (years)**	**Stem Volume (m^3/ha)**	**CO_2 (t/ha)**
Kauri	20	52	164
	40	352	644
	60	844	1,285
	80	1,394	1,827
Tōtara	20	36	136
	40	255	478
	60	637	925
	80	1.091	1,286
Shrubs	20	-	160
	40	-	295
	60	-	303
	80	-	267

Economic returns from kauri and tōtara

Kauri log values

Prices for kauri logs are surprisingly difficult to obtain. At present there isn't a developed market for plantation grown kauri – so what one is forced to use are price projections such as those given by Holt et al (2014) in work advocating for a new industry in Northland or updating, via indexation such as the Reserve Banks' calculator (https://www.rbnz.govt.nz/monetary-policy/inflation-calculator), older price data, or to look at prices being paid for other iconic New Zealand native species, e.g. rimu, and argue that kauri, as another iconic species, would achieve similar (or higher) stumpage/'at mill' prices.

The basis for choosing these prices are reported 'at mill' prices for Cyclone Ita recovered rimu logs of $400/m3 (McIntyre, et., al. 2018) which translates to a stumpage for helicopter recovered material of between $200 ~ $250 per cubic metre and one that is approximately $100 per cubic metre higher for ground-based recovered rimu (helicopter recovery costs more but the buyer of a log pays the same price regardless of costs incurred in harvest). In our base kauri analysis, depending on the harvest age, harvest and transport averages between $60 and $70 per cubic metre. If one assumed the best quality plantation grown kauri (i.e., the oldest crop age material) we would have a similar 'at mill' log price to rimu of $400 per cubic metre.

Barton & Horgan (1980) used stumpage of $60/$m^3$ for 80 -year old plantation grown kauri. Using the Reserve Bank's inflation calculator (CPI indexation) to update this price to 2019 terms produces a current equivalent figure of $306 to $363/$m^3$ depending on precisely when one decides the $60 price applied – at the date of paper publication or a few months earlier when the paper was written. Given the range of one might opt for a quick point source approximation of say $325/$m^3$ which tagging on the $60 to $70 harvest/transport cost assumed in the base analysis produces an 'at mill' price of around $390/$m^3$.

The Scion 2014 paper (Holt et al. 2014) considered a kauri option that had a thinning harvest at age 40 and with a final crop harvest at age 60. Prices used in that study were effectively $275 for the age 40 thinning material and average $450/m^3 for the 80-year old material.

Synthesizing from the material in the three cited three studies the Table 5 gives the average 'at mill' kauri log prices used in the analysis report here.

Table 5: Log price 'at mill' for kauri at different rotations based on Holt et al. (2014)

Crop Age at Harvest (years)	**Assumed Average 'at mill' log price (\$/m^3)**
40	275
60	388
80	450

There is one further analysis that is may be relevant to this discussion – that of Steward et al. 2014. The suggested stumpage prices in this work are shown in Table 6. Adding our $65 log /load & deliver cost to these stumpages produces 'at mill' prices ranging from $365 to $565/m^3 - depending on stand mean DBH. The mean DBH gets larger with older crops but a quick look at these prices compared to those in Table 5 might suggest that the base being suggested are possibly a little low – with perhaps the greatest undervaluation applying to 40-year-old material. However, the data for the kauri plantation in the Holts Forest Trust (Table 3) suggests that the average DBH at age 40 might well be less than 25 cm – so if that is the case an all up price that is less than $365/ m^3 for material of that age isn't necessarily that unreasonable. The material is also likely to be all sapwood too.

Table 6: Stumpage prices for kauri for 4 size diameter size classes (Steward et al. 2014).

Diameter size classes (cm)	Log value (per m^3)
25 < DHB <35	$300
35 < DHB < 45	$350
45 < DHB < 55	$400
55 < DHB	$500

When one gets to older aged material, one would certainly be operating with an average DBH in the 25 to perhaps 45 cm range with the 60-year-old crop – so the price suggested in Table 6 is in line with might be expected based on Steward et al. For the 80-year-old crop the suggested average price of $450/m^3 (Table 5) to be consistent with Steward et al. (2014), requires the average DBH for the whole crop to be 45 to 55 cm, which isn't unreasonable. In short, one could argue that the base prices suggested are at least consistent with the prices suggested in Steward et al. (2014) stumpage prices.

Northland tōtara log values

Paul Quinlan, trustee of Tāne's Tree Trust and leader of the Northland Tōtara Working Group, provided the Northland Regional Council with indicative figures for possible values of tōtara logs at the mill, rather than as stumpage (Quinlan 2017). This was based on limited experiences with harvesting and selling tōtara logs and timber from naturally regenerated tōtara trees off farms in Northland.

There are however, two main differences between this natural resource of 'farm-tōtara' and what will be the plantation tōtara of the future. These are first, that the existing natural resource is untended (i.e., not pruned or thinned), and second, that its harvest is controlled by the Forests Act, and therefore must be done on a sustainable basis, i.e. continuous-cover-forestry (CCF) - not clear-felling (Quinlan 2017).

Based on various sources including prices for macrocarpa log sales, Quinlan (2017) provides an estimate of log value for tōtara assuming a plantation management regime and clear-fell harvest systems (Table 7).

Table 7: Indicative log value at the mill for tōtara logs (Quinlan 2017)

Log grades	**Tōtara log value ($/m3)****
Pruned minimum SED* 40 cm	420 - 487.5
Pruned minimum SED 30cm	204 - 247
Small branch minimum SED 30cm	174 - 195
Small branch minimum SED 20cm	138 – 162.5
Large branch/sleeper/box minimum SED 20cm	120 - 143
Firewood logs	65-75

*SED = Small end diameter of log

** Based on price of Macrocarpa plus 20-30% on advice from Allan Laurie regarding comparative current market value.

From these figures we are suggesting the base indicative 'at mill' value of tōtara logs for this Hawke's Bay analysis is given in Table 8.

Table 8: Base Indicative' at mill' tōtara log values for base Hawke's Bay anlysis.

Log grades	**Tōtara log value ($/m3)**
Pruned minimum SED 40 cm	480
Pruned minimum SED 30cm	240
Small branch minimum SED 30cm	185
Small branch minimum SED 20cm	155
Large branch/sleeper/box minimum SED 20cm	130
Firewood logs	70

In our base analysis we assumed that were tōtara material to be harvested at age 40 the mix of harvested logs would be an equal mix of the last four grades of Table 8, i.e., that harvest by volume would consist of 25% each of small branch minimum SED 30 cm; 25% small branch minimum SED 20 cm; 25% Large branch/sleeper/box minimum SED 20 cm and 25% firewood. That assumption and mix gives an average price for age-40 harvest of $135/m^3. For 60-year-old material the assumed harvest split was 20% in each of the last five listed categories, i.e., no large pruned material in the mix, while for harvest of 80-year-old material the assumption was that the harvest would consist of equal (16.67%) shares of all six listed log types.

As a result of these assumptions the default average tōtara log values used in our analysis for the three possible harvest ages that we considered are given in Table 9.

Table 9: Default mean tōtara log values used in base analysis.

Harvest Age	Tōtara log value ($/m3)
40 Years	135
60 Years	156
80 Years	210

Cashflows for tōtara and kauri

Table 10 sets out, at various discount rates, the present value of a dollar of income 40 to 100 years into the future. At a discount (or time value of money) rate of 1 percent, a dollar of income 40 years into the future has a present value of just over 67 cents. If one must wait 60 years for the dollar of income, its value now is some 55 cents; with an 80 year wait, it's 45 cents and for a 100 year wait, its current 'value' is approximately 37 cents.

With higher discount rates, the present value of a dollar of future income is progressively less –for example, with a 2 percent discount rate, a dollar of income 100 years hence has a current worth of less than 14 cents while, with a 4 percent discount rate, its present value is less than 2 cents. With discount rates of 8 percent and higher, the present value of a dollar of future income is less than a cent after a wait of only sixty years – 0.99 of a cent for an 8 percent discount rate and approximately only a third of a cent for a 10 percent discount rate.

Table 10: Present value of a dollar of future Income for various discount rates.

Income Year (Crop Rotation Length)	Year Zero Value of $1 at a Discount Rate (percent) of:				
	1	2	4	8	10
40	0.6717	0.4529	0.2083	0.0460	0.0221
60	0.5504	0.3048	0.0951	0.0099	0.0033
80	0.4511	0.2051	0.0434	0.0021	0.0005
100	0.3697	0.1380	0.0198	0.0005	0.0001

The information in Table 10 can be used to help understand the how critical, or more accurately how lacking in criticality, to the economics of longer-rotation (native) forestry is estimation of the correct stumpage value of wood.

With tōtara and kauri one is dealing with species with minimum modelled rotation lengths of, typically, at least forty to sixty years. Real-world for these species, as opposed to that of the model rotations, may well be 80 or more years. In addition commercial investors, particularly when they factor in the risks associated with growing these species (e.g., questions about how well the species/crop will perform/grow on their site; concern about possible risk of disease such as kauri dieback and perhaps total crop loss should their crop contract this; debate about the market size; and the possible failure to develop/grow what at present appears to be a limited market for species such as tōtara and kauri in the period from now until when their commercial plantation product comes on stream) are likely to be using discount rates in excess of 4 percent – and quite possibly greater than 10 percent. However, this means that for most 'commercial' investors any projected dollar of stumpage return (based on the above figures) is likely to have a current (year zero) value of less than 4 cents in their economic analysis.

Even if one goes with an extremely optimistic harvest - e.g., say 1,000 m3/ha, and a lowish (year zero) establishment cost (based on the data in Figure 3) of say $9,000/ha to simply cover those establishment costs, with each dollar of stumpage valued in year zero terms at $0.04 - the per cubic metre harvested 'stumpage value' has to be $225. In fact, the real stumpage required for economic viably is going to be greater than this figure because establishment costs are not the only costs associated with producing a merchantable crop.

Moreover, setting aside the issue of the impact of costs over-and-above establishment on the required stumpage, one can also note that the required per cubic metre stumpage to breakeven on establishment costs will be greater than the figure cited if one's discount rate is greater than 4 percent, if rotation length is longer than 80 years (at 4%) or more than 40 years for discount rates above 8%, or should harvest yields prove to be less than the postulated 1,000 cubic metres per hectare.

Clearfell vs Continuous Cover Forestry

In practice, it is highly likely that harvest will be less than this figure - if only because of the likelihood that any commercial indigenous forest will be run on a continuous cover rather than a plant and clearfell basis. Non-timber values – environmental, biodiversity, recreational etc – for a continuous cover regime are likely to be (significantly) greater with a clearfell option. While harvests will be more frequent than with a clearfell option, volumes removed at any harvest will be a significantly lower, costs greater and the mathematics of the analysis more complex than for a clearfell option.

Whatever option one choses to analyse though, unless one is prepared to postulates an extremely high stumpage price (and looking at Table 10 and the establishment costs of Table 1 that means a stumpage in thousands of dollar per cubic metre) one then has to question just how large a market is likely to exist for the product. It is clear that economic viability for long rotation forestry requires that forest to generate value/income while it is growing to a harvestable maturity. Without such an income it is difficult to see long-rotation forestry as commercially viable – and if one does have this income, the case for continuous cover and maintenance of this income even while obtaining a (small) stumpage income is strengthened. The fact though that one has this income diminishes the importance of the stumpage income in determining project economic viability – and the critical necessity to get the stumpage right.

Carbon and native forestry

Carbon models have been developed to determine typical carbon sequestration rates for native trees and shrub species commonly planted in New Zealand (Kimberley, Bergin & Beets 2014). These carbon models are based on growth and yield models developed from the TTT Indigenous Plantation Database and using published allometric equations for estimating carbon stocks from height and diameter measurements of natives (Beets et al. 2012).

Carbon yield curves showing predicted mean carbon sequestration rates on average sites are shown in Figure 3 for selected podocarp and hardwood tree species, and for mixed native shrub species commonly planted in restoration and afforestation programmes throughout New Zealand. A carbon yield curve typical of radiata pine stands is included for comparison.

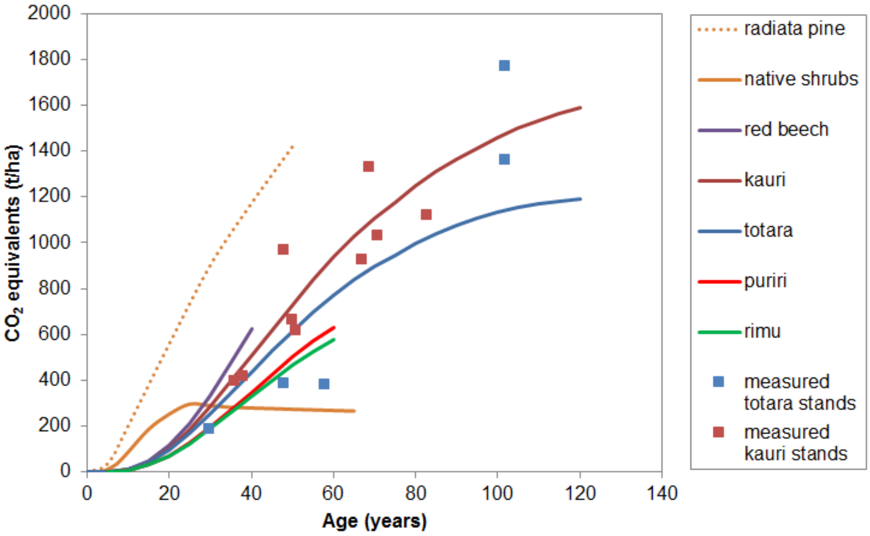


Figure 3: Predicted carbon sequestration on average sites for several native tree species, a mixed species shrub hardwood planting, and a typical radiata pine stand based on growth models developed from the Tāne's Tree Trust Indigenous Plantation Forestry Database.

Of the native conifers, kauri provides the fastest sequestration followed by tōtara and rimu which are somewhat slower. Because they are often planted at higher stockings, relatively fast-growing native shrub hardwood and small tree species often used in revegetation programmes on open sites can provide faster sequestration rates than native tree species over the first two decades after planting. However, they provide little additional sequestration beyond ages 20-30 years.

Carbon sequestration rates of New Zealand native tree species are slower than those of fast growing exotic species at young ages. However, beyond about age 50 years, the total carbon sequestered in a native stand can approach that of exotic species. As many native species are very long lived, they can be expected to continue sequestering carbon well beyond the age range shown in Figure 3. Unlike most radiata pine stands that are usually felled before 30 years of age at 800 t/ha CO2 equivalents, native forest can be managed as permanent forestry sinks potentially maintaining 2000 t/ha CO2 equivalents. These native forests can be established as conservation forests or on appropriate sites managed as sustainable production forests using Continuous Cover Forestry (CCF) principles where only small volumes are extracted as individual stems and hence maintaining near maximum levels of carbon storage.

Summary results for a generic base case analysis

Kauri

A summary of results on economics of planted kauri based on the assumptions discussed in this paper is provided in Table 11. On the assumptions used with the kauri analysis a 60-year rotation seems to give the best overall results and the IRR for this is 5.01 percent. At very low discount rates time is relatively unimportant, so the higher log price associated with older material compared to younger aged material dominates – and the greatest NPV is associated with the longest rotation. However, as one increases the discount rate the economically optimal rotation length shortens. Once the discount rate exceeds 5.01 percent the NPV turns negative.

As the discount rate is increased still further above NPV will continue to remain negative and (should a person with a higher than 5.01% discount rate continue to persist with kauri forestry, despite the negative present value) the optimal rotation length will continue to reduce. At a 6% discount rate (given that the model as set up only allows for three possible rotation lengths of 40, 60 or 80 years) the 60-year option is still the preferred one. It loses value but the loss is less than with either of the alternatives. However, once the discount rate exceeds 7%, the preferred rotation length reduces to 40 years.

Table 11: Summary of modelling results for kauri for three discount rates and three rotation lengths.

Discount rate (%)	Harvest age (years)	Harvest cost including roading ($/ha)	Merchantable volume at 70% TSV (m^3/ha)	Average 'at mill' log price ($/m3)	NPV of regime
2	40	$12,440	246	275	$11,874
	60	$26,232	590.8	388	$47,897
	80	$41,632	975.8	450	$66,996
4	40	$12,440	246	275	$45
	60	$23,232	590.8	388	$7,907
	80	$41,632	975.8	450	$6,011
6	40	$12,440	246	275	-$5,237
	60	$23,232	590.8	388	-$4,276
	80	$41,632	975.8	450	-$6,552

Tōtara

A summary of results on economics of planted tōtara based on the assumptions discussed in this paper is provided in Table 12. As with the kauri analysis the tōtara analysis shows the importance of value placed on time. Tōtara does not appear to be as profitable as kauri - if the focus is just on the sale of timber. That should scarcely cause any surprise as the average per cubic metre prices used for tōtara in this analysis are, depending on the rotation length, only 40 ~60 percent of those used in the kauri analysis. In addition, the merchantable yields used in the tōtara analysis for any rotation length are typically only something like three quarters those being used in the kauri analysis. Thus, the analysis is for a lower yield of lesser valued wood. Not surprisingly, then because of this the IRR for tōtara, at just over 3% Is considerably lower than for kauri. However, because the relativities between the wood prices for the various rotation ages differ between the two - the percentage increase between ages 60 and 80 being greater for tōtara (56%) compared to kauri (16%) – the rotation length associated with this IRR is 80 compared to the 60 years for kauri.

Table 12: Summary of modelling results for tōtara for three discount rates and three rotation lengths.

Discount rate (%)	Harvest age (years)	Harvest cost including roading ($/ha)	Merchantable volume at 70% TSV (m^3/ha)	Average 'at mill' log price ($/m3)	NPV of regime
2	40	7,140	178.5	135	-$6,477
	60	17,863	445.9	156	$1,839
	80	30,548	763.7	210	$12,395
4	40	7,140	178.5	135	-$8,168
	60	17,863	445.9	156	-$6,209
	80	30,548	763.7	210	-$5,274
6	40	7,140	178.5	135	-$8,773
	60	17.863	445.9	156	-$8,436
	80	30,548	763.7	210	-$8,639

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Hardwood Silvopastoral Systems

Ian Millner, Rural Directions

Introduction

The development of a pastoral industry in New Zealand has been a very recent (in historical terms) initiative. Pastoralism has developed through the modification of indigenous vegetation over the last 150 years with pastures developed out of extensive native grasslands and cleared native bush.

In New Zealand the need for soil conservation was recognised during the 1930s. The intense storm of April 1938, in which the Esk Valley suffered extensive soil loss and associated damage, is widely credited as the catalyst for both a regional soil conservation service and the Soil Conservation and Rivers Control Act 1941. This resulted in the establishment of exotic hardwoods (Poplar and Willow) for the express purpose of reducing sediment loss from farmland. Interest in and techniques for the co-management of pasture and tree species has evolved over the last 50 years.

The need for and subsequent development of an emissions trading scheme in New Zealand has re-energised interest in the potential for silvopastoral systems to provide co-benefits of production, environmental protection and carbon sequestration of and within the nations agricultural landscape.

This summary paper is a high-level discussion of the opportunities for silvopastoral systems within the agricultural landscape using hardwoods.

Hardwood vs Softwood

The definition of hardwood vs softwood can cause confusion as to the type of trees being discussed. In general, the distinction is as simple as the difference between conifer and broadleaf. However, confusion can arise where not all conifers (softwood) are less dense than all broadleafs (hardwoods). The distinction is based on botanical characteristics rather than wood properties. The prototypical hardwood was an Oak whereas the prototype softwood was a Scots pine; the wood of these two species has significantly different densities.

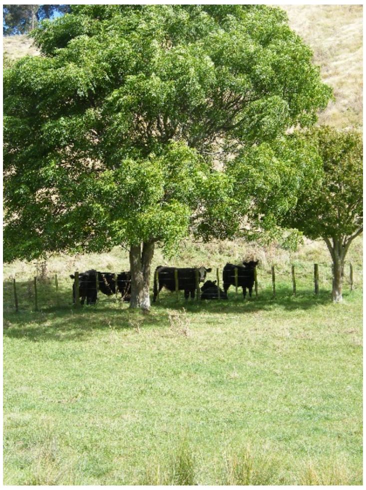
The actual difference between the two distinctions is that hardwoods have a complex cellular structure whereas softwoods are comparatively simple. This difference can often be seen in the visual appearance of finished timber with hardwoods often valued for the visual appearance of their grain.

Poplars

Traditionally, silvopastoral systems in New Zealand have been very simple approaches to managing soil conservation needs within a pastoral landscape. This has led to the predominant use of poplars (and willows) when establishing soil conservation planting for the very simple reasons that

they readily establish from cuttings (2-3 year old poles) and do not require the retirement of the planted are from livestock. This provides for the maintenance of cashflow for the pastoral enterprise.

The primary service that poplars provide is soil conservation and in general they perform this role very well. There are many reports of well-managed stands of soil conservation trees reducing the risk of erosion significantly.



However, the roles that poplars can and do fill within a pastoral enterprise are more than simply soil conservation. The various roles that poplars can provide within a silvopastoral regime can be summarised as the 6 S's. These are interrelated but distinct services or values that poplars can provide.

The 6 S's are:

1. **Soils** – when planting poplars, the predominant value that will be delivered is the protection of soil. In general, it is far more cost effective to plant poles in areas where soil value is high and where erosion is a significant risk.
2. **Structures** – soil conservation plantings can and do protect infrastructure. Often it is the loss of infrastructure after large storm events that hinders the recovery. Obviously planting trees next to infrastructure requires evaluation of the appropriate variety and management and the respective opportunities.
3. **Shade** – the provision of shade is a frequently undervalued service provided by the establishment of silvopastoral systems. In recent detailed research of the effects of shade on the behaviour of Angus cows, shade was shown to increase the amount of time animals spent grazing[1].
4. **Shelter** – trees are proven to reduce the energy in wind and therefore both the evaporative and chill factor downwind. This has the effect of contributing to slower soil moisture decline and reduces the amount of energy that animals need to consume in order to overcome the stress of being cold. In hill country, well placed soil conservation tress can have positive effects on animal performance, in particular lambing percentage.
5. **Stock fodder** – poplars (and willows) can provide nutritious forage for grazing livestock that can provide a positive contribution to total feed supply during dry seasons. However, this does require specific management and therefore trees planted with stock fodder as an objective need to be accessible and manageable.
6. **Sequestration** – poplar does sequester carbon and as such will have some value if accounted for within a properties carbon profile. Poplar can have similar density to

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[1] *Impact of Shade Trees on Angus Cow Behaviour and Physiology in Summer Dry Hill Country: Grazing Activity, Skin Temperature and Nutrient Transfer Issues'* Keith Betteridge, Des Costall, Sam Martin, Brenden Reidy, Angela Stead, Ian Millner. http://flrc.massey.ac.nz/workshops/12/Manuscripts/Betteridge_1_2012.pdf

radiata pine. Actual sequestration will depend on planting density and basal area (see figure) and age.

Other species

Alder –Alders have a range of possible sites where they will grow well. Nitrogen fixing, making them well suited to eroded areas. Fast growth rates in right site. Deciduous.

Oak – well known timber tree, fast growing in the right site.

Plane – advantage is that it can establish from poles (same process as poplar). Very strong and tough root systems. Needs to be sited well. Has timber value. Can coppice hard.

Eucalyptus – huge variety of species, most grow well in Hawke's Bay. Range of opportunities from timber to carbon. Disease and pest risk.

Walnut – well known tree, valuable timber, produces nuts that will produce seedlings.

Robinia – fast growing, deciduous, Nitrogen fixing, very durable timber – traditional vineyard post timber, good form can be hard to achieve.

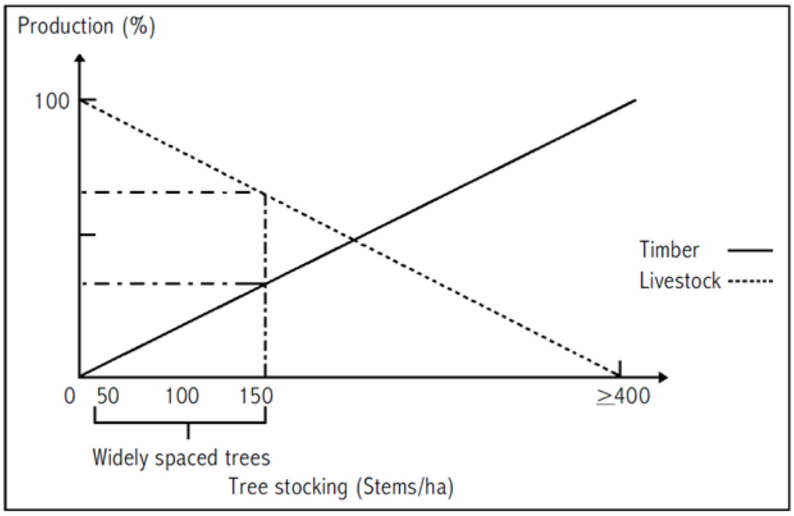
Natives – beech, Rewarewa, Tawa – slow growing, valuable timber, specialised management.

Trees vs Grass

Planting trees within a pastoral system can change the soil moisture dynamics of the existing system. This occurs as trees in effect have a much higher leaf area index (6-8 vs pasture 2-3) and therefore intercept higher amounts of rainfall. The canopy from space planted poplars can evaporate approximately 1mm every time it rains. In addition, the pasture itself will evaporate a similar amount which means rainfall would need to exceed 2mm before soil moisture can be affected.

However, as trees also shade the pasture to some extent (depending on canopy area) soil moisture under trees can decline much slower than in open pasture because pastures under shade are typically less dense and therefore transpire less water.

Pasture losses under trees need to be balanced with the risk of future erosion events that will reduce pasture growth, and changes to animal performance.

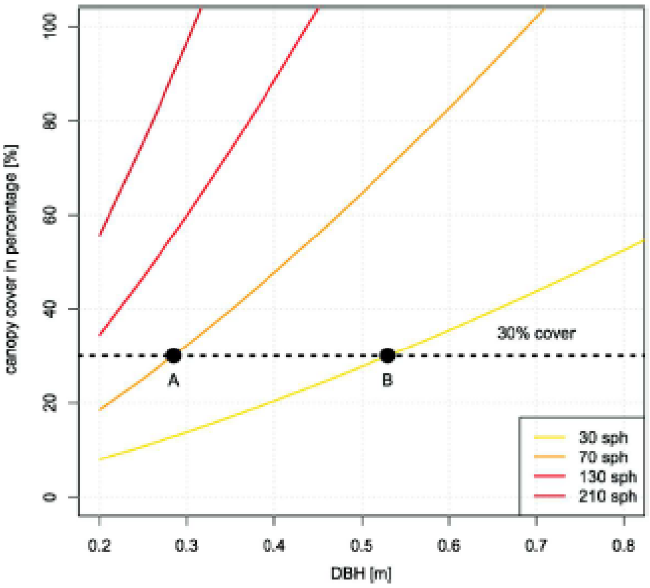


Pasture management in a silvopastoral system will need to be adjusted to realise the potentials of a new system in comparison to the existing system. Adaption of current management to a silvopastoral system include:

- Grazing frequency and severity. Growth rates, composition and dynamics of pasture growing under trees will be different from that growing in open pasture. Consideration should be given to the type of livestock class at different times, the types of forage that might perform in a low light environment, and the system requirements (e.g. lambing vs finishing).
- Infrastructural development. Silvopastoral systems will require a different approach to infrastructure, i.e. the shape of paddocks, access, reticulation etc.
- During establishment grazing may not be possible for 2-3 years if species other than poplar are established. If this is the case, then consideration needs to be given to what stock classes are reintroduced and in what order to minimise overall farm system disruption.

Ultimately, it may be more beneficial to consider a complete re-evaluation of the farm system employed within a silvopastoral system. This may include the quantification of other income streams (carbon, nuts, timber, ecosystem services) or it may include the evaluation of other species growing between and under the trees. Species like Tagasaste may be beneficial in this regard as they would enable the development of a browse system.

A browse system has the potential to deliver large quantities of high value forage that can have tactical value at differing times of the year. The conversion from a pasture-based system to a browse-based system has the same time frame to establish and may enable multiple species to be established. This in turn will enable the transition to a mixed age mixed species silvopastoral system.



The establishment of a mixed age mixed species system could provide for long term high value timber species to be established alongside shorter term high value species.

If establishment is done within the protection of a Tagasaste nurse crop (which then becomes a browse block) tree form and growth will be higher. Obviously, any animal products produced in this type of system will have unique value and emissions profiles that may offer additional opportunities for capable marketers.

Other value – carbon

The development of an emissions trading scheme (ETS) in New Zealand has led to the opportunity to sequester carbon through the development of forests on previously unforested land. Carbon is accounted for through estimations of the total tonnes of timber within a stand multiplied by the density of the timber. Table 1[2] outlines the relative density of dried timber for a range of different species. The respective age of the trees this data was obtained from is unknown. Timber density may change for different species with age.

Table 1: Dried timber density

Species	**Kg/M3**
Totara	480
Silver Beech	610
Radiata	500
Macrocarpa	475
Poplar	465
English oak	750
E. Fastigata	615

The ability to grow trees and receive an annualised income ‘upfront’ has considerable appeal for anyone managing hill country land with an erosion potential. However, while this option may appear favourable to the current generation the opportunity is not without risk. Obviously should carbon ever be lost (fire, wind, disease) or should the land ever need to be deforested, carbon sold will need to be purchased in order to remove any liability. It is clear that the sale of carbon provides intergenerational opportunity and risk.

However, the establishment of a poplar hardwood plantation that includes poplar as a nurse crop and provides transitional income through carbon, along with a longer-term high value timber such as oak, provides further options. A silvopastoral regime of this type would be designed to exploit the fast establishment and short-term carbon option of poplar that will enable the cost-effective establishment of a long-term timber tree (with some carbon potential) and still provide some utility/ options within a livestock operation. Incorporating different tree species into any overall farm silvopastoral strategy will enable an effective balance between pasture and carbon revenues.

Site Specific Strategies

The specific management or regime of any silvopastoral system should be guided by the site-specific requirements. These requirements will influence:

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[2] Table : Wood density values (12%moisture) for a range of common tree species. (From: NZ Timbers, N.C. Clifton, 1991.

- Species to be planted that will successfully establish. Based on known extremes within site
- Management requirements for both trees and farm system
- Additional value opportunities (carbon, fibre, nuts etc).

The potential variation within landscapes is almost infinitely variable. Variation is driven by differences in slope, soils, geology, climate, altitude etc. The types of issues to be managed in the landscape are also driven by this variation. In hill country the predominant issues to be managed are erosion and subsequent effects (e.g. loss of infrastructure). Consequently, erosion and its effects will be highly spatially variable.

The response to the spatial variability of erosion should therefore also be spatially variable, whereby strategies employed to control shallow soil slip mid slope will be different from strategies to control stream bank erosion.

Examples:

- A poplar regime to control shallow soil slip may involve the space planting of poplars in a matrix across the slope, with the degree of erosion or slope angle being reflected in the spacings between trees (with distance varying from 8m spacings for severe erosion risk to 15m – 18m for marginal erosion risk).
- Poplar (or willow) planting to control stream bank erosion is more effective when trees are simply pair planted (or planted in a zigzag) adjacent to the stream (not within the steam banks). The distance between trees will reflect the size and steepness of the stream.

The site-specific management regime is the predominant method to influence cost benefit of silvopastoral systems. Three-meter poles can cost between $15 – $20 per pole (when accounting for planting costs). This is a significant investment and should be planned to maximise actual and potential benefits. These benefits are best considered within a whole farm system analysis that considers physical, management, and financial outcomes.

Hydrology

Trees planted in pastoral landscapes have many and varied effects. One significant effect that is frequently overlooked is that trees can and do influence local hydrology – they can lower the water table. Wall et al[3] have outlined situations where Pinus radiata has lowered the water table by 2m in New Zealand and in Australia, and where tree cover with 35% canopy also reduced the water table by 2m over a 9-10-year period.

From this, it becomes apparent that the strategic use of trees in the landscape may offer benefits beyond soil conservation. These benefits potential include the ability to manipulate soil hydrology to minimise potential risk around contaminants other than soil. For example, the ability to establish a silvopastoral system that lowers the water table and reduces drainage may have significant benefits for the prevention of N and P loss. This aligns with the practice many farmers have adopted of using tree blocks as stand-off pads when conditions are wet.

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[3] The impact of widely spaced soil conservation trees on hill pastoral systems, A.J.Wall et al. proc NZGA 59: 171-177 (1997)

Franklin et al[4] concluded "These deep rooting species could intercept leached N at greater depths than the root zone of pastures and their high growth and evapotranspiration rates are likely to enhance N uptake" when discussing the potential for silvopastoral systems to mitigate nitrate leaching from intensive agriculture in New Zealand.

In a 2018 study on the effects of poplars on the nitrogen and water balance in an outdoor piggery Manevski[5] et al found "The poplar zone showed significantly lower nitrate leaching, by 75–80%, compared to the grass zone." This study provides proof of concept that trees do lower potential contaminant loss, although additional work is required to adequately describe this opportunity within a New Zealand pastoral system. Further studies of local hydrology would need to be undertaken. Within a farm planning context the opportunity to identify ground water seeps and change their character and risk through the use of Silvopastoral systems is of value.

Harvest returns and timber regimes

(personal comments from Tim Forde, HB Farm Forester.)

Harvest returns are problematic to predict for such a system and are subject to wide ranging species, silviculture and site access. Success in current markets will be dependent on niche marketing of domestic and export sawlogs or on-farm/portable milling and custom treatment.

However there are small scale examples of success with marketing and trial use of poplar in Hawke's Bay based on a 28 year rotation and portable milling, and small batch CCA treatment for farm use and specialty end uses such as truck decks, furniture and toys. The innovative grower or processor may capitalise on this, probably at low volumes.

As a base regime (subject to enormous variation)

Rooted cuttings can be established in pasture with single wire electric fencing maintained to exclude cattle but allow controlled grazing by sheep. Costs for a possible timber and grazing regime (planting at 100 per hectare =10mx10m spacing) have been quoted at:

Regime	Per tree	Total
Pre spray	$0.50	$150
Cuttings	$6.00	$600
Planting	$2.00	$200
Fencing	$6.00	$600
Pruning/form pruning	$6.00	$600
Stumpage for estimated 370 tonnes/ha		$30-50K

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[4] Franklin H., McEntee D. and Bloomberg M., 2016. The potential for poplar and willow silvopastoral systems to mitigate nitrate leaching from intensive agriculture in New Zealand. In: *Integrated Nutrient and Water Management For Sustainable Farming*. (Eds L.D. Currie and R.Singh). http://flrc.massey.ac.nz/publications.html. Occasional Report No. 29. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand. 10 pages. (Free online)

[5] K. Manevski et al. / Science of the Total Environment 646 (2019) 1448–1458

Returns (stumpage) from on-site milling have been claimed at $30-$50K per hectare at 28 years.

Further research is indicated to identify optimal regimes, species, milling and treatment practices in Hawke's Bay. This is probably merited given the multiple potentials for grazing, timber, stock welfare and carbon and the fact that there is now an optimistic local example and a significant underutilised resource.

Reference: https://www.nzffa.org.nz/farm-forestry-model/species/poplars-and-willows/videos/new-zealand-poplar-farm-milling/

RIGHT TREE, RIGHT PLACE

HAWKE'S BAY AFFORESTATION PROGRAMME (HBAP)

Species assessment – Cypresses

1. Introduction

There are three main species of cypress grown in New Zealand – macrocarpa (commonly known as Monterey cypress, *Cupressus macrocarpa*), lawsoniana (commonly known as Lawson cypress *Chamaecyparis lawsoniana*), and lusitanica (commonly known as Mexican cypress *Cupressus lusitanica*). As of 2007, approximately 8,000ha of these species had been planted around the country (NZ Wood, 2008).

Most of the cypresses that are commonly encountered in New Zealand were first introduced during the 1860's and were widely planted because of good growth rates and adaptability to New Zealand's climate. Many were planted as shelterbelts rather than in plantations, and as such grade recoveries can be variable but because of age, colour tends to be rich. There is good demand for macrocarpa as it can be a high-quality softwood timber. All three of the above are approved species for building construction (enclosed framing, weatherboards, decking) in New Zealand.

2. Site Requirements

2.1 Climate

- **Temperature** affects many aspects of growth. Macrocarpa is a relatively wind-hardy species that does best on cooler sites, whereas lusitanica requires some shelter from wind and in particular salt-laden wind.
- **Rainfall** is also an important consideration. Lawsoniana is susceptible to drought and requires a high rainfall site. Macrocarpa is slightly more tolerant of drought conditions than lusitanica, whereas torulosa is very drought resistant.
- **Wind** can have adverse effects on tree form and growth. Lawsoniana is a hardy species that can withstand wind and snow. Macrocarpa is capable of enduring salt-laden winds but does better with some shelter. Lusitanica requires more shelter than macrocarpa and can suffer dessication of foliage when exposed to salt-laden winds.

Cypresses are best suited to reasonably sheltered sites with moderately fertile soils and a mild climate. A summary of site preferences by species is shown below.

Table 1: Climate profile for cypresses (Miller, 1996).

Climate variables	C. macrocarpa preferred	C. lusitanica preferred	C. lawsoniana preferred	Hawke's Bay actual (Chappell, 2013)
Frost limit (°C)	-10.0	-10.0	-15.0	-6.0 to -12.0
Mean annual rainfall (mm)	500 – 2,000	800 – 3,000	1,000+	707 - 2,000+

2.2 Topography

- **Elevation** has effects on tree growth, primarily due to its modification of climatic variables such as temperature and snow (see above). Lawsoniana can survive severe conditions up to 900m and produces well-grown trees in some locations up to 600m. However, lower altitudes between sea level and approximately 350m are preferred by macrocarpa and lusitanica.

- **Slope** can be a limiting factor for commercial plantations, primarily for health and safety and environmental reasons. With increasing focus on safety of planting operations, some very steep slopes may not be planted due to unacceptable risk for workers. Slope also affects the cost and complexity of harvest operations, and the susceptibility to erosion. Cypress species, particularly lusitanica, can be prone to toppling on some sites, with exposure, rainfall, and soil weight all risk factors.
- **Aspect** has a reasonable impact on productivity, as it alters the pattern of radiation. North-facing slopes are warmer than south-facing slopes. North-westerly aspects are often more exposed to high winds in the Hawkes Bay region. A southern, cooler aspect is favoured for macrocarpa as a means to reducing cypress canker (NZFFA, 2007).

Table 2: Topography requirements for cypresses.

Topography variables	C. macrocarpa preferred	C. lusitanica preferred	C. lawsoniana preferred
Altitude range (m)	0 – 600+	0 - 600	0 – 600, up to 900

2.3 Soils

For best growth cypresses prefer moderately fertile, free-draining soils with adequate moisture, mild climates and reasonably sheltered sites (Miller, 1996).

2.4 Access and infrastructure

If establishing a cypress crop for eventual harvest, access to the crop will be required into the future. The following should be considered before establishing a plantation forest:

- **Distance to market** (is there a viable customer located within a reasonable distance of the site?)
- **Legal access** (can the site be accessed without encumbrance?)
- **Infrastructure requirements** (can the site be accessed for planting and ongoing management; can roads and skids be installed to get produce off the site profitably?)
- **Harvest requirements** (can the crop be harvested profitably using available harvest systems?)

2.5 Species and species selection

A range of cypress species can be grown in Hawkes Bay and these can be propagated from either seed or cuttings.

Clonal cypress

Clonal (cutting-grown) cypress can be planted at considerably lower densities than seedlings. This is because clones are selected for good growth and form and grow consistently. However, cutting-grown trees are more expensive to produce than those grown from seed.

Cypress is well suited to clonal propagation and research suggests that clonal selection offers the best short term deployment pathway for improved planting stock (Satchell, 2017). However, only a small number of clonal selections are currently available for deployment and to date these have only been selected for good form and growth rates. Selection criteria should also include wood properties, in particular structural properties, heartwood content and durability.

As breeding programmes mature, improved seed will become available. The advantage with seedlings is that these can be grown at considerably lower cost than cutting-grown stock, which equates to lower establishment costs because of a lower required selection ratio. This has been the case for decades for radiata, with stocking rates going down as tree genetics have improved.

Species

Cypress species can be matched to every production forestry site in Hawkes Bay. Understanding the limitations of different species allows selection and deployment of the right species for the site. Where there is uncertainty with exact matching of species to site, two species can be planted together so that the best species prevails.

General information on siting by species and clone is provided below:

***Cupressus lusitanica* Mexican cypress**

Should not be planted where exposed to prevailing or salt-laden wind. Requires adequate shelter and free draining soils. Requires moderate fertility for good growth rates. Reasonably drought tolerant. Similar growth rate to macrocarpa.

***Cupressus macrocarpa* macrocarpa**

A canker resistant seedline or clone is a prerequisite to planting in Hawkes Bay. Copes well with coastal conditions but suffers from severe snow damage in sites subject to heavy snowfall. Requires moderate fertility for good growth rates. Reasonably drought tolerant. Similar growth rate to lusitanica.

***Chamaecyparis lawsoniana* Lawson cypress**

Lawson cypress requires cool and moist conditions and should only be planted in high-elevation Hawkes Bay sites. Tolerates heavy snowfall and severe frost. Requires regular rainfall and is not tolerant of drought. Slower growing than macrocarpa and lusitanica (2/3 growth rate). Light-coloured timber.

***Cupressus torulosa* Himalayan cypress**

Himalayan cypress is extremely drought tolerant, extremely wind hardy and canker resistant. Himalayan cypress tolerates heavy snowfall and severe frost. Requires moderate fertility for good growth rates. Suitable for most of Hawkes Bay including extreme climatic conditions, with the exception of salt spray. Suitable for eroding hill country but will require an extended rotation length if soil conditions are poor or skeletal. Slower growing than macrocarpa and lusitanica (1/2 to 3/4 growth rate, equivalent to Himalayan cedar, *Cedrus deodara*). The timber is highly scented and a colour similar to macrocarpa.

***Cupressus x Ovensii* Ovens cypress**

Ovensii is a hybrid clone and cross between *Chamaecyparis nootkatensis* and *Cupressus lusitanica*. Ovensii has a well proven track record in New Zealand as a well formed canker resistant cypress cultivar. The timber is a lighter colour than macrocarpa and lusitanica and with less lustre. Durability and mechanical properties have not yet been assessed but are expected to be similar to Leyland cypress. Requires free-draining soils of moderate fertility. Fairly wind hardy and resists heavy snowfall. Resistant to canker. Slower growing than macrocarpa and lusitanica (2/3 to 3/4 growth rate).

***Cupressus x Leylandii* Leyland cypress**

Leyland cypress are hybrid clones from a cross between *Chamaecyparis nootkatensis* and *Cupressus macrocarpa*. The Leyland cultivars have proven to be highly susceptible to canker in New Zealand and are not generally recommended for plantations. One cultivar "Ferndown" has proven to have good form and can be grown in cooler areas where canker is a low risk. The Leyland cypress cultivars are very wind resistant and tolerate heavy snowfall without damage. The timber is a lighter colour than macrocarpa and lusitanica and with less lustre. Durability and mechanical properties tend to be slightly better than macrocarpa and lusitanica. Leyland cypress is generally slower growing than macrocarpa and lusitanica (2/3 growth rate).

3. Establishment and early growth

3.1 Land preparation

Land preparation is undertaken to promote early growth, control weed competition, and promote wind firmness. Preparation activities are usually undertaken using hand tools, machinery, fire, chemicals or animals (grazing). The specific type of land preparation will depend on the condition of the land.

- **Ex-grazing land.** Land preparation requirements for land that is primarily grass are relatively little. The most efficient pre-plant preparation will be hard grazing prior to planting. If grazing is not possible prior to planting, an aerial broadcast application of herbicide may be required. Boundary fences will likely need to be installed or modified, and internal fences may need to be removed to avoid future hindrance.
- **Scrub or brush land.** On sites with high incidence of scrub, gorse, blackberry or other brush species, an aerial application of brushkiller may be required. If this brush is dense or > 2m in height, it may also require some mechanical clearance too, either via roller crushing, or line cutting.
- **Cutover land**. Prior to replanting land following harvest, it is often necessary to complete some form of mechanical land preparation, to clear away logging slash. This is especially so on flatter areas that have been harvested using mechanised systems. Usually machines will heap slash up into windrows to clear space for the new crop.

  A desiccation spray is also usually required to supress weed growth prior to replanting.
- **Spot mounding.** To prevent frost damage to young trees, frost-prone areas will often be spot mounded. This lifts the tree up out of the frost hollow. Spot mounding is also used to aid establishment in areas of high soil compaction.

The following table shows some indicative land preparation costs that could be expected for operations undertaken in the Hawke's Bay region.

Table 3: Indicative land preparation costs ($/ha)

	Operation cost estimate ($/ha)		
Operation type	**Ex-grazing land**	**Scrub / brush land**	**Cutover land**
Grazing	0		
Aerial spraying		250	300
Roller crushing / line cutting		0-500	
Windrowing /Spot mounding			0-700
Tracking and fencing	50	50	
Total	50	300-800	300-1,000

3.2 Planting stock

When selecting which planting stock to plant, the following options should be considered:

- Genetics. Cypress is grown as either clonal or seedling stock. Selections should have a proven track record and only improved stock grown where possible. Clonal stock has the advantage of rapid selection whereas seedling stock must undergo a longer process of generational improvement.
- Propagation method. Cypress can be either propagated as bare rooted or containerised stock. Bare-rooted stock should be regularly wrenched to encourage a fibrous root system and then planted properly to minimise root distortion. Bare rooted stock must be planted in winter. Containerised stock must be grown with minimal root distortion, through appropriate pricking out processes and management of container-wall root deflection (e.g. by

using side-slot containers). Containerised planting stock has an extended planting season through winter and spring. Good quality seedlings that are planted well minimise subsequent toppling of trees.

- Nursery location and transport. Bare rooted stock is easier and lower cost to transport long distances. Bare rooted stock must be refrigerated immediately upon receipt and planted within a week. Containerised stock can be lined out in nursery conditions after receipt and planted at the nearest convenience.
- Clonal Hybrids

  Some cypress hybrids have been developed. The most notable is the Leyland cypress (x Cupressocyparis leylandii), but these tend to suffer from canker disease. “Ovensii” has established a reputation in New Zealand as a reliable clonal variety. Clonal stock are reproduced by cuttings and specialised facilities are require for mass propagation. Clonal stock is more expensive than seedling stock but offers more consistency in growth and form. Clonal selections have been made in New Zealand from putative hybrids between lusitanica and macrocarpa and Scion have released *Chamaecyparis nootkatensis* hybrid clones for field evaluation.

3.3 Initial stocking rates and survival

It is most common to plant more cypress than are required at harvest, for the following reasons:

- Isolated mortality can be compensated for
- Selection of best performing trees is possible at time of pruning and/or thinning
- Trees influence the growth of their neighbours, so planting close together can result in improved straightness, smaller branching, and better early height growth (Maclaren, Radiata pine growers' manual - FRI bulletin No.184, 1993)

Supervision and quality control of planting operations is crucial to ensuring that trees are planted safely, correctly, in the right locations, and at the appropriate stocking rates. Survival assessment is also usually undertaken in the months following planting. This helps to determine what areas may require “blanking” – restocking the following winter.

Cypresses are relatively shade-tolerant and produce best log volumes at higher stockings than what is normal for pines. High initial stockings of between 1000 and 2000 stems per hectare are typically recommended for seedling stock. This high initial stocking helps to promote canopy closure, supress weeds, reduce branch size, and provides a large selection ratio for thinning (Miller, 1996).

3.4 Planting

Planting of cypress is almost always a manual operation, with planting crews using spades to cultivate the spot before hand planting the seedling. Labour shortages exist in many regions including Hawkes Bay, primarily due to the seasonal nature of the task. Labour is also affected by reduced demand for other silviculture operations such as pruning.

Costs for planting labour and management will usually vary on area, stocking rate, travel distance, terrain, access limitations (e.g. how closely you can have trees delivered) and land cover (scrub or cutover land being generally more expensive to plant than grass).

The table below summarises expected costs for planting cypresses in Hawke’s Bay.

Table 4: Indicative cypress planting costs

	Planting cost ($ per hectare)		
Cost Type	**Easy**	**Medium**	**Hard**
Labour cost (833 sph)	550	650	750
Operations management	130	200	260
Total	**680**	**850**	**1010**

4. Silviculture and forest management

4.1 Post-plant weed control

Cypresses usually need releasing from weeds at least once after planting. Releasing by over-spraying is effective with the correct chemical type.

Table 5: Indicative cypress releasing costs (using Prad as default for now)

Cost type	Releasing cost ($ per hectare)		
	Chemical – Aerial	**Chemical - knapsack**	**Manual**
Labour / equipment cost	90-120	200-250	500-700
Chemical cost	100-160	20-35	-
Operations management	40	60	70
Total	**230-320**	**280-345**	**570-770**

4.2 Fertiliser

Cypress requires soils of at least moderate fertility (Nicholas, 2007). Growth rates should be monitored and foliar or soil tests undertaken where trees are not performing, Individual sites, in particular eroded sites should be examined closely to determine potential fertiliser requirements.

4.3 Silviculture strategy

The primary consideration when developing a silviculture strategy for cypresses in Hawke's Bay is whether to prune. Pruning is the removal of lower branches at a young age, which allows future diameter growth to be free of knots. The resulting "clearwood" is of considerably higher value when the trees are harvested. Thinning is essential and is the removal of a selection of trees to a target "final crop stocking" which allows the best trees more space to grow in height and especially diameter. This is especially important for a pruned stand, as clear heartwood development relies on a tree's ability to add significant diameter growth. However, even an unpruned regime requires thinning to retain well-formed trees and produce diameter growth, essential for generating both log value and biomass.

Table 6: Possible silvicultural regimes for the production of clear cypress timber (Miller, 1996)

Thinning regime	Mean top height (m)	Residual stocking (stems/ha)	Operations
Heavy early thinning		2000	Plant at a spacing of 2.0 – 2.5m
	5	600	Waste thin and prune to 2m
	9	200	Waste thin and medium prune to 4m
	13	200	High prune to 6m
	30		Clearfell
Production thinning		1000	Plant at 3 x 3m spacing
	3	600	Malform thin when visible
	5		Waste thin, low prune to 2m
	9	600	Medium prune to 4m
	13	300	Waste/production thin, high prune to 6m
	20 – 25	150 – 200	Production thin (optional)
	30 - 40		Clearfell

4.4 Pruning

Pruning of lower branches is undertaken when trees are relatively young, as this helps to minimise the "defect core" - the interior section of a pruned log that contains unsightly pruning scars. It is also easier and cheaper to prune trees when their branches are still relatively small.

Pruning should not be excessively severe and should retain sufficient crown depth for the tree to recover and continue growing. However, pruning should also check growth sufficiently so that branch diameters and stem diameters do not exceed specifications at the next intervention. Branch size should never exceed 40mm and diameter over stubs (DOS) should never exceed 15 cm. As such, pruning of cypresses should be light and frequent to avoid formation of pruning scars that encroach into the clearwood (Miller, 1996).

4.5 Thinning

Stocking should be maintained at the original level until well formed trees with good growth rates can be distinguished in the crop, as this is the general aim of tree selection. Thinning regimes should be flexible but the general rule is thin little and often to mitigate risk of windthrow. In pruned stands retaining a maximum final stocking of 300 stems per hectare is essential for clearwood production, whereas for unpruned regimes final stocking should be higher, up to 600 stems per hectare. Lusitanica has shallow roots and intensive thinning on soils known to be conducive to windthrow should be avoided (Miller, 1996).

4.6 Forest management

Forest management requirements will depend usually on the scale of the forest resource and expertise of the owner. Very small forests may be managed with little effort by the owner, but owners with little spare time or experience, or with a large forest asset may choose to engage the services of forest manager. The specific forest management required will vary from forest to forest, but primary management roles and responsibilities can include:

- Preparation of budgets and work plans/schedules
- Contractor engagement and supervision of forest operations
- Mapping and stand record-keeping
- Cost tracking and reporting
- Consent application and administration
- Security, protection and infrastructure maintenance
- Health and Safety and Environmental (HS&E) compliance
- Professional and technical advice
- Liaison with regulatory bodies and other agencies, neighbours, iwi and affected parties as required

Costs for undertaking forest management activities will depend on agreed scope of responsibility, and will also vary based on forest location, scale and competition for services. The table below summarises some indicative forest management costs that could be expected for forests in Hawke's Bay.

Table 7: Indicative cypress forest management costs

	Cost ($ per hectare)		
Cost type	**Low**	**Medium**	**High**
Forest management	15	25	35
Administration	5	15	25
Protection and maintenance	10	20	30
Total	**30**	**60**	**90**

5. Pests, diseases and other risks

5.1 Wild animals

Cypresses are most susceptible to damage when young, as trees are reasonably well defended once their branches have grown to protect the stem. Control of wild animals is often as much for protection of biodiversity and environment as it is about protecting the tree crop. Wild animals can be vectors for disease such as bovine tuberculosis and can also predate on indigenous wildlife. Some wild animals have recreation value through hunting, and so control of these species may be achieved with little or no cost.

The requirements for control of animal pests will vary from site to site. The primary animal pests that are likely to be encountered in Hawke's Bay forests that are an issue for cypresses:

- **Hares and rabbits** are attracted to young trees, especially those freshly planted. Trees are sliced off at an angle near ground level and are left where they lie. Because they are not eaten, this is likely to be territory marking and can be very destructive. Hares and rabbits should be well controlled.before planting.
- **Possums** can also cause considerable damage in some lusitanica stands, which results in stem malformation. Possums tend to be controlled through poisoning, trapping or shooting, and will be warranted if planting lusitanica in areas known to be high in possum numbers.
- **Pukekos** can be extremely destructive to newly planted containerised stock. Trees are pulled out of the ground by the stem and abandoned. This appears to be in search of worms and large numbers of trees can be destroyed.
- **Livestock** such as sheep and cattle can be problematic on ex-farm sites. Some root damage is caused by trampling, but cattle in particular must be excluded from cypress trees of all ages to avoid severe bark stripping which kills the trees. Cypresses can also induce abortion in cattle if the wilted foliage is digested, so in-calf cows should be kept away from cypress stands. Sheep pose some risk to young trees but cypress stands can be grazed by sheep. Livestock can be controlled simply through effective fencing.
- **Goats** are potentially a risk, particularly in northern Hawke's Bay. Control is usually by shooting, and risk areas should be managed pre and post-planting.
- **Pigs and deer** are also prolific in certain parts of Hawke's Bay, and should be managed appropriately where deemed to be a risk to successful establishment. Deer are very destructive to large numbers of trees by stripping of bark and rubbing that ringbarks them and leads to their death.

5.2 Insect pests

A wide range of insects and larvae have been found in dead or decaying cypress, but few attack living cypresses. The cypress bark beetle and native two-toothed longhorn beetle are the two most prevalent insects that affect cypresses, but clean and timely pruning can help to provide insurance against such attacks (Miller, 1996).

5.3 Diseases

The main disease that affects cypresses in New Zealand is cypress canker. Symptoms are resin bleeding and bark discolouration, resulting in distorted growth, cankers and branch dieback. It is known to affect at least five different types of cypress, including macrocarpa, lusitanica and lawsoniana, and is arguably the main reason why the former has not been widely planted as a plantation species (NZFFA, 2007).

Warmer parts of the North Island tend to have higher levels of cypress canker, and therefore consideration towards more resistant species such as lusitanica and torulosa and resistant clones such as Ovensii should be given in regions such as Hawkes Bay. The disease tends to be more prevalent on trees in warm sites that are physically stressed, so it is important to consider siting factors that cause stress such as drought and wind, or planting resistant seedlines or clones.

5.4 Fire

Fire is a known risk for plantations in New Zealand, with over 40,000 hectares burned in the last 60-70 years. The principal causes of fire are arson, escaped burns, forestry operations, spontaneous combustion, vehicles and campsites. Fires started outside the forests usually pose the biggest risk (Mead, 2013).

Management of fire risk will likely be a combination of protection operations and fire insurance. Forest design can also influence fire risk, by providing fire breaks and buffers of less flammable species in risk areas like road edges and powerline corridors.

5.5 Wind

Cypress has a high risk of windthrow. Wind is a known risk factor in Hawke's Bay, with severe damage caused to pine plantations across the north and east of the North Island when Cyclone Bola struck in March 1988. Significant damage could also occur to cypresses if a similarly extreme event occurred in the future.

Risk of wind damage will primarily depend on level of exposure and age of the trees. Timing of silviculture (especially late thinning) and quality of planting and treestocks can also influence risk of windthrow or stem breakages (Somerville, Wakelin, Whitehouse, & (Eds), 1989). Management of wind risk will often include a combination of methods, such as:

- Site selection
- Treestock quality
- Timing and intensity of silviculture (especially thinning)
- Harvest planning and scheduling
- Insurance
- Windthrow salvage

5.6 Insurance

Risks associated with fire and wind damage can usually be mitigated through appropriate insurance cover. Insurance will usually compensate a proportion of the current tree crop value, and often also provides compensation for the costs of clearing and replanting land. Public liability cover is also usually included. The table below summarises indicative insurance cover costs for an average Hawke's Bay radiata pine forest.

Table 8: Indicative radiata pine insurance costs, average of first 28 years.

	Cost ($ per hectare)	
Cost type	**Pruned**	**Unpruned**
Fire	22	16
Wind	22	16
Public Liability	1	1
Total	**45**	**33**

5.7 Wilding spread risk

There is minimal wilding spread risk from cypresses.

6. Productivity and Returns

6.1 Market value and timber properties

Cypress or "macrocarpa" is a well-known tree species and specialty timber in New Zealand, appreciated for its unique properties, including colour, aroma and appearance. Typical applications include cladding, decking, appearance beams, rafters and framing, along with timber joinery such as fittings and furniture.

Cypress species and hybrids have gained a solid reputation in New Zealand for producing a premium softwood timber. Natural durability combined with decorative appearance generates a premium for the timber over radiata pine. However, of most interest to the prospective grower of cypress are the potential returns. Estimating financial returns would require estimating both productivity and log values. Productivity is a function of species, regime and site factors whereas estimating future log values is inherently speculative.

The combination of lack of scale, lack of co-ordination between growers and resulting lack of market development activities suggest that market potential has not been realised to date in the export log market. Despite this, the small volumes exported to date have achieved a significant premium over the prices received for equivalent grades of radiata pine. Such premiums can only be attributed to specific desirable wood properties and demand for these and with some effort these properties could potentially be exploited for pecuniary gain. The growers' levy-funded Specialty Wood Products programme is currently considering options to facilitate this for cypress.

6.2 Cypress timber properties

Because cypress wood is soft, this can negatively influence demand for some high-value appearance applications, thus potentially limiting market value to below that received for top-end premium furniture-making species in the global market.

Mechanical properties tend to be lower than for radiata pine but cypress species do have adequate stiffness for most structural applications. Machine grading for stiffness does allow segregation and reallocation of low strength timber to other applications. There is also some evidence that density, stiffness and strength are consistent both radially and vertically in the tree, suggesting that tree age is not an important determinant for structural properties. This contrasts with radiata pine, where strength increases with age and may sometimes negatively influence NPV's by extending rotation lengths for adequate wood quality.

Scented timber attracts a market sector. The Asian market tends to place a premium on highly scented softwood timbers.

Natural durability as a quality currently does not attract a significant market premium in New Zealand but this could change according to public perceptions. Indeed this property alone could be the most significant predictor of increased future market value if the general public were to find chemical preservative treatment unacceptable. New Zealand's performance-based building code recognises the natural durability of cypress and allows untreated heartwood to be used for enclosed structural applications, weatherboards and decking. Radiata requires treatment for all these applications and suppliers report growth in the market for "chemical-free" building materials.

6.3 Return on investment

In order to estimate financial returns for various plantation forest species, productivity and log value are the two variables of most importance. Productivity can be measured for different species and regimes as an annualised quantity, and tools are available (e.g. the Cypress Calculator) for estimating productivity according to regime and rotation length. However, estimating future market value for logs according to species can be more problematic. This is because of:

1. The difficulty with estimating future changes to demand according to species quality characteristics; and
2. Supply of (and price of) alternatives in the market.

The simplest measure for estimating future log value is current log value. However, future applications for timber are not necessarily likely to remain the same as current applications. The 'materials playing field' undergoes constant change as a result of innovation and evolving public perceptions, leading to unpredictable changes in demand for materials. Likewise, future supply of alternative materials is unpredictable, both existing competing materials (for example the effects from 'locking up' of old growth forests) and new materials resulting from innovation (for example plastic/wood composites).

Another method to estimate future market value for a wood species is to value and weight individual quality characteristics and estimate future price according to the sum of individual qualities. This approach allows for assumptions that some qualities are more likely to attract future premiums than others, which might result in a more robust model for estimating residual future value for logs than estimating this based on current log value.

The aim should be to estimate returns per hectare per year based on reasonable and plausible assumptions, for an estimate that is as accurate as possible. However, perhaps the greatest constraint is that currently available information on grade recoveries according to regime remains very limited, thus regimes optimised for greatest returns are yet to be determined. In contrast, radiata regimes have a history of being fine-tuned to maximise returns and respond to market signals.

Grade recoveries for sawn product (and therefore log value) will vary according to regime, in particular stocking level and rotation length. Thus for a reasonable estimate of returns from growing cypress plantations, further work will be required to quantify market value of timber according to grades (market research), in conjunction with work that determines sawn timber grade recoveries according to regimes.

6.4 Regimes

Clear heartwood carries the highest market value and therefore traditional regimes have targeted this with low final crop stockings of pruned trees grown in long rotations (35-40 years). Demonstrating the profitability of this regime has proved to be difficult, primarily because recoveries of clear heartwood per hectare per year tend to be too low to compete with clearwood radiata pine regimes, despite the premium for the timber. Rotation length is the key factor limiting profitability.

Using the Cypress Calculator to quantify production from two contrasting regimes, with species as lusitanica and a site index of 15, volumes of just over 500 m^3/ha are likely from both a 23 year unthinned regime planted at 800 stems per hectare and a 35 year rotation planted at 800 sph and thinned three times down to 200 sph. This demonstrates the same productivity from different regimes. The longer rotation will require a significantly higher log price per m^3 because of the time value of money. There is a trade-off between rotation length and regime, which can be optimised for highest returns, but this depends on being able to assign values for the logs that result from a regime.

Domestic small diameter unpruned cypress logs currently yield a premium of only 20-30% above the equivalent radiata pine log. Export logs sell for up to twice the price of an equivalent radiata log but prices are volatile. The export market also accepts much smaller log sizes than the domestic market, which could influence economic value and regimes, in particular stocking rate and rotation length.

Predictive models could be built that resolve this trade-off and optimise regimes for the grower. However, data would be required for building such models. The Specialty Wood Products partnership have begun this process, with research underway into determining grade recoveries for unpruned 21 year rotation cypress.

6.5 Expected lifespan

Cypress can live for hundreds of years and grow into very large trees. In plantations, average lifespan would likely be a function of tree stocking, with highly stocked stands being more vulnerable to windthrow and collapse because of the high height to diameter ratio. Cypress may be well suited to permanent forestry and continuous canopy production forestry on steep slopes because of shade tolerance, the ability to grow into large trees and produce high volumes of wood per hectare, along with and a potentially high log value that justifies single tree harvesting (Satchell, 2018).

7. Log production

7.1 Harvest systems

There are two primary systems employed for harvesting forestry plantations in New Zealand.

Ground-based logging utilises wheeled or tracked machinery such as skidders, tractors and excavators to extract felled stems to processing sites. These systems are usually restricted to flatter terrains, although new technology such as tethering or remote / tele-operation is enabling machines to operate on steeper slopes in certain areas. Tree felling is also usually undertaken using machinery in this easier terrain.

Hauler logging involves specialised machinery suspending cable systems over the ground to haul logs to processing sites. These systems are usually required on steeper terrain, or where sensitive ground conditions or access problems prevent the use of ground-based systems. In general hauler systems are significantly more expensive to run, as more machinery and manpower is usually required, but productivity is usually lower than for ground-based systems.

Helicopters are sometimes employed for logging, but this is relatively rare in cypresses, as the cost of such an operation usually outweighs the value of the logs produced.

In addition to terrain, other considerations that may influence harvest system and machinery requirements could include:

- Stream locations and sizes
- Infrastructure locations (e.g. roads and processing sites)
- Resource consent conditions
- Ground conditions and expected weather
- Contractor availability
- Ecological or archaeological constraints

A robust harvest planning process is essential to identify these considerations well ahead of harvest, to ensure that infrastructure is fit for purpose, and harvest operations can be completed in a safe, efficient and environmentally friendly manner.

7.2 Harvest productivity and cost

In addition to harvest system requirements, there are several other factors that can affect the productivity and therefore costs of a plantation harvest operation. Such factors include (but are not limited to):

- Piece size – smaller trees are costlier to handle and process. Very large trees can also be more expensive to harvest, especially if they are too big to handle with normal size machinery.
- Haul distance – if trees need to be extracted long distances to processing sites, this will affect productivity and therefore cost. Reducing haul distance usually is a trade-off as it inevitably requires more cost in terms of infrastructure.
- Remoteness – if the forest requires significant travel or accommodation for harvest crews, this will affect productivity and/or cost. Costs associated with transporting machinery and equipment will also be affected.
- Complexity – jobs that have complicated requirements will usually cost more to harvest. This could include traffic management, power lines, archaeological sites, access restrictions or multiple land-uses.
- Competition – There is generally a shortage of experienced harvesting contractors across New Zealand, including in Hawke's Bay. This lack of competition is having an adverse effect on harvest costs as forest owners try to secure contractors for their forests.

The following table summarises harvest costs that could be expected for a range of harvest systems and factors that would commonly be encountered in Hawke's Bay.

Table 9: Indicative radiata pine harvest costs

Harvest type	Harvest cost ($ per m^3)		
	Easy	Medium	Hard
Ground-based	19.00	23.00	30.00
Hauler	33.00	40.00	55.00

7.3 Infrastructure requirements

Harvesting of plantation forests will usually require the design, installation, maintenance and rehabilitation of a network of forest roads and processing sites. Stream crossings, entranceways, fences and gates may also be required.

Infrastructure requirements and costs are very site-specific. Detailed harvest planning and engineering design work will often be required to properly quantify requirements. This process will normally consider the implications of:

- Existing infrastructure location and condition
- Topography and climate
- Soil types and erosion potential
- Regulatory requirements
- Health, safety and environmental best practice
- Trade-offs between harvest costs and infrastructure costs
- Harvest systems and productivity
- Landowners, neighbours, iwi and other affected party considerations
- Aggregate sources

Below is a table summarising some expected ranges of infrastructure costs that could be expected for typical forests in Hawke's Bay.

Table 10: Indicative cypress infrastructure costs (first rotation, ex farm) based on Prad but depends on TRV

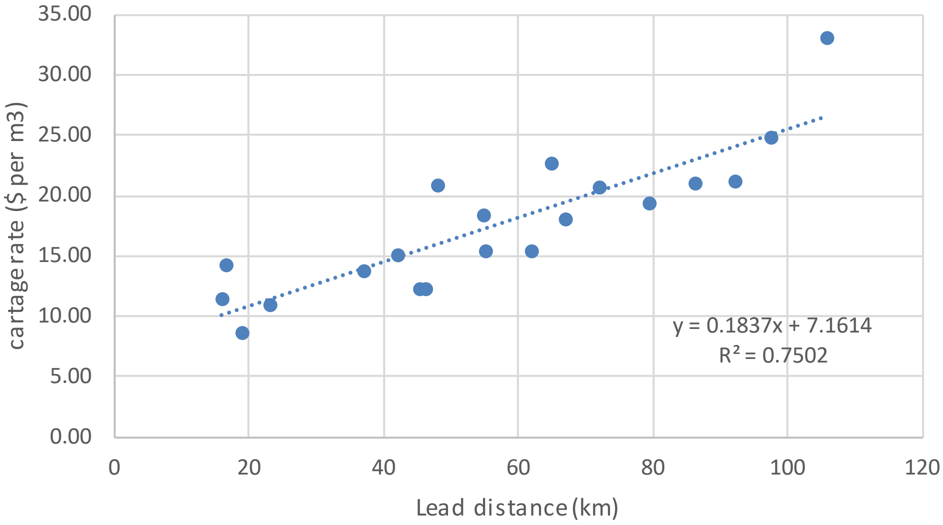
Cost Component	Infrastructure cost ($ per m^3)		
	Low	Medium	High
Road and Skid Construction	3.00	6.00	10.00
Maintenance	0.50	1.00	1.50
Post-harvest rehabilitation	0.50	1.00	1.50
Total	**4.00**	**8.00**	**13.00**

7.4 Log cartage

Transporting logs from forest to customer in Hawkes Bay has historically been by road and rail. Currently rail transport is limited to logs moving north to Napier port from the Manawatu / Whanganui region, but funding is in place to re-open the Napier – Wairoa rail line to facilitate log transport south to Napier. This has the potential to reduce transport costs and improve safety for road users on State Highway 2.

Log cartage costs will usually have a fixed component, and a variable component based on lead distance, as this is the key factor in determining cartage costs. Regression analysis can be used to compare actual cartage rates and lead distances, to develop a formula for predicting cartage rates. Below is a graph showing regression analysis for log cartage in the Southern North Island over 2017-2018. This analysis shows that cartage costs over this period can be approximated by using the formula ***Cartage cost ($/m3) = $7.16 + ($0.18 x Lead distance)***.

Figure 1: Cartage rate analysis for Southern North Island, July 2017 - June 2018 (Source: PF Olsen).



Fuel prices have a significant impact on cartage rate, with approximately 20% of cartage costs being attributed to diesel consumption. Diesel prices across the analysis period above averaged $1.26 per litre[1]. Diesel prices since this period (up to October 2018) have increased by approximately 20%, and this is likely to have resulted in cartage costs increasing by around 4%. It is worth noting that this increase would also likely be felt in harvest costs, where diesel costs have a similar influence.

Factoring the increased fuel component, the cartage formula that best approximates current cartage costs would be:

Cartage cost ($/m^3) = $7.45 + ($0.19 x Lead distance)

Table 11: Indicative cartage costs

Lead distance (km)	Cartage cost ($/m^3)
25	$12.20
50	$16.95
100	$26.45
150	$35.95

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[1] Discounted retail price – Source: https://www.mbie.govt.nz/info-services/sectors-industries/energy/liquid-fuel-market/weekly-fuel-price-monitoring

7.5 Other costs of production

Management of harvesting operations by a suitably qualified individual or company will usually be required. Management tasks include:

- Harvest planning
- Contract and contractor management
- Health & safety and environmental compliance monitoring.
- Production monitoring
- Log value recovery and quality control
- Log marketing
- Reporting and documentation
- Weighbridge fees and consumables (paint, stencils etc)

Post-harvest clean-up may be required on some sites, and can include slash management, fence repairs, drainage works and erosion control works.

The Commodity Levies (Harvested Wood Material) Order 2013 imposes a levy on all harvested wood material from plantation forests in New Zealand. Levies are payable to the Forest Growers Levy Trust and the levy is currently set at **\$0.27 per m^3** or tonne and cannot exceed \$0.30 per m3 or tonne during the six-year levy period. The levy period ends in 2019, at which point forest growers will hold a referendum to decide whether to continue for another six years. The levy was introduced to provide funding for the following categories:

- Research, science and technology (64%[2])
- Forest health and biosecurity (13%)
- Health & safety (10%)
- Promotion (9%)
- Fire (1%)
- Forest resources and environment (1%)
- Transportation (1%)
- Small and medium forest enterprises (0.1%)

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[2] Source: Forest Growers Levy Trust 2017 Annual Report

8. Log markets and wood availability

8.1 Domestic processing capacity

Macrocarpa currently dominates the market of cypresses being milled and traded; other species such as lawsoniana, lusitanica, and very small volumes of Leyland cypress are also present, although it is likely that higher volumes of lusitanica are actually being milled due to it commonly not being distinguished from macrocarpa.

The domestic market is currently under-supplied, but cypresses have the advantage that they can be readily sawn on mobile mills. This is beneficial for shelterbelt trees in particular, as it can allow for the efficient recovery of timber, whilst avoiding transport. Depending on cost efficiency of the operation, on-site milling can add extra costs for the grower however, and it is recommended that the grower evaluate relative costs between on-site milling and transport to a fixed sawmill.

8.2 Wood availability

The main source of macrocarpa has traditionally been from old shelterbelts planted on farms, with smaller quantities of mature plantation timber available. There has been no attempt at co-ordinating supply of plantation timber, with most liquidated by corporate owners without thought to future supply (M. Grant, pers. comm). Smaller plantations owned by individual growers are now becoming increasingly available. Shelterbelt timber tends to be from large, older trees and wood quality tends to be unpredictable, sometimes going to low-grade uses such as firewood and garden sleepers. Better grades of macrocarpa are still sought after as a high-quality softwood (Miller, 1996) and it is anticipated that plantation timber will supply that niche.

Continuity of timber supply is likely to improve the future prospects of growing macrocarpa, as past supplies have often been sporadic and come from a single age class. This lack of continuity has not encouraged their commercial acceptance by sawmillers and merchants alike (NZFFA, 2007).

8.3 Log prices

A 1986 FRI Bulletin quotes green density of 820 kg/m^3 for macrocarpa and Leyland cypresses, and 910 kg/m^3 for lusitanica heartwood (NZFFA, 2007).

The best quality pruned macrocarpa and lusitanica logs can sell for approximately $300-400 per tonne on truck. These are usually selected from the skid site by the purchaser. As with all species, log prices reduce with smaller size and log quality, shown in Table 12:

Table 12: Macrocarpa log prices (NZFFA, 2019)

Macrocarpa logs	South Island Landed at mill door $/tonne
Pruned Min SED 40cm	350 – 375
Pruned Min SED 30cm	170 – 190
Small branch Min SED 30cm	160 – 165
Small branch Min SED	135 - 145
Large branch/Boxing/Sleeper	115 – 120
Firewood logs	75 - 80

8.4 Timber prices

Sawn timber prices vary according to grade. Timber that has been stored and fully air dried for around 12 months can dramatically improve returns. Good quality cut of log sawn timber that has not been dried is traded at between $800 to $1,000/m^3, whereas the same grade fully air dried, tends to be traded at $1,500/m^3 . Dry clear heartwood trades at between $2,500 and $3,000/m^3.

8.2 Log exports

Cypresses are poised to be the third most important genus in New Zealand plantation forestry. These species already have excellent market acceptance, with a substantial price advantage over radiata pine and a major premium for quality (Miller, 1996).

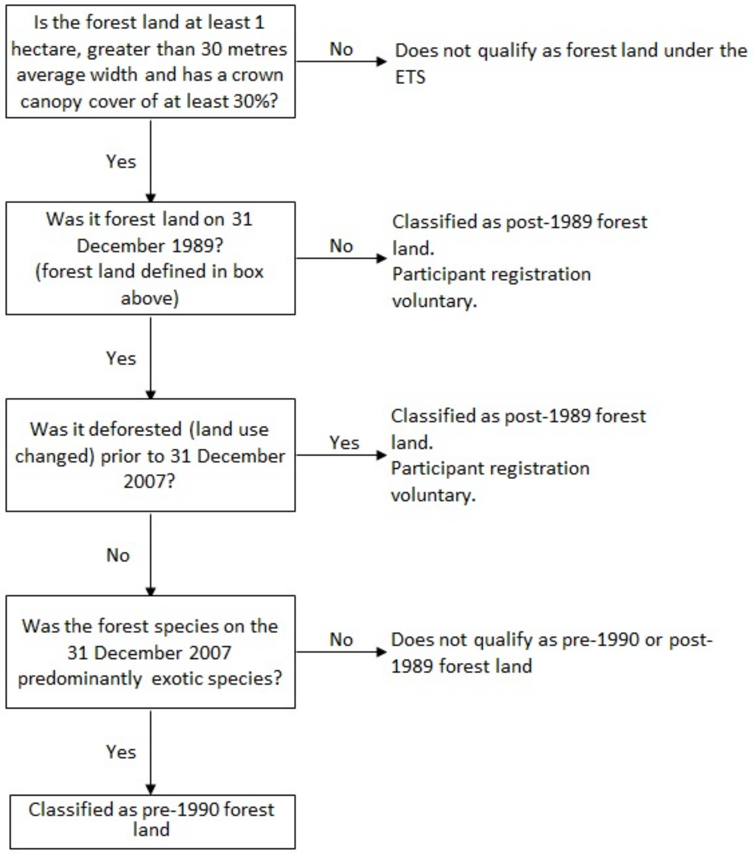
Some studies suggest that cypress timber has excellent prospects in overseas markets, particularly those of eastern Asia such as Taiwan and South Korea. Japan could also be a lucrative market, as Japan has very specific product dimensions that are used for traditional building construction. Whilst it is unlikely that New Zealand cypress could substitute directly into the highest quality bracket, a clearwood timber product of uniform quality would likely have good market prospects (NZFFA, 2007).

9. Carbon forestry

9.1 ETS eligibility

In order to enter the Emissions Trading Scheme (ETS) and claim credits for the carbon sequestration of a forest, the forest must reside on Post-1989 eligible forest land. This means that the land must not have been forest land on the 31st December 1989 and must also meet minimum size requirements. Land that **was** forest at the end of 1989 is only eligible for entry into the ETS if it was converted to another land-use prior to 31 December 2007. The following flowchart summarises the process for determining ETS eligibility of forest land.

Figure 2: ETS Eligibility assessment process



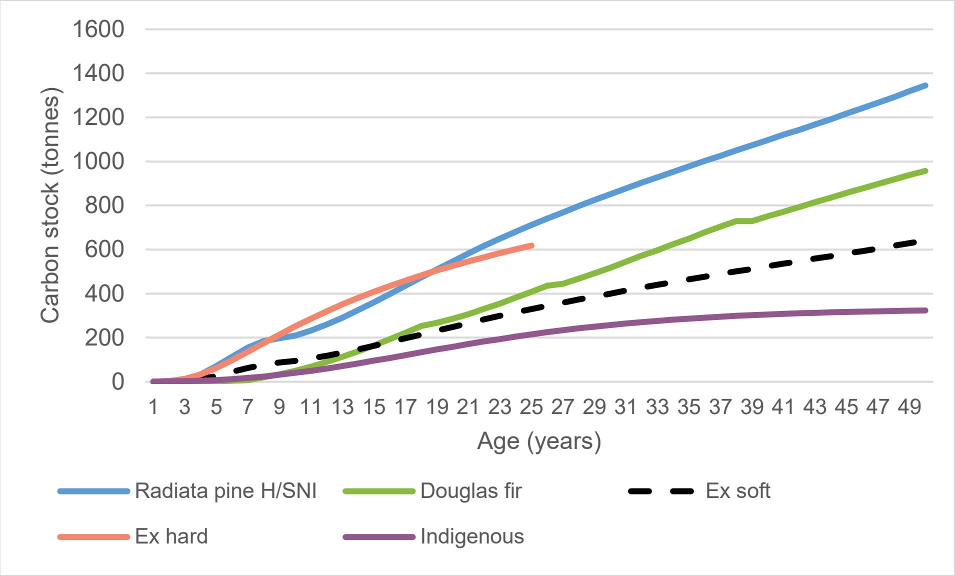
Although land may be deemed as eligible Post-1989 forest land, it does not automatically enter the ETS. A landowner (or forestry right holder) is required to apply to have their land added to the ETS. MPI will assess the application, including eligibility, legal ownership and mapping accuracy, prior to approving entry into the ETS.

As HBRC is interested in encouraging afforestation, we assume that land considered for planting will generally be Post-1989 eligible forest land. In saying this, in most cases there are small areas of ineligible land in a parcel that is assessed for eligibility. This is often due to patches of scrub being deemed as ineligible, or areas of patchy survival being assessed as not meeting the definition of forest land. Offsetting this is the fact that ETS mapping standards can allow certain gaps to be closed up and future crown growth around boundaries to be factored, often resulting in slightly more area being accepted into the ETS. From recent experience, The ETS eligible area of a newly planted forest is often around **5% less** than the nett stocked area.

9.2 Carbon sequestration

Radiata pine carbon sequestration rates are generally higher than most other commercial species in New Zealand. Currently any cypresses grown for carbon fall under the exotic softwood category, which is a single category for entire country. The following graph compares MPI generic look-up tables for cypresses (exotic softwood) with radiata pine in the Hawke's Bay / SNI and national averages for other species groups.

Figure 3: MPI generic look-up tables for different species groups.



The sequestration rates shown in the figure above are applied to ETS participants with a total ETS registered area of less than 100 hectares. For those participants with larger areas registered, permanent sample plots must be installed and measured each reporting period to derive participant-specific look-up tables (PSTs).

9.3 Carbon strategies

The current method of carbon accounting is by carbon stock change, where units are earned as the forest grows. When it comes to harvest time, the landowner or entity must surrender units to the government that equal the deemed emissions, or carbon harvested and taken offsite. The government is considering changing the accounting approach to averaging, which essentially gives a consistent value for carbon stocks once a certain age is reached. This results in a carbon stock that increases through a stand's development, before levelling off once this long-term average is reached. It means that no unit liability is faced upon harvesting so long as the area is replanted.

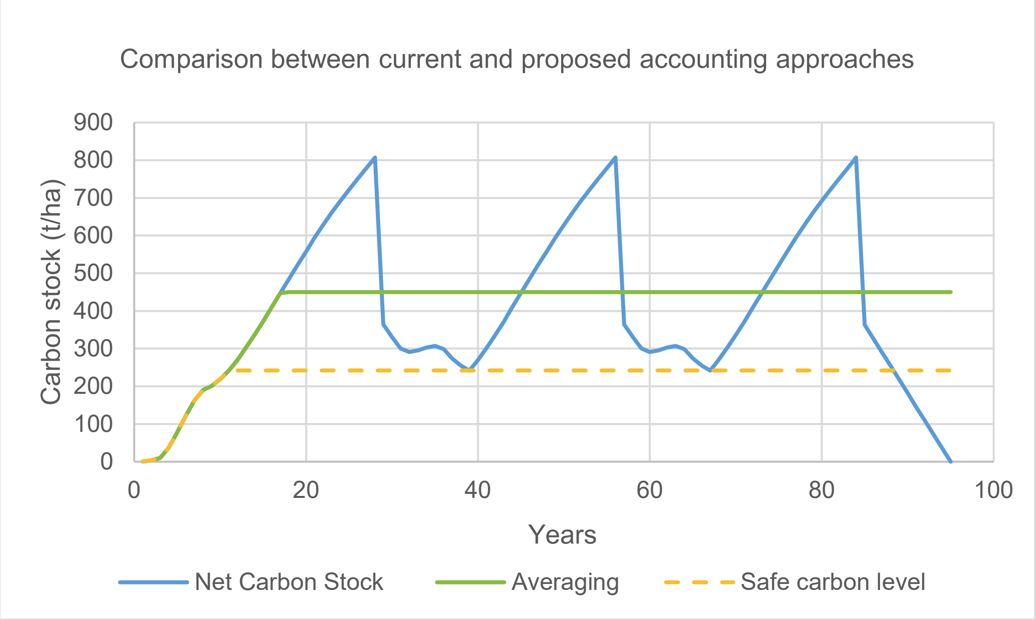


Figure 4: Variations in carbon stock from different accounting methods over multiple rotations, assuming a 28-year rotation age

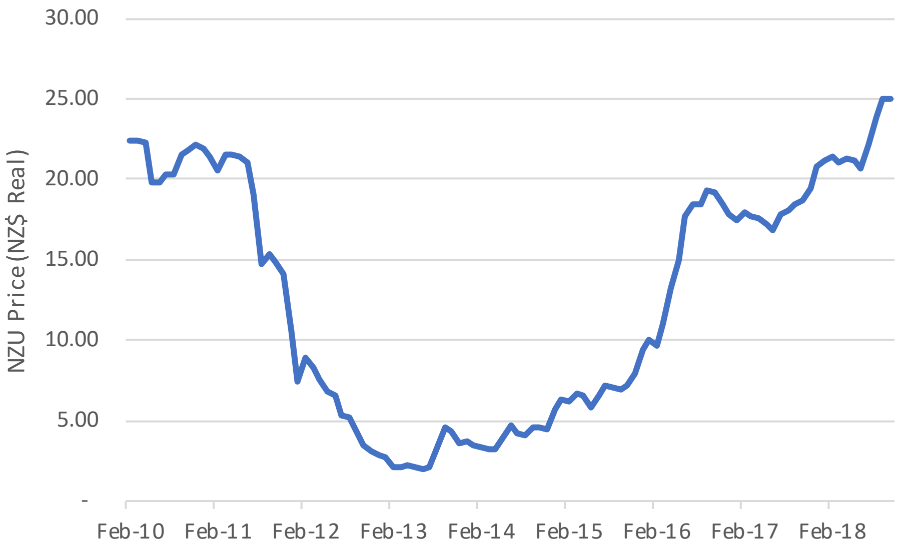
9.4 Carbon pricing

Carbon pricing can be somewhat volatile, and is influenced by several factors including (but not limited to):

- Industrial emissions levels
- Regulatory changes and political influences
- The $25 Fixed Price Option (FPO) available to emitters in lieu of acquiring units for surrender
- Market access and liquidity
- Seasonality of demand
- International trends

The following graph shows the trend in NZU pricing since 2010. The large price drop that occurred in late 2011 was primarily due to the introduction of cheap European units into the ETS market. Low prices were maintained through to 2014 when the Government blocked use of these cheaper units. Prices have since slowly recovered and are now trading around the $25.00 mark, with market prices being heavily influenced by the $25.00 FPO option available to emitters. The Government has announced an intention to review the nature and level of the existing price cap, and a number of reports have noted that considerably higher carbon prices may be required to trigger meaningful emissions reductions in the future.

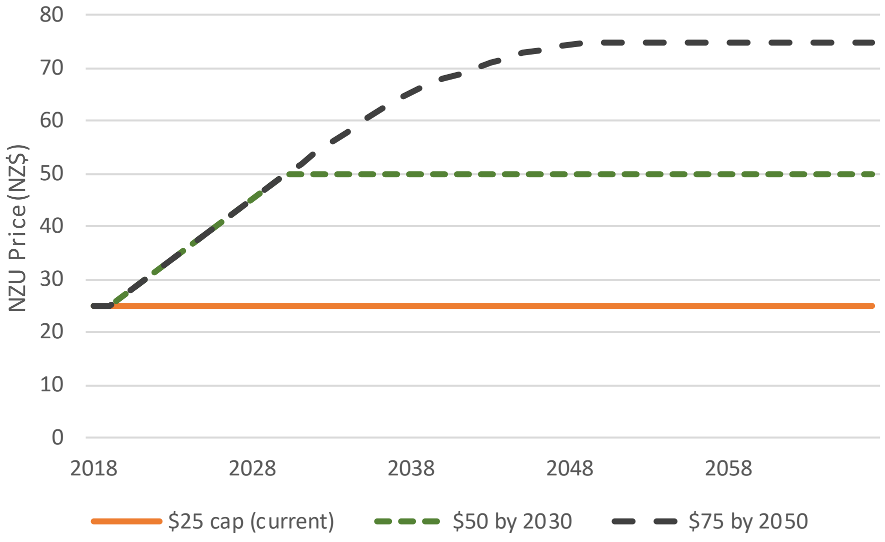
Figure 5: NZU price history, 2010 - 2018.



Forecasting future carbon prices is difficult and very dependent on future carbon policy, emissions reduction goals and international linkages. A report produced for the Parliamentary Commissioner for the Environment (PCE) in 2010 projected that NZ carbon prices could be in the range of $50-$150 per tonne by 2030 (COVEC, 2010). Since then New Zealand has signed up to the Paris Accord, and agreed a Nationally Determined Contribution (NDC) of reducing GHG emissions to 30% below 2005 levels, by 2030. The Productivity Commission recently released their final report on a transition to a "low-emissions economy". Modelling for this report suggests that carbon prices may need to rise to between $75 and $152 a tonne by 2050 (New Zealand Productivity Commission, 2018) to achieve desired emissions outcomes.

It is recommended that modelling of carbon price should use a baseline of $25.00 remaining static into the future, as this is the current pricing, and reflects the current known price cap mechanism.

Figure 6: Example future carbon price scenarios



9.5 ETS costs

ETS participation will usually incur initial set up costs such as planning, mapping, preparing applications and associated MPI fees. There will also be ongoing costs associated with emissions return preparation and submission, record keeping and Field Measurement Approach (FMA) plot measurement and data processing (if >100 hectares). The following table summarises expected costs for radiata pine ETS participation. It is assumed that for small areas (<20ha) the forest owner would complete most work themselves, while for larger areas a forestry expert would be engaged. FMA costs are assumed to be $350 per plot for measurement, management and data processing.

Table 13: Estimated ETS costs

	ETS Cost ($ per hectare per year)	
ETS Cost	0-99ha	100ha+
Planning, mapping and registration	$40	$20
Administration	$10	$5
FMA measurement	-	$10
Total	**$50**	**$35**

Update references to only those that are used

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RIGHT TREE, RIGHT PLACE

HAWKE'S BAY AFFORESTATION PROGRAMME (HBAP)

Species assessment – Manuka

1. Introduction

Manuka (*Leptospermum scoparium*) is indigenous to New Zealand and Tasmania. It is a native, pioneering woody species that is often dominant in poorly draining and/or infertile soils. Manuka has antibacterial properties and has long been used by Māori both medicinally and culturally. Because manuka is fast-growing, hardy, and more effective at reducing the leaching of nitrogen than pasture and pine, it is favoured for riparian planting (Boffa Miskell , 2017).

Manuka is well-regarded by the general population for complementary product streams such as honey, timber, fuel wood, oil, and tea leaves. For the purposes of this report, manuka has been considered both for its economic application for the production of high 'Unique Manuka Factor' (UMF^{TM}) honey and good sediment and moderate erosion control and also on harsher sites for the predominant function of erosion control.

Land managers need to have clear differentiated objectives when considering manuka as part of a land use matrix. If honey is a key commercial objective, then lower establishment stockings, more climatically benign sites and requirements for access to maintain production, imply establishment for this purpose will have less impact in a landscape for erosion protection.

Conversely, manuka established or arising from reversion can be established on many sites and if established at high densities can relatively quickly achieve canopy closure and good erosion protection from shallow land sliding. It may be particularly suitable on the steep faces of skeletal soils overlaying soft rock geologies that form a major part of the region's landscapes, are a major contributing source of regional erosion and sediment and are increasingly considered unsuitable to 'large tree' afforestation for timber production.

2. Site Requirements

2.1 Climate

- **Temperature** affects many aspects of growth. Depending on the variety, manuka can tolerate variable temperatures, as it has a natural range that covers coastal to alpine environments. However, in the coldest areas of New Zealand manuka is limited to warmer microclimates.
- **Rainfall** is also an important consideration. Manuka prefers higher rainfall areas compared to kanuka and will not often occur in dry areas with less than 750mm of rainfall per year.
- **Wind** can have an adverse effect on vegetation survival, form and wood quality. Exposure and the lower fertility found in ridge sites can slow manuka growth to an extent, however, in coastal areas manuka can occur naturally in parts too exposed for exotic forest species.

Generally, manuka is suited to a wide range of climates found in New Zealand, including that of the majority of Hawke's Bay. The following table summarises the optimal climate conditions for manuka.

Table 1: Climate profile for manuka.

Climate variables L. scoparium preferred. (Greer, 1991)	**Manuka Honey production**	**Manuka Erosion control**	**Hawke's Bay actual** (Chappell, 2013)
Mean annual air temperature (°C)	12-15	Within regional range	8.0 - 13.5
Mean winter minimum air temperature (°C)	-4.0 to -8.0		2.0-7.0
Frost limit (°C)	-2	-8	-6.0 to -12.0
Mean annual rainfall (mm)	900-1800 summer low	750 - >2200	707 - 2,000+
Snow at low levels?	NA	Low risk	Rare (1-2 days per 10 years)

2.2 Topography

- **Elevation** has effects on tree growth, primarily due to its modification of climatic variables such as temperature and snow (see above). Manuka can grow from sea level up to 1000m in but for the purposes of achieving good and predictable flowering for honey production site altitudes below 500m are desirable.
- **Slope** Steep slopes may be operationally limiting for manuka honey sites to the extent that access and suitable sites are needed for the management of the hives. Furthermore, if the floral activity of honey producing manuka is to be extended and or maximised, machine access may be desirable.

  There are no constraints on slope for erosion protection other that the operational logistics of one-off access and the safety of those involved in planting a site.
- **Aspect** has a reasonable impact on productivity, as it alters the pattern of radiation. North-facing slopes are warmer than south-facing slopes; north-westerly aspects are often more exposed to high winds in the region. Manuka generally does well on northern and eastern facing hillsides and warm sheltered aspects are important for floral honey production. Other than for the influence on rate of site occupancy aspect has little relevance for erosion protection establishment.

Table 2: Site requirements for manuka.

Prime purpose	Topography variables	L. scoparium preferred
Honey	Maximum altitude (m)	500
	Site	Valley floors, lower slope, northerly aspects.
Erosion control	Maximum altitude (m)	1000
	Site	Avoid frost flats and wet hollows

2.3 Soils

Soil type: Manuka can tolerate a wide range of soil types, particularly low-nutrient soils such as peat, volcanic pumice, waterlogged pakihi, coastal cliffs, geothermal areas, and shifting braided riverbanks. Manuka will dominate in wet soils. However, for good honey production free draining soils are best.

Nutrient supply: This is crucial to all plants and, although manuka is fairly hardy, it grows best on fertile sites. **M**oderate to good fertility is required for areas where investment for honey production is contemplated.

2.4 Access and infrastructure

While access is not required for harvesting activity, it is necessary for planters as aerial seed dropping manuka has shown very variable results. If honey is being collected, access is required for beekeepers to service hives as helicoptering of hives is both costly and can be dangerous.

When establishing manuka, the following should be considered regarding access and infrastructure:

- **Distance to market -** is there a viable customer located within a reasonable distance of the site?
- **Legal access -** can the site be accessed without encumbrance?
- **Infrastructure requirements** -can the site be accessed easily for planting, for crop rejuvenation and the ongoing management required for beekeeping?.

3. Establishment and early growth

3.1 Land preparation

Land preparation is usually undertaken to promote early growth, control weed competition, and promote wind firmness. Preparation activities are often undertaken using hand tools, machinery, fire, chemicals or animals (grazing). The specific type of land preparation will depend on the condition of the land.

- **Ex-grazing land.** Land preparation requirements for land that is primarily grass are relatively simple. The most efficient pre-plant preparation will be hard grazing prior to planting. If grazing is not possible prior to planting, an aerial broadcast application of herbicide may be required. Boundary fences will likely need to be installed or modified, and internal fences may need to be removed to avoid future hindrance.
- **Scrub or brush land.** On sites with high incidence of scrub, gorse, blackberry or other brush species, an aerial application of brush killer may be required. If this brush is dense or >2m in height, it may also require some mechanical clearance too, either via roller crushing, or line cutting. However, be sure to check the local District Plan. Often clearance of partially regenerated native vegetation will not be permitted under the RMA.
- **Cutover land**. Prior to manuka replanting land following forest harvest, it is often necessary to complete some form of mechanical land preparation, to clear away logging slash. This is especially so on flatter areas that have been harvested using mechanised systems. Usually machines will heap slash up into windrows to clear space for the new crop. A desiccation spray is also usually required to supress weed growth prior to replanting.
- **Spot mounding.** To prevent frost damage to young trees, frost-prone areas will often be spot mounded. This lifts the tree up out of the frost hollow. Spot mounding is also used to aid establishment in areas of high soil compaction.

The following table shows some indicative land preparation costs that could be expected for operations undertaken in the Hawke's Bay region.

Table 3: Indicative land preparation costs

	Land preparation cost estimate ($/ha)		
Operation type	**Ex-grazing land**	**Scrub / brush land**	**Cutover land**
Aerial or spot spraying	200	250	300
Roller crushing / line cutting		0-500	
Windrowing /Spot mounding			0-700
Tracking and fencing	25-50	50	64
Total	**50-250**	**300-800**	**300-1,000**

3.2 Planting stock

A nursery (given they have proper capacity) will need 9-12 months to produce seedlings with a 3mm basal stem diameter, 20-30cm in height. Seedlings will be in root trainers, lifted before delivery. Availability should not be an issue if nurseries are given proper notice. Gathering of seed is straightforward if access to a mature population is available.

When selecting which planting stock to plant, the following options should be considered:

- Genetics

  There is a variety of manuka available throughout the country. Manuka is phenotypically extremely variable and adapted to wide ranges of the New Zealand ecosystem. Eco-sourcing seed for planting is considered good risk management in terms of addressing establishment success in more extreme site conditions where erosion control is the dominant objective. Local populations tend to be well-adapted to the local climate and growing conditions.

For honey production, there are a number of cultivars (Manuka Farming New Zealand, n.d.) now available on the market and associated supporting trial work that is providing important information about which cultivars might provide the best flowering characteristics for a given site. Expert advice should be sought for the site location in question. Manuka that performs well in some regions has been known to perform poorly when planted into different regional conditions.

- Nursery location and transport

  Hawke's Bay has no forest nurseries producing bulk manuka planting stock. Seedling supplies, especially for improved genetics and bulk supply, will require transport into the region, at least in the near term. Logistics of delivering treestocks from nursery to planting site need to be considered carefully due to the time-critical nature of transplanting. Increased demand for treestocks may necessitate development of nursery capacity within the Hawke's Bay region.

3.3 Initial stocking rates and survival

It is common to plant more manuka seedlings than are required at harvest, to account for future mortality as well as optimum stocking for honey production. With best practices, survival rates can be expected of over 90%. For honey production, stockings range from 800-1600 stems/ha. If planting primarily for erosion control on steep country, higher stocking rates up to 2500 stems/ha should be considered.

Supervision and quality control of planting operations is crucial to ensuring that trees are planted correctly, in the right locations and at the appropriate stocking rates. Survival assessment is also usually undertaken in the months following planting. This helps to determine what areas may require 'blanking' – restocking the following winter.

3.4 Planting

Planting is almost always a manual operation, with planting crews using spades to cultivate the spot before planting the seedling. Labour shortages exist in many regions including Hawke's Bay, primarily due to the seasonal nature of the task. Labour is also affected by reduced demand for other silviculture operations such as pruning.

Costs for planting labour and management will vary on area, stocking rate, travel distance, terrain, access limitations (e.g. how closely trees can be delivered) and land cover (scrub or cutover land being generally more expensive to plant than grass).

When including seedlings, one source estimated planting costs at between $2,500 and $3,500 per hectare, with lower costs associated with larger areas due to the economies of scale. Seedlings could cost between $0.90 and $1.10 for less than 20,000 or between $0.60 and $0.80 for more than 20,000 (Boffa Miskell , 2017).

Table 4: Indicative manuka planting costs

	Manuka planting costs ($ per hectare)		
Genetics type	**Manuka (Honey)**	**Manuka (Erosion)**	**Manuka (Erosion)**
Cost element (spha)	1100	1600	2000
Seedlings	935	1360	1700
Planting	715	1040	1300
Transport	66	100	120
Total	**2816**	**4100**	**5120**

4. Silviculture and forest management

4.1 Post-plant weed control

Weed control is essential for high survival of planted manuka. The control of woody weeds prior to planting is highly recommended to prevent shading, competition, and loss of seedlings. Presence of gorse can be especially problematic given the similar niche of the three species, leading to high interspecific competition. Manuka will eventually dominate but early growth will be significantly reduced. Control of herbaceous weeds is recommended and can be done pre- or post- planting. Reduction of these species in the establishment phase allows less inhibited growth in the first year, consequently providing a better environment for root establishment and foliage increase.

Table 5: Indicative manuka post planting costs

	Post plantings costs ($ per hectare)		
Plantation function	**Manuka (Honey)**	**Manuka (Erosion)**	**Manuka (Erosion)**
Cost element (spha)	1100	1600	2000
Releasing	360	400	600
Blanking (10%)*	88	265	302
Pest control**	23	23	50
Total	**1571**	**2288**	**2952**

* blanking only required if establishment failure

** annual cost that could be required for at least 5 years depending on site and local pests

4.2 Fertiliser

In general, it is not expected that manuka grown in Hawke's Bay will need to be fertilised. Studies have not yet been completed regarding the relationship between nectar DHA levels and soil fertility. Costs for plant release spraying over a two-year, post-planting period are usually around $1.50 per plant, however this will vary depending on a number of factors such as terrain and spray type (Boffa Miskell , 2017).

4.3 Silviculture strategy

Generally no silviculture strategy is required with manuka as it is a native and naturally occurring plant. However, there may be some benefit for honey production in thinning to allow full floral canopies to be maintained. No thinning techniques have as yet been tested and therefore it is important for landowners to seek professional advice before engaging in any silvicultural activities. No pruning is required.

4.6 Forest management

Manuka forest management requirements are unique in that the majority of the returns are created by the beekeeper. The forest owner and beekeeper relationship can include honey income sharing, a lease or beekeeper also owns forest. As with tree crop forests, forest management will depend on the scale of the forest resource and expertise of the owner. Very small forests may be managed by the owner or beekeeper, but owners with little spare time or experience, or with a large forest asset may choose to engage the services of forest manager. The specific forest management required will vary from forest to forest, but primary management roles and responsibilities can include:

- Preparation of budgets and work plans/schedules
- Contractor engagement and supervision of forest operations
- Ensuring access for establishment and ongoing honey operations
- Mapping and stand record-keeping
- Cost tracking and reporting
- Consent application and administration
- Health and Safety and Environmental (HS&E) compliance
- Professional and technical advice

- Liaison with regulatory bodies and other agencies, neighbours, iwi and affected parties as required.

Costs for undertaking forest management activities will depend on agreed scope of responsibility, and will also vary based on forest location, scale and competition for services. The table below summarises some indicative forest management costs that could be expected for forests in Hawke's Bay.

Table 5: Indicative manuka forest management costs (these will need to be defined for any individual project)

Cost type	Cost ($ per hectare per year)			Manuka (erosion)
	Low	Medium	High	
Management	15	20	25	
Administration	5	10	15	rates
Protection / maintenance*	10	23	30	23
Total	**30**	**53**	**70**	

*includes tracking to maintain good access

5. Pests, diseases and other risks

5.1 Wild animals

Pest control of animals is essential for manuka plantations. Manuka presents new growth in the late winter/early spring which often draws in hungry animals at a time when feed is lacking. Young seedlings can easily be nipped off at ground level by most pests. Control of wild animals is often as much for protection of biodiversity and environment as it is about protecting the tree crop, as animals can be vectors for disease such as bovine tuberculosis and can also predate on indigenous wildlife. Some wild animals have recreation value through hunting, and so control of these species may be achieved with little or no cost.

The requirements for control of animal pests will vary from site to site. The primary animal pests that are likely to be encountered in Hawke's Bay forests that manuka must be protected from are:

- **Goats** are potentially the biggest risk in terms of animal pests, particularly in northern Hawke's Bay. Control is usually by shooting, and risk areas should be managed pre and post-planting.
- **Rabbits, hares, and wallabies** should also be effectively managed as they are amongst the more destructive pests for manuka.
- **Possums** will eat young trees but are often not prolific on an ex-farm site due to prior land management. Possums tend to be controlled through poisoning, trapping or shooting.
- **Pigs and deer** are also prolific in certain parts of Hawke's Bay, and should be managed appropriately where deemed to be a risk to successful establishment.
- **Livestock** such as sheep and cattle can be problematic on ex-farm sites. Damage is usually through trampling rather than browsing and can be controlled simply through effective fencing.

For honey plantations, pest control should be continued for the first 5-6 years in the late winter/early spring to protect new seasonal growth. Flower buds for both manuka and kanuka present on new growth so preventing browse damage to these branches will help ensure flower numbers and therefore nectar supply for the following season. A similar exclusion time applies to stock.

5.2 Insect pests

The Manuka Beetle is a small beetle that feeds on manuka and does not usually cause problems with growth. However, the larvae can eat the roots of pasture and crops, and consideration should be given to the possibility of Manuka Beetle damage (Boffa Miskell , 2017).

5.4 Diseases

American Foul Brood (AFB) is a highly persistent bacterial disease that can spread quickly and have devastating effects on hives. Beekeepers in New Zealand are legally required to be registered and pay levies to MPI for regulation and government surveillance.

Myrtle rust has been a major issue for closely related species in other parts of the world, as well as in New Zealand (Myrtle Rust in New Zealand, n.d.). While it has so far mainly affected other species and infection is present in NZ manuka, current information at this stage does not indicate a loss of productivity. However, it remains a potential business risk that should be considered by landowners, especially those in regions where the disease has been most prevalent.

Manuka blight can also reduce growth significantly and there is no industry remedy if it becomes established in a plantation. One specialist believes that plants on harsh, dry sites may be more susceptible to the blight, especially if under drought stress (Boffa Miskell , 2017).

5.5 Fire

Fire is a known risk for any dense woody vegetation in drier regions and seasons in New Zealand. Management of fire risk will likely be a combination of protection operations and fire insurance. Forest design can also influence fire risk, by providing fire breaks and buffers of less flammable species in risk areas like road edges and powerline corridors.

5.6 Wind

Strong wind is a known risk in Hawke's Bay, however this poses little direct physical threat to a well-established manuka plantation. Wind exposure will impact manuka productivity and flowering as well as the ability of bees.

5.7 Insurance

Risks associated with fire can usually be mitigated through appropriate insurance cover. Insurance will usually compensate a proportion of the current tree crop value, and often also provides compensation for the costs of clearing and replanting land. Forest insurers are currently indicating that they are likely to insure manuka for crop replacement value only. The manuka industry in New Zealand has more work to do with insurers to ensure adequate coverage for any potential future loss in earnings from honey resulting from a crop loss event. Public liability cover is also usually included. The table below summarises indicative insurance cover costs for an average Hawke's Bay manuka plantation.

Table 6: Indicative manuka insurance costs - coverage for replacement of crop only

	Annual Cost ($ per hectare)
Cost type	**Honey Plantation**
Fire	12
Wind	-
Public Liability	1
Total	**13**

5.8 Wilding spread risk

There is no risk of wilding spread as manuka is a native species, but if the environment is suitable then both manuka and kanuka will expand into open or undisturbed habitats.

5.9 Regulatory risk

Both manuka and kanuka are seral species, which means they will colonise bare ground to provide an environment for canopy species such as beech, kauri, and totara to become established. If left undisturbed and given proper conditions, it is possible for these forest dominants to grow through and exclude the pioneering scrub species.

If intergenerational income is a primary driver of plantation development, regulatory restrictions on thinning and replanting manuka should be well understood and regularly reviewed as part of plantation management (Boffa Miskell , 2017). Depending on the specifics and evolution of a region's Resource Management Act regulatory framework and the influence of the National Policy Statement on Biodiversity currently under development, it is conceivable that plantations planted in earlier years may have significant restrictions placed upon them regarding any interventions that might be sought .

6. Productivity

6.1 Growth models

Currently there are no growth or productivity models that exist for manuka.

6.2 Rotation length

Plantation manuka can be expected to be productive for between 15 and 30 years with no interference beyond pest control and some trimming. After this time, manuka will usually be outcompeted by canopy species. Manuka cannot be cultivated indefinitely and, although continuous trimming will extend the plant's productive life, it will not change the lifespan.

6.3 Long-term impact

Both kanuka and manuka are known as nursery species to the larger native timber trees of New Zealand. If left undisturbed and give proper conditions, it is possible for these forest dominants to grow through and exclude the pioneering scrub species. This nursery effect is somewhat attributed to the mycorrhizal partnerships formed by both manuka and kanuka as they are the only woody species that form these relationships with both ectomycorrhizal and endomycorrhizal fungi, which is fairly rare in the plant world. Ectomycorrhizal presence allows increased germination and growth by the larger timber species.

Manuka and kanuka are both known to increase water quality as the anti-bacterial properties (measured in the honey and oils) are qualities also present in the root systems. Microbial loads are reduced significantly faster under both species. The lowered bacteria levels also affect the cycling of nitrogen, with manuka and kanuka significantly reducing the leaching of nitrogen versus pasture or pine.

7. Honey production

7.1 Honey yields

Manuka honey yields generally range between 15 and 25kg per year per hive on average, depending on location and various other factors. There is often high variability between years. Industry best practice is to allocate one hive per hectare of manuka plantation, although some manuka cultivars can support two hives (Boffa Miskell , 2017).

7.2 Honey prices

The price of manuka honey is strongly dependent on the UMF™ (Unique Manuka Factor) content. Methylglyoxal (MGO) is created from a component of manuka nectar and is also used in conjunction with UMF™ to distinguish the value of manuka honey. Sourcing honey with a high UMF™/MGO factor is the goal of honey producers.

Prices can range from $16/kg to $60+/kg for high UMF™/MGO honey. There is also an increasing drive to create plantation owner collectives, to market packed and branded honey to retailers rather than bulk supply and obtain some price certainty (Boffa Miskell , 2017).

7.3 Managing beehives

Managing beehives is a time-consuming occupation, and usually landowners will contract hive management to professional beekeepers. Beekeepers are legally required to use best practices to reduce the spread of AFB, as well as other disease management. Hives may need moving or supplementary feed to maintain optimum health.

7.4 Honey contracts

There are various ways that income is obtained from a manuka honey plantation. If a landowner or plantation manager chooses not to own hives, beekeepers can supply their own and pay a land rental, honey royalty, or both. Most beekeepers sell honey at a set price to the wholesale market, however there is an increasing drive to form collectives of plantation owners due to the strong international demand for retail packed and branded honey over bulk supplies (Boffa Miskell , 2017).

Beehives with a box and starter colony can cost as much as $1,100 per hive, with operational costs generally ranging between $250 and $350 per hive, per year. As with most costs discussed in this report, they are liable to be higher or lower depending on individual sites (Boffa Miskell , 2017).

7.5 Infrastructure requirements

In order to allow beekeepers safe access to manuka plantations, the design, installation, maintenance and rehabilitation of a network of forest roads will be required. This may need to include additional infrastructure such as stream crossings, entranceways, fences and gates.

Infrastructure requirements and costs are very site-specific. Detailed planning will often be needed to properly quantify requirements. This process will normally consider the implications of:

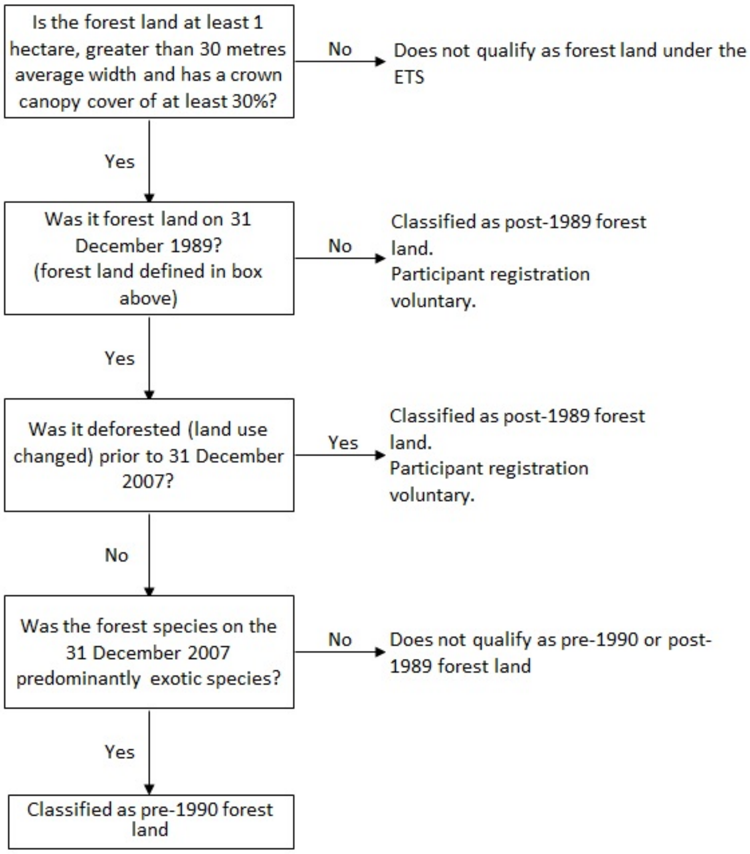
- Existing infrastructure location and condition
- Topography and climate
- Soil types and erosion potential
- Regulatory requirements
- Health, safety and environmental best practice
- Landowners, neighbours, iwi and other affected party considerations
- Aggregate sources

8. Carbon forestry

8.1 ETS eligibility

In order to enter the Emissions Trading Scheme (ETS) and claim credits for the carbon sequestration of a forest, the forest must reside on Post-1989 eligible forest land. This means that the land must not have been forest land on 31 December 1989 and must also meet minimum size requirements. Land that **was** forest at the end of 1989 is only eligible for entry into the ETS if it was converted to another land-use prior to 31 December 2007. The following flowchart summarises the process for determining ETS eligibility of forest land.

Figure 1: ETS Eligibility assessment process



Although land may be deemed as eligible post-1989 forest land, it does not automatically enter the ETS. A landowner (or forestry right holder) is required to apply to have their land added to the ETS. MPI will assess the application, including eligibility, legal ownership and mapping accuracy, prior to approving entry into the ETS.

As Hawke's Bay Regional Council is interested in encouraging afforestation, we assume that land considered for planting will generally be post-1989 eligible forest land. In saying this, in most cases there are small areas of ineligible land in a parcel that is assessed for eligibility. This is often due to patches of scrub being deemed as ineligible, or areas of patchy survival being assessed as not meeting the definition of forest land. Offsetting this is the fact that ETS mapping standards can allow certain gaps to be closed up and future crown growth around boundaries to be factored, often resulting in slightly more area being accepted into the ETS. From recent experience, the ETS eligible area of a newly planted forest is often around **5% less** than the nett stocked area.

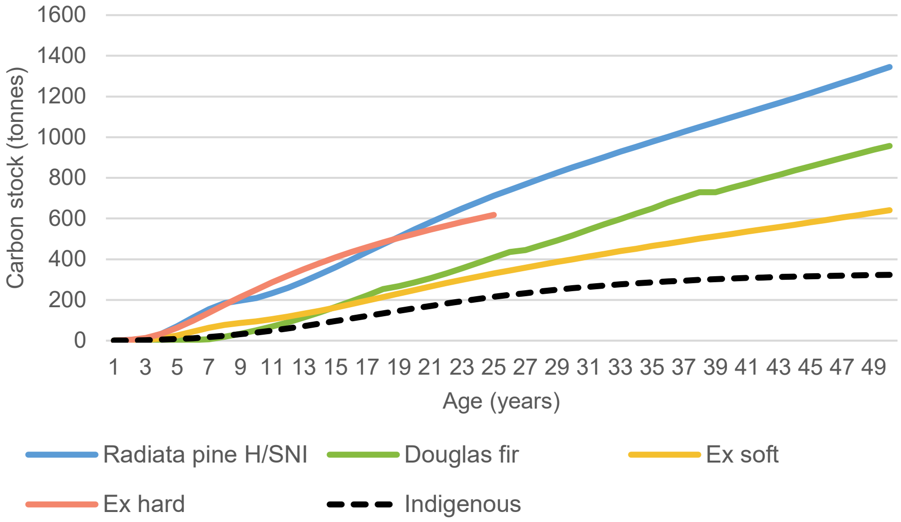
8.2 Carbon sequestration

The sequestration rates shown in the figure below are applied to ETS participants with a total ETS registered area of less than 100 hectares. For those participants with larger areas registered, permanent sample plots must be installed and measured each reporting period to derive participant-specific look-up tables (PSTs).

Manuka falls under the indigenous category in the ETS carbon lookup tables. Currently these tables show elevated levels of carbon storage for manuka plantations under 100ha in size. Caution is urged when using these numbers for manuka, as less carbon will be stored than legally counted. The end land use should also be considered as this will affect future carbon obligations.

The following graph illustrates MPI generic look-up tables in the Hawke's Bay / SNI region.

Figure 2: MPI generic look-up tables for different species groups.



8.3 Carbon strategies

This will be heavily dependent on treatment of indigenous species under the future ETS policies. Expert advice is essential.

8.4 Carbon pricing

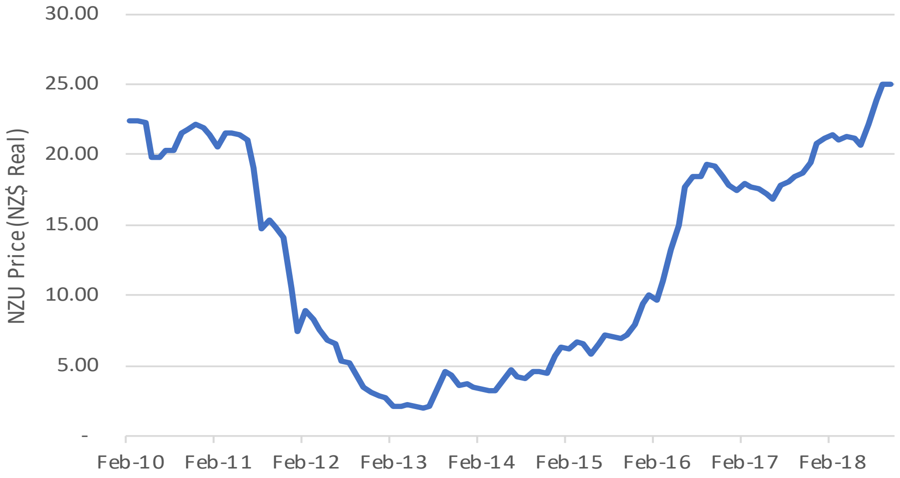
Carbon pricing can be somewhat volatile, and is influenced by several factors including (but not limited to):

- Industrial emissions levels
- Regulatory changes and political influences
- The $25 Fixed Price Option (FPO) available to emitters in lieu of acquiring units for surrender
- Market access and liquidity
- Seasonality of demand
- International trends.

The following graph shows the trend in NZU pricing since 2010. The large price drop that occurred in late 2011 was primarily due to the introduction of cheap European units into the ETS market. Low prices were maintained through to 2014 when the Government blocked use of these cheaper units. Prices have since slowly recovered and are now trading around the $25.00 mark, with market prices being heavily influenced by the $25.00 FPO option available to emitters.

The Government has announced an intention to review the nature and level of the existing price cap, and a number of reports have noted that considerably higher carbon prices may be required to trigger meaningful emissions reductions in the future.

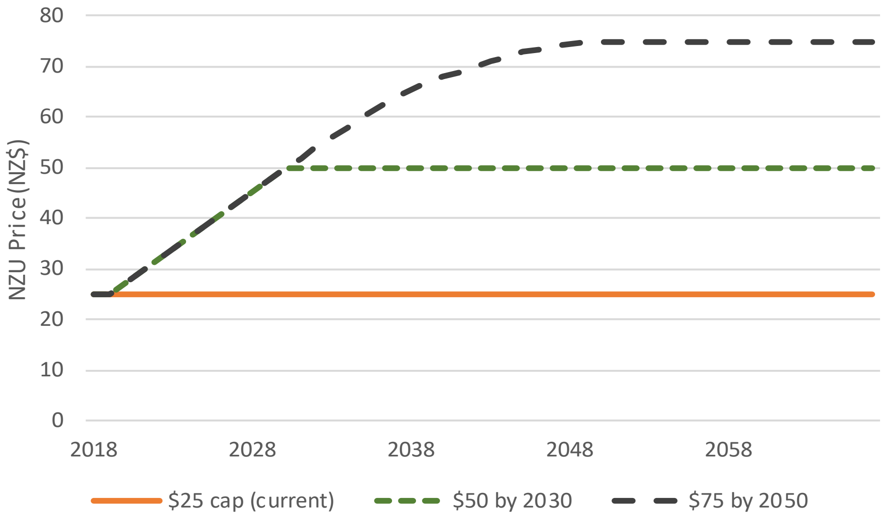
Figure 3: NZU price history, 2010 - 2018.



Forecasting future carbon prices is difficult and very dependent on future carbon policy, emissions reduction goals and international linkages. A report produced for the Parliamentary Commissioner for the Environment (PCE) in 2010 projected that NZ carbon prices could be in the range of $50-$150 per tonne by 2030 (COVEC, 2010). Since then New Zealand has signed up to the Paris Accord, and agreed a Nationally Determined Contribution (NDC) of reducing GHG emissions to 30% below 2005 levels, by 2030. The Productivity Commission recently released their final report on a transition to a "low-emissions economy". Modelling for this report suggests that carbon prices may need to rise to between $75 and $152 a tonne by 2050 (New Zealand Productivity Commission, 2018) to achieve desired emissions outcomes.

It is recommended that modelling of carbon price should use a baseline of $25.00 remaining static into the future, as this is the current pricing, and reflects the current known price cap mechanism.

Figure 4: Example future carbon price scenarios



8.5 ETS costs

ETS participation will usually incur initial set up costs such as planning, mapping, preparing applications and associated MPI fees. There will also be ongoing costs associated with emissions return preparation and submission, record keeping and Field Measurement Approach (FMA) plot measurement and data processing (if >100 hectares). The following table summarises expected costs for ETS setup and on-going participation. It is assumed that for small areas (<20ha) the forest owner would complete most work themselves, while for larger areas a forestry expert would be engaged. FMA costs are assumed to be $350 per plot for measurement, management and data processing.

Table 7: Estimated ETS costs

ETS Cost	**ETS Cost ($ per hectare)**	
	0-99ha	100ha+
Planning, mapping and registration – one off cost	$40	$20
Administration – annual cost	$10	$5
FMA measurement – annual cost	–	$10
Total	**$50**	**$35**

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NZ Manuka Farming https://www.manukafarming.co.nz/our-products/

RIGHT TREE, RIGHT PLACE

HAWKE'S BAY AFFORESTATION PROGRAMME (HBAP)

Species assessment – Douglas-fir

Contents

1. Introduction

Douglas-fir (*Pseudotsuga menziesii* var. *menziesii)* is native to western North America, occurring in a broad coastal band of mountain ranges from British Columbia to California. Douglas-fir has long been an important timber species in its native range, but environmental pressures for protection (particularly of old-growth forests) may see restriction of supply in the future.

Douglas-fir was first introduced to New Zealand around 1870 (Cown, 1999), and the first significant plantings were undertaken by the NZ Forest Service in 1896 near Rotorua (Maclaren, 2009). Douglas-fir is the second-most widely planted exotic forest species in New Zealand, with approximately 104,000 hectares making up 6% of the total plantation forest area (MPI, 2017). Eighty percent of Douglas-fir area is located in the South Island, with the Otago and Southland regions being the most popular.

Douglas-fir is the most abundant non-native tree species grown in Central Europe, with France, Germany and the United Kingdom all having substantial resources as a result of major reforestation programmes after the Second World War (Da Ronch, et al., 2016).

2. Site Requirements

2.1 Climate

Generally, Douglas-fir prefers cooler, high altitude sites. It enjoys moderately high rainfall (1200mm+ annually) and is not tolerant of severe drought conditions (Thomsen, K, et al., 2005). It is intolerant of salt-laden winds, so coastal areas should be avoided.

Douglas-fir is less susceptible to snow than radiata pine – it sheds snow more easily because branches bend until the snow falls off rather than breaking. However, severe storms can still cause extensive damage (Maclaren, 2009). Douglas-fir is relatively frost-resistant during its dormant winter phase but can be very susceptible to out-of-season frosts.

2.2 Topography

Douglas-fir can grow successfully at altitudes up to 1,000m, although growth can be affected by altitudes above 800m. At lower altitudes Douglas-fir may be limited to southerly aspects where water is reliably available. Slope is not generally a limiting factor, although slopes of less than 3 degrees with limited airflow should be avoided due to potential for frost hollows.

2.3 Soils

Douglas-fir prefers well drained soils, performing poorly on heavy clay soils. Preferred soil orders include upland *Allophanic, Pumice, Brown, Podzol* and *Recent* steepland (Thomsen, K, et al., 2005). Soil moisture is very important, hence the preference for southerly aspects in areas of lower rainfall. Preferred soils will be slightly acidic (pH of 5-6), as there is a decline in vigour on calcareous soils. Addition of fertiliser is not usually required for Douglas-fir to grow successfully.

3. Establishment and early growth

3.1 Land preparation

Douglas-fir is more sensitive to early weed competition than radiata pine, so effective weed control is very important. On ex-pasture that has been grazed hard prior to planting, there may not be any requirement for pre-plant spraying, but if rank grasses, scrub or herbaceous weeds are present, an application of glyphosate or metsulfuron may be required. Mechanical clearing will only be required if thicker patches of scrub persist, and spot mounding is generally not required as frost-prone areas are best avoided altogether with this species.

Fencing may be required if parts of paddocks are being set aside, and requirements for access tracking will vary from property to property, but will usually require some upgrade to enable forestry crew vehicle access.

In general, land preparation costs for Douglas-fir are likely to be in line with those of radiata pine.

Table 1: Indicative land preparation costs

Operation type	Operation cost estimate ($/ha)		
	Low	Medium	High
Grazing	0	0	
Aerial spraying			60 ($300 x 20% of area)
Roller crushing / line cutting			$50 ($500 x 10% of area)
Tracking and fencing		50	100
Total	**0**	**50**	**210**

3.2 Planting stock

New Zealand banned the importation of Douglas-fir seed in 2003 after the discovery of Pine Pitch Canker on some genetic material. Fortunately a good cross-section of seed from promising locations had been collected by this point. Provenance selection will usually consider growth potential, but also stiffness and disease resistance. The most common provenances utilised in New Zealand originate from California and southern Oregon. Ultimately for smaller growers though, specific provenance selection will come down to availability, as only a handful of nurseries grow douglas-fir for the open market, and make decisions on seed sourcing 2-4 years in advance.

'Fort Bragg' and 'Berteleda' seedlots originate from California and are often recommended for Hawke's Bay. Tramway is another popular seedlot from Beaumont forest in Tapanui. This seed is primarily of Washington ancestry.

Tree stocks need to be well conditioned to ensure successful establishment. Bare-root seedlings are often chosen as they can be easier to condition. Seedlings are usually 2 years old (2/0) in order to ensure a minimum root collar diameter of 10mm. Some nurseries will grow a "plug +1" treestock, where seedlings are propagated in a plug before being transplanted into the nursery bed for their second year. This often results in better seed efficiency.

The larger seedlings are required due to slower initial growth (than radiata). Larger trees are lees likely to be destroyed by animal browsing or smothered by competing weeds. Beneficial mycorrhizae can also develop more effectively.

Table 2: Indicative Douglas-fir treestock costs

	Treestock cost ($ per 1,000 trees)	
	2/0 Bareroot Tramway ex Southland	**2/0 Bareroot Tramway ex Nelson**
Tree stocks	420	550
Transport to Hawke's Bay	100	50
Total	**520**	**600**

3.3 Initial stocking rates and survival

Initial planting is recommended to be at stocking rates of 1200 – 1600 stems per hectare. The higher end of this range will be required if animal browsing or site conditions are deemed as adverse to optimal survival. Square spacing is recommended to ensure control of branch size.

Douglas-fir seedlings are less hardy than Radiata pine, so careful planning is required to ensure that treestocks are delivered to planting sites on time and in good condition. Seedlings are also relatively delicate, so extra care should be taken in packaging, handling and transport.

Supervision and quality control of planting operations is crucial to ensuring that trees are planted safely correctly, in the right locations, and at the appropriate stocking rates. Survival assessment is also usually undertaken in the months following planting. This helps to determine what areas may require "blanking" – restocking the following winter.

3.4 Planting

Planting should be planned for the month of June (unless the ground is frozen or snow-covered) as this is when Douglas-fir seedlings are most dormant. In frost or snow-prone areas it may be necessary to wait until the end of Winter to plant.

Costs for planting labour and management will usually vary on area, stocking rate, travel distance, terrain, access limitations (e.g. how closely you can have trees delivered) and land cover (scrub or cutover land being generally more expensive to plant than grass).

The table below summarises expected costs for establishing Douglas-fir in Hawke's Bay.

Table 3: Indicative Douglas-fir planting costs

Cost Type	Planting cost ($ per hectare)		
	Low (1,200 sph)	Medium (1400 sph)	High (1600 sph)
Treestock cost	670	780	900
Labour cost	600	700	800
Operations management	100	150	200
Blanking (5%, + 1 year)	70	80	95
Total	**1440**	**1710**	**1995**

4. Silviculture and forest management

4.1 Post-plant weed control

Releasing is usually completed in the spring after planting, while soil moisture is high and soil temperatures are starting to rise, but before seedlings are actively growing. Trees should not be sprayed if seedlings are stressed, e.g., during drought (Maclaren, 1993). Costs will vary based on the method, and type and quantity of chemical required. Some indicative costs are provided in the table below.

A re-treatment may be required in Year 1 or 2 if weed competition is vigorous, or initial growth of trees is slow. Often this may only be required in parts of the planted area.

Table 4: Indicative radiata pine releasing costs

Cost type	Releasing cost ($ per hectare)		
	Low (1,200 sph)	Medium (1400 sph)	High (1600 sph)
Labour / equipment cost (Spot spray)	324	378	432
Chemical cost (Terbuthylazine 3L/ha)	87	102	116
Operations management	40	50	60
Repeat treatment (25% area + 2 years)	110	130	150
Total	**561**	**660**	**758**

4.2 Fertiliser

In general, it is not expected that Douglas-fir grown in Hawke's bay will need to be fertilised, unless there is a very site-specific nutrient deficiency.

4.3 Silviculture strategy

Actual strategy choice will depend on site factors, distance and nature of log markets, and financial and risk profiles, and will also depend on personal preference. For simplicity, we have analysed a single strategy that is most likely to be employed in Hawke's Bay. This is a timber strategy, focussed on framing timber (no pruning).

4.4 Pruning

Pruning is not generally recommended for Douglas-fir, as primary end-use is structural construction rather than appearance grade lumber. Costs of pruning Douglas-fir are also generally higher than those of radiata pine, due to the higher frequency of branches.

4.5 Thinning

Waste thinning assumes that any cut trees are left where the fall, to decay over time. **Production thinning** involves extracting felled stems and merchandising into logs for sale. Production thinning of Douglas-fir can yield reasonable quality logs at ages of 25 years +, but the viability of such operations will be limited by terrain and accessibility to stands. It is unlikely that much area suited to Douglas-fir in Hawke's Bay would be located on sites suited to profitable production thinning. The delay in thinning for production thinning can also add to the windthrow risk of the remaining stand.

Timing of thinning will be determined by how big the trees are. Thinning should occur once the benefit of close competition on branch size has been realised, but before canopy closure starts to have an impact on growth rates of the final crop trees. A single waste thin is usually sufficient, undertaken when trees reach a **Mean Top Height[1] (MTH) of 14 metres**. Site productivity will determine when this target height is reached, and in Hawke's Bay is likely to be between 17 and 27 years old.

Final crop stocking chosen will again depend somewhat on the productivity of the site, but **450 – 700 stems per hectare** is usually targeted. The lower end of this range can be utilised in areas where Swiss Needle Cast (SNC) is a particular risk.

Table 5: Indicative Douglas-fir thinning costs

	Cost ($ per hectare)		
Cost Type	**Low (1,200 sph)**	**Medium (1400 sph)**	**High (1600 sph)**
Waste thin (to 550 sph)	1200	1400	1600
Operations management	80	120	160

4.6 Forest management

Forest management requirements will depend usually on the scale of the forest resource and expertise of the owner. Very small forests may be managed with little effort by the owner, but owners with little spare time or experience, or with a large forest asset may choose to engage the services of forest manager.

Costs for undertaking forest management activities will depend on agreed scope of responsibility, and will also vary based on forest location, scale and competition for services. The table below summarises some indicative forest management costs that could be expected for forests in Hawke's Bay.

Table 6: Indicative radiata pine forest management costs

	Cost ($ per hectare)		
Cost type	**Low**	**Medium**	**High**
Forest management	15	25	35
Administration	5	15	25
Protection and maintenance	10	20	30
Total	**30**	**60**	**90**

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[1] Mean Top Height is defined as the height predicted by the Petterson height/dbh curve for a dbh corresponding to the quadratic mean dbh of the 100 largest trees per hectare (based on dbh) in a stand (Goulding, 2005).

5. Pests, diseases and other risks

5.1 Wild animals

Browsing by animals is a significant risk to successful establishment of Douglas-fir, and it is therefore advised to eradicate goats, hares, rabbits and possums prior to planting. Possums in particular can continue to cause damage in Douglas-fir for up to 10 years. Piers Maclaren goes as far as to say that if animal pests are uncontrollable then the site should be reconsidered as appropriate for Douglas-fir.

It is recommended that pre-planting control, and post-plant monitoring (and control if required) is budgeted by those planning to plant Douglas-fir in Hawke's Bay.

5.2 Insect pests

A number of insects feed on Douglas-fir foliage, particularly the caterpillars of several native moths, but they seldom cause material damage. Douglas-fir is not susceptible to the common borer beetles that can infect radiata pine.

There are a number of beetles and moths in Europe and America that can cause significant damage to Douglas-fir trees, but the likelihood of incursion into New Zealand is deemed to be very low.

5.3 Diseases

Swiss Needle Cast (SNC) is the only significant disease to affect Douglas-fir in New Zealand. It is caused by the fungus *Phaeocryptopus gaeumannii* and causes premature needle loss and significant (20-30%) growth constraint.

SNC is distributed across New Zealand but is of primary concern in warmer climates. Abundance appears to be aggravated by warm winters and wet spring foliage. Risk and severity in Hawke's Bay are moderate to high, with infection likely to cause needle losses of 30-50% across most of the region. Various climate change scenarios suggest that severity could increase substantially in the future, particularly in the northern and eastern parts of the region (Watt, et al., 2010).

Management of SNC is somewhat limited. Breeding is likely to play a role, and the Specialty Wood Products Research Partnership (SWP[2]) breeding programme includes improved SNC resistance in its objectives. Careful site selection can also help to reduce risk, as can silvicultural management (lower stockings and aerated stands).

5.4 Fire

There is some suggestion that Douglas-fir forests can help to reduce the speed of fire spread due to the impact of denser canopies on understorey fuel availability and wind penetration. In general though, fire risk is deemed to be similar to that of radiata pine, and management of that risk is expected to be the same in terms of a combination of protection operations and insurance.

5.5 Wind

Generally Douglas-fir is less susceptible to wind damage than radiata pine, due to the advantages of root grafting and canopy/branch resistance.

5.6 Insurance

Risks associated with fire and wind damage can usually be mitigated through appropriate insurance cover. Insurance will usually compensate a proportion of the current tree crop value, and often also provides compensation for the costs of clearing and replanting land. Public liability cover is also usually included. The table below summarises indicative insurance cover costs for an average Hawke's Bay Douglas-fir forest.

Table 7: Indicative Douglas-fir insurance costs, average through first rotation.

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[2] https://fgr.nz/programmes/alternative-species/swp-programme/

Cost type	Cost ($ per hectare)		
	Low	Medium	High
Fire	8	10	13
Wind	8	10	13
Public Liability	1	1	1
Total	**17**	**21**	**27**

5.7 Wilding spread risk

Douglas-fir is a significant wilding spread risk in many parts of the country. Its light seed and shade tolerance allow wildings to establish easily in extensively grazed grass and shrubland. Although it has not been accorded "pest" status within the proposed HBRC Regional Pest Management Plan[3], it has been identified (along with radiata pine) as an "Organism of Interest" whereby future control requirements could arise, for example through site-led programmes.

Douglas-fir is generally considered to be a moderate risk species in the North Island, with scores of 1/5 for spreading vigour and 3/5 for palatability in the DSS1 wilding spread risk calculator (Paul, 2015). It is unlikely to be a major wilding risk for adjoining farmland in Hawke's Bay, but could pose problems with spread into areas of regenerating indigenous scrubland. The following table compares Douglas-fir DSS1 scores for spreading vigour and palatability with other common conifer species planted in New Zealand.

Table 8: Species comparison of DSS1 spreading vigour and palatability scores

	DSS1 score (/5)	
Species	**Spreading vigour**	**Palatability**
Redwood, cedar, spruce	0	N/A[4]
Radiata pine	1	1
Douglas-fir (Nth island)	**1**	**3**
Larch	2	0
Corsican pine	3	4
Douglas-fir (Sth island)	4	3
Pinus contorta	5	2

Plantation design and management can effectively manage much of the risk, while in the future it is hoped that tree breeding and genetic engineering could result in sterile Douglas-fir being available to the industry.

6. Productivity

6.1 Productivity rating systems

Productivity of sites for growth of Douglas-fir are generally characterised using two indices, being Site Index and 500 Index.

Site Index is a measure of height productivity and is defined as the height of the 100 largest diameter trees per hectare at a given reference age. For Douglas-fir that reference age is 40 years. The average Site Index in Hawke's Bay is **28.2m**, based on measurements from 241 PSPs (Ledgard, et al., 2005).

500 Index is a measure of volume productivity and is defined as the mean annual volume increment (MAI), at an age of 40 years, for a stand planted at 1250-1650 stems/ha and waste thinned to 500 stems/ha by MTH 15m. The average 500 Index in Hawke's Bay is **14.6m3 per year,** based on measurements from 143 PSPs (Ledgard, et al., 2005).

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[3] https://www.hbrc.govt.nz/services/pest-control/biosecurity/pest-management-plan-review/

[4] Palatability not scored as spreading vigour of zero means very low risk of spread

The following productivity settings are recommended for use in modelling. The ranges of productivity from the average have been derived from work completed by the New Zealand Douglas-fir Cooperative (Knowles, 2005).

Table 9: Productivity estimates for low, medium and high productivity classification

Class	Productivity index		Notes
	Site Index (m)	500 Index (m^3/ha/yr)	
Very High	34.0	20.5	SI +20%
High	31.0	17.5	SI +10%%
Medium	**28.2**	**14.6**	**HB average** (Ledgard, et al., 2005)
Low	25.0	11.5	SI -10%
Very Low	22.0	8.5	SI -20%%

6.2 Growth model

Growth modelling is required to predict future yields, as this information is crucial to cashflow forecasting. The primary growth model for Douglas-fir is the 500 Index growth model, derived from the Douglas-fir calculator v4.0

The 500 Index Model is intended for use in any site in New Zealand. The growth model is calibrated for any given site using the two site productivity indices Site Index and 500 Index. The model was developed from an initial dataset of 1082 trial plots throughout New Zealand.

6.3 Rotation length

Douglas-fir is typically harvested at an older age than radiata pine, primarily due to slower growth. Typical rotation lengths for Douglas-fir are between 40 and 50 years. Based on productivity modelling, the following rotation lengths have been assumed.

Table 10: Rotation lengths assumed by productivity class

Productivity	Rotation length (years)	Piece size at harvest (m^3)
Very High	40	1.5
High	43	1.4
Medium	**45**	**1.2**
Low	47	1.0
Very Low	50	0.9

6.4 Log Yields

The following table summarises yield forecasts by log grade, based on the various inputs noted in previous sections of this report. Yields have been modelled using Forecaster software.

Table 11: Indicative clearfell yields by log grade for Douglas-fir in Hawke's Bay.

Grade	Min SED (cm)	Max branch (cm)	Total recoverable volume by site productivity (m^3 per hectare)		
			Low	Medium	High
CF+ Large sawlog	32	12	92	186	281
CF- Small sawlog	22	10	300	307	311
DKIS Small industrial	12	20	79	70	76
DPULP Domestic pulp	10	Open	41	36	23
Total			**512**	**599**	**691**

7. Log production

7.1 Harvest productivity and cost

In general, harvest costs are likely to be slightly higher for Douglas-fir than for radiata pine. This is due to the smaller piece size impacting handling times and therefore productivity. The following table summarises harvest costs that could be expected for a range of harvest systems and difficulty factors that would commonly be encountered in Hawke's Bay.

Table 12: Indicative radiata pine harvest costs

Harvest type	Harvest cost (\$ per m^3)		
	Easy	Medium	Hard
Ground-based	20.00	30.00	35.00
Hauler	35.00	45.00	55.00

7.2 Infrastructure requirements

Infrastructure requirements and costs are very site-specific. Detailed harvest planning and engineering design work will often be required to properly quantify requirements. Below is a table summarising some expected ranges of infrastructure costs that could be expected for typical forests in Hawke's Bay.

Table 13: Indicative radiata pine infrastructure costs (first rotation, ex farm)

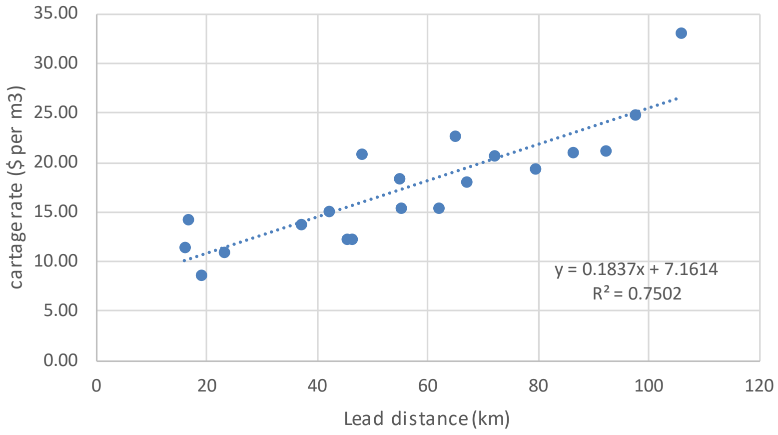
Cost Component	Infrastructure cost (\$ per m^3)		
	Low	Medium	High
Road and Skid Construction	3.00	6.00	10.00
Maintenance	0.50	1.00	1.50
Post-harvest rehabilitation	0.50	1.00	1.50
Total	**4.00**	**8.00**	**13.00**

7.3 Log cartage

Transporting logs from forest to customer in Hawke's bay has historically been by road and rail. Currently rail transport is limited to logs moving north to Napier port from the Manawatu / Whanganui region, but funding is in place to re-open the Napier – Wairoa rail line to facilitate log transport south to Napier. This has the potential to reduce transport costs and improve safety for road users on State Highway 2.

Following is a graph showing regression analysis for PF Olsen log cartage in the Southern North Island over 2017-2018. This analysis shows that cartage costs over this period can be approximated by using the formula ***Cartage cost (\$/m3) = \$7.16 + (\$0.18 x Lead distance)***.

Figure 1: Cartage rate analysis for Southern North Island, July 2017 - June 2018 (Source: PF Olsen).



Fuel prices have a significant impact on cartage rate, with approximately 20% of cartage costs being attributed to diesel consumption. Diesel prices across the analysis period above averaged $1.26 per litre[5]. Diesel prices since this period (up to October 2018) have increased by approximately 20%, and this is likely to have resulted in cartage costs increasing by around 4%. It is worth noting that this increase would also likely be felt in harvest costs, where diesel costs have a similar influence.

Factoring the increased fuel component, the cartage formula that best approximates current cartage costs would be:

Cartage cost (\$/m^{3}) = \$7.45 + (\$0.19 x Lead distance)

Table 14: Indicative cartage costs

Lead distance (km)	Cartage cost ($/m^{3})
25	$12.20
50	$16.95
100	$26.45
150	$35.95

7.4 Other costs of production

Management of harvesting operations by a suitably qualified individual or company will usually be required. Management tasks include:

- Harvest planning
- Contract and contractor management
- Health & safety and environmental compliance monitoring.
- Production monitoring
- Log value recovery and quality control
- Log marketing
- Reporting and documentation
- Weighbridge fees and consumables (paint, stencils etc)

Table 15: Indicative harvest management costs

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[5] Discounted retail price – Source: https://www.mbie.govt.nz/info-services/sectors-industries/energy/liquid-fuel-market/weekly-fuel-price-monitoring

Complexity	Management cost ($ per m^3)
Low	$3.00
Medium	$5.00
High	$7.00

The Commodity Levies (Harvested Wood Material) Order 2013 imposes a levy on all harvested wood material from plantation forests in New Zealand. The levy was introduced to provide R&D funding to the commercial forestry industry. Levies are payable to the Forest Growers Levy Trust and the levy is currently set at **$0.27 per m^3** or tonne and cannot exceed $0.30 per m3 or tonne during the six-year levy period. The levy period ends in 2019, at which point forest growers will hold a referendum to decide whether to continue for another six years.

8. Log markets and wood availability

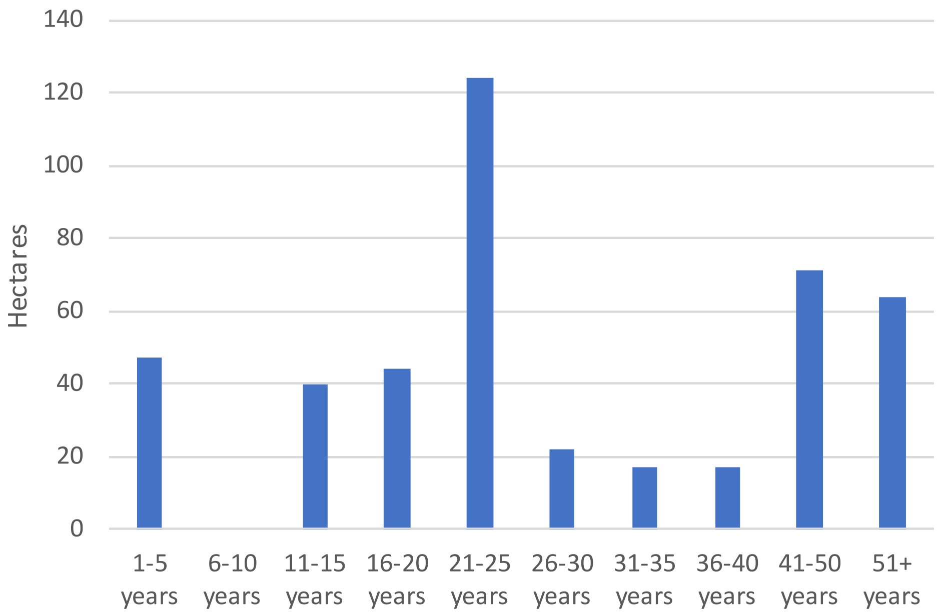
8.1 Domestic processing capacity

There is very little sawmilling capacity for Douglas-fir in Hawke's Bay, as most local mills are setup for processing radiata pine for clearwood.

8.2 Wood availability

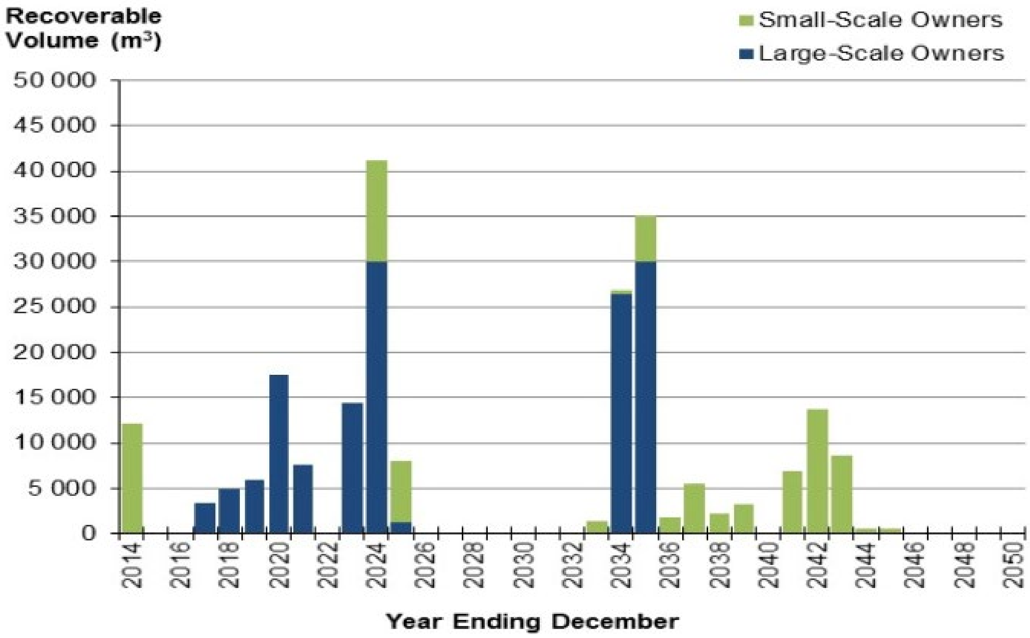
Hawke's Bay is one of the least popular regions for Douglas-fir in New Zealand, with 446 hectares of Douglas-fir plantation making up only 0.4% of the area planted nationally (MPI, 2017). The age-class profile of Hawke's Bay Douglas-fir is shown in the following graph.

Figure 2: Douglas-fir age-class profile for Hawke's Bay (Source: NEFD 2017)



Wood availability forecasts for Hawke's Bay were produced by MPI in 2014 using several scenarios in terms of forest owner decisions. The small size of the estate in Hawke's Bay, along with the age-class profile suggests that wood availability is unlikely to be consistent. The following graph shows predicted availability.

Figure 3: Hawke's Bay Douglas-fir availability - (from MPI 2014 wood availability forecast).



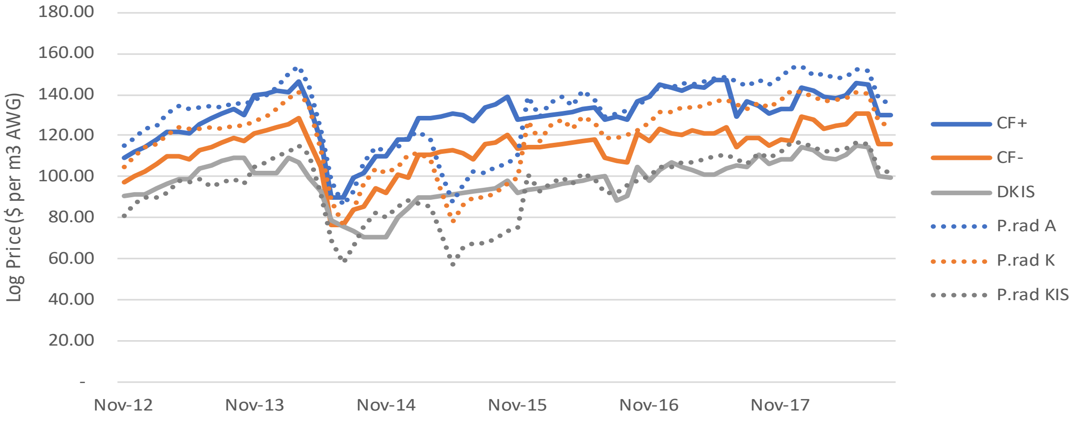
8.2 Log exports

The lack of domestic processing capacity combined with a small and inconsistent future wood availability suggests that export will be the primary market for Douglas-fir logs originating from Hawke's Bay. Exporters in the region are set up to handle Douglas-fir as it arises and will be active in the region with future radiata pine demand, so no issues with market access and logistics of Douglas-fir export logs are foreseen.

8.2 Log prices

The graph below shows price trends over time for key Douglas-fir log grades, and comparison with similar radiata pine grades.

Figure 4: Export log price comparison between radiata pine and Douglas-fir (All ports, 2012-2018).



Douglas-fir logs have historically received a premium over radiata pine, although this varies considerably with time and grade. Analysis of price data from the last five years enables an average "premium" over radiata pine to be estimated. The following table summarises Douglas-fir price premiums used in this exercise.

Table 16: Douglas-fir log price premium/discount (over radiata pine) – 5-year average.

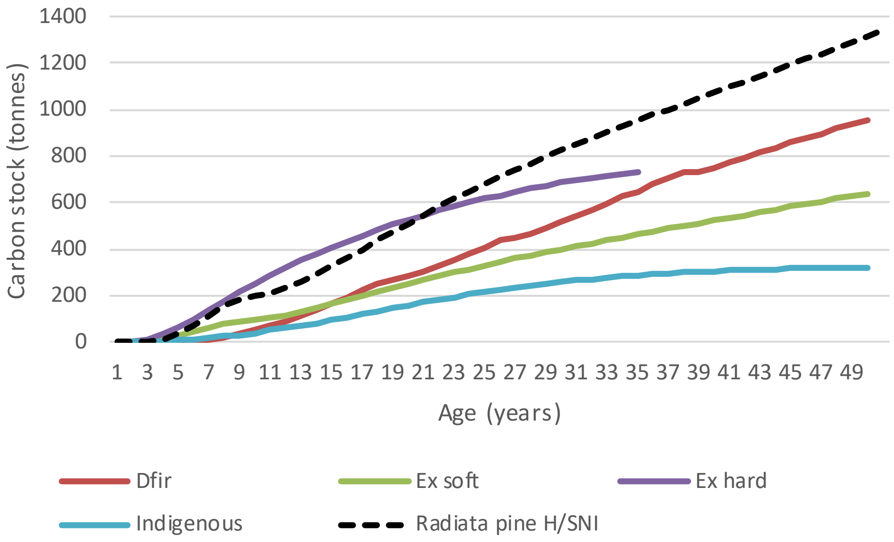
Grade	Premium ($/m^3)
CF+	+10.00
CF-	+5.00
DKIS	+10.00
DPULP	-2.00

9. Carbon forestry

9.1 Carbon sequestration

Douglas-fir carbon sequestration rates are generally lower than radiata pine in New Zealand. The following graph compares MPI generic look-up tables for Douglas-fir in New Zealand with other species groups.

Figure 5: MPI generic look-up tables for different species groups.



The sequestration rates shown in the figures above are applied to ETS participants with a total ETS registered area of less than 100 hectares. For those participants with larger areas registered, permanent sample plots must be installed and measured each reporting period to derive participant-specific look-up tables (PSTs).

Recent experience has shown that participant-specific tables for radiata pine usually result in greater sequestration rates than those provided by the generic tables, likely due to a higher level of conservatism being applied to generic tables for their widespread application. It is uncertain whether the same could be said for Douglas-fir, as PF Olsen has not had the opportunity to analyse such data for Douglas-fir.

A conservative approach to modelling sequestration is recommended, as there are many variables that can impact actual sequestration rates for a participant. Therefore, we recommend that the generic lookup table is used in all scenarios, regardless of actual registered area and FMA status.

9.2 Carbon strategy

For simplicity it has been assumed that anyone planting Douglas-fir in Hawke's Bay will be targeting a timber crop. The carbon strategy employed would therefore most likely be to sell only the low-risk ("safe") carbon level. "Safe" carbon is a term used to describe the long-term minimum carbon storage of a forest across multiple rotations. This minimum is only greater than zero if all carbon growth is accounted for, by having the trees entered into the ETS at a young age. The risks of this strategy are lower, but there is still some uncertainty as the "safe" level is only an estimate until after harvest and replant. It could also change again in the future if rotation lengths were adjusted or if there was a delay before replanting.

The following figures show carbon flow profile and balances for a typical Douglas-fir safe carbon strategy.

Figure 6: Example carbon stock balances (D-fir national lookup table, age 45 harvest)

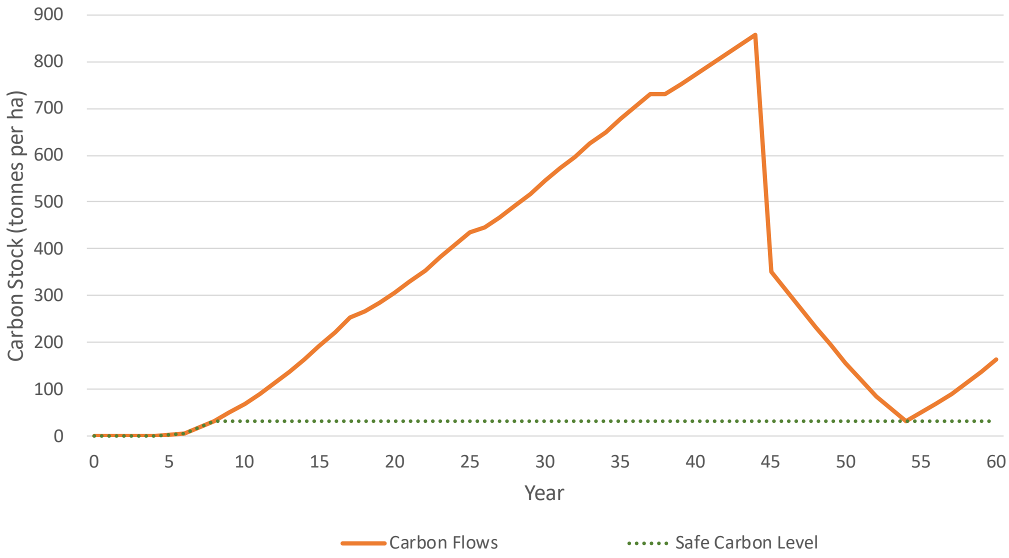
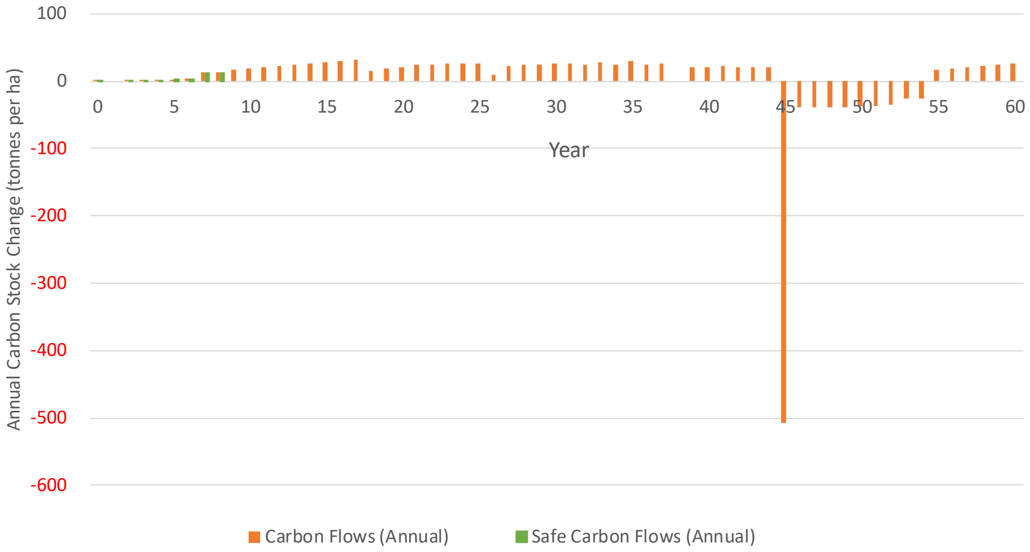


Figure 7: Example annual carbon flows (D-fir national lookup table, age 45 harvest)



9.3 Carbon pricing and ETS costs

Carbon pricing and ETS costs are not likely to vary by species for exotic timber regimes. Therefore, it has been assumed that these inputs will be identical to those of radiata pine.

Figure 8: Example future carbon price scenarios

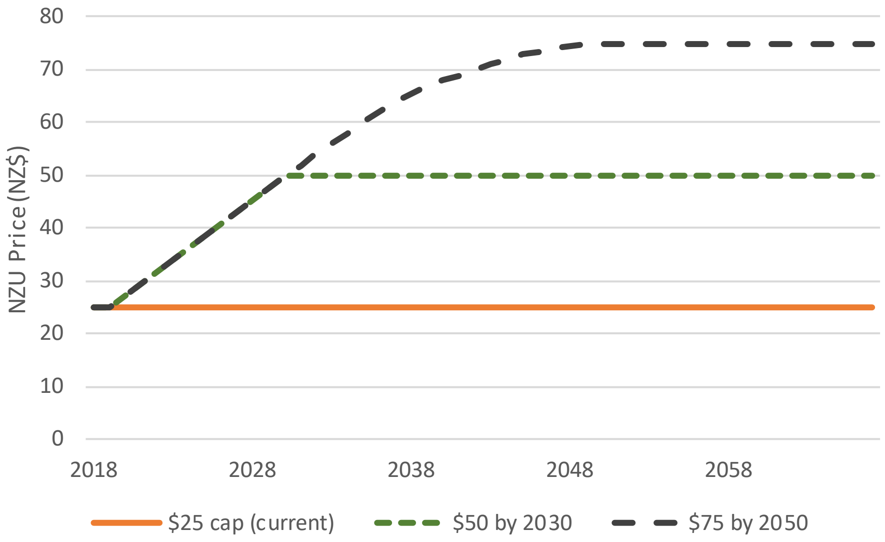


Table 17: Estimated ETS costs

ETS Cost	ETS Cost ($ per hectare)	
	0-99ha	100ha+
Planning, mapping and registration (~Age 3)	$40	$20
Administration (annual)	$10/year	$5/year
FMA measurement (every 5th year)	-	$50

10. Discounted cashflow analysis

The following tables summarise results from discounted cashflow analysis for a typical regime.

Table 18: Indicative Douglas-fir framing regime cashflow analysis summary (pre-tax, real)

Metric	Douglas-fir – Framing		
	Low	Medium	High
Net stumpage ($/ha)	$13,000	$23,000	$45,700
Log IRR	0.0%	0.1%	4.3%
Log + Carbon IRR	0.0%	0.1%	4.3%
Log + Carbon NPV @ 7% ($/ha)	-$8,100	-$5,900	-$3,300

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RIGHT TREE, RIGHT PLACE

HAWKE'S BAY AFFORESTATION PROGRAMME (HBAP)

Species assessment – Redwood

1. Introduction

Coast redwood (*Sequoia sempervirens*) occurs naturally along the Pacific coast of California (Knowles, 1993). Redwood is a long-lived tree that has an iconic status in the USA not dissimilar to that of Kauri in New Zealand (Nicholas, 2007). It is one of the tallest and oldest tree species in the world, along with the giant sequoia (*Sequoiadendron giganteum*).

Coast redwood was first introduced to New Zealand in 1860 and planted around the country. The Redwood Memorial Grove in Whakarewarewa, Rotorua is perhaps the most successful example of redwood in New Zealand (Knowles, 1993). Correct siting as well as weed control and site preparation is important when establishing redwood, and a lack of the aforementioned were primary reasons why many planted areas failed.

The international market for redwood, almost exclusively in Californian is strong, as the demand is high and supply is dwindling (Knowles, 1993) Restricted access to natural stands in the USA enhances the potential for developing an export market for New Zealand-grown redwood. However, the US lumber market is very different to the radiata pine market in New Zealand, as clear heart grades attract a large premium over those with sapwood content and unpruned grades. This presents some challenges regarding silviculture requirements that New Zealand redwood forest growers may not necessarily be familiar with (Nicholas, 2007).

Redwoods have unique characteristics that could see them provide distinct benefits toward the objective of soil erosion and sedimentation. The species is relatively shade tolerant, very long lived and the roots and stumps coppice if a tree is cut down or gets windblown. This means the species has potential for planting to protect riparians, to provide permanent protection from landsliding, or potentially for management under continuous cover silviculture as well as clearfelling. The tendency for many erosion prone landforms to also have shallow relatively less fertile soils will be a limitation on widespread deployment.

2. Site Requirements

2.1 Climate

- **Temperature** affects many aspects of growth. Coast redwood does best in sheltered inland areas like river flats and gullies. Not much is known in New Zealand about the optimum temperature for coast redwood, although it is thought that warmer, humid temperatures are preferred. Some success has been had on colder sites such as the one in Rotorua; however, this may be due primarily to other factors other than temperature such as soil and rainfall. Young trees can be damaged by frosts less than -9 degrees Celsius, and the species is vulnerable to out-of-season frosts. Frost damage can be lessened through land preparation and removing vegetation from around trees.
- **Rainfall** is also an important consideration. A reasonably high, well-distributed rainfall is essential for redwood success.
- **Wind** can have an adverse effect on redwood survival, and it is generally intolerant of strong prevailing winds. However, redwood is resistant to toppling and breakage from periodic storms due to an expansive albeit shallow root structure. Despite the common name of coast redwood, it is highly intolerant of salt-laden coastal winds (Nicholas, 2007).

Generally, redwood is suited to a wide range of lowland sheltered sites found in New Zealand particularly in the North Island, including areas of the Hawke's Bay. The following table summarises the optimal climate conditions for redwood.

Table 1: Climate profile for redwood

Climate variables	C.Redwood preferred	Hawke's Bay actual (Chappell, 2013)
Mean annual air temperature (°C)	12.5	8.0 - 13.5
Mean winter minimum air temperature (°C)	~?	2.0-7.0
Frost limit (°C)	-9	-6.0 to -12.0
Mean annual rainfall (mm)	1250	707 - 2,000+
Snow at low levels?	None	Rare (1-2 days per 10 years)

2.2 Topography

- **Elevation** has effects on tree growth, primarily due to its modification of climatic variables such as temperature. In its natural habitat redwood can grow up to 900m above sea level but less than 750m is where it is most abundant (Nicholas, 2007) and in NZ conditions an altitude <500m is considered desirable.
- **Slope** is a limiting factor for commercial plantings, primarily for health and safety and environmental reasons. With increasing focus on safety of planting operations, some very steep slopes may not be planted due to unacceptable risk for workers. Slope also affects the cost and complexity of harvest operations, and the susceptibility to erosion.

Table 2: Topography requirements for redwood in the North Island.

Topography variables	S. sempervirens preferred
Maximum altitude (m)	500

2.3 Soils

- **Soil moisture** is very important to the success of redwood plantings. This is dependent on rainfall in the area, and depth and texture of the soils. Although redwood can occur on rocky, dry slopes when supported by other conifers and hardwoods (Knowles, 1993), it grows best on moist slopes or alluvial outwash soils that are deep and well drained but moisture retentive. Compacted or dense soils are not optimal for growth.
- **Nutrient supply** is crucial to all plants, and identifying nutrient deficiency is usually completed through foliar analysis. Redwoods perform best in moderate to fertile soils.

2.4 Access and infrastructure

If establishing a redwood crop for eventual harvest, access to the crop will need to be guaranteed in the future. The following should be considered before establishing a redwood forest:

- **Distance to market** (is there a viable customer located within a reasonable distance of the site?)
- **Legal access** (can the site be accessed without encumbrance?)
- **Infrastructure requirements** (can the site be accessed for planting and ongoing management; can roads and skids be installed to get produce off the site profitably?)
- **Harvest requirements** (can the crop be harvested profitably using available harvest systems?)

3. Establishment and early growth

3.1 Land preparation

Land preparation is undertaken to promote early growth, control weed competition, and promote wind firmness. Preparation activities are usually undertaken using hand tools, machinery, fire, chemicals or animals (grazing). The specific type of land preparation will depend on the condition of the land.

- **Ex-grazing land.** Land preparation requirements for land that is primarily grass are relatively little. The most efficient pre-plant preparation will be hard grazing prior to planting. If grazing is not possible prior to planting, an aerial broadcast application of herbicide may be required.

  Boundary fences will likely need to be installed or modified, and internal fences may need to be removed to avoid future hindrance.
- **Scrub or brush land.** On sites with high incidence of scrub, gorse, blackberry or other brush species, an aerial application of brushkiller may be required. If this brush is dense or > 2m in height, it may also require some mechanical clearance too, either via roller crushing, or line cutting. However, be sure to check the local District plan. Often clearance of partially regenerated native vegetation will not be permitted under the RMA.
- **Cutover land**. Prior to replanting land following harvest, it is often necessary to complete some form of mechanical land preparation, to clear away logging slash. Usually machines will heap slash up into windrows to clear space for the new crop. For redwoods, between the windrows, ripping or spot cultivation is recommended to ensure good root penetration and aeration. This is especially so on flatter areas that have been harvested using mechanised systems

  A desiccation spray or large spot spray is also usually required to supress weed growth prior to replanting.

The following table shows some indicative land preparation costs that could be expected for operations undertaken in the Hawke's Bay region.

Table 3: Indicative land preparation costs

Operation type	Operation cost estimate ($/ha)		
	Ex-grazing land	**Scrub / brush land**	**Cutover land**
Grazing	0		
Aerial spraying		250	300
Roller crushing / line cutting		0-500	
Windrowing /Spot mounding	Spot cultivation?	Spot cultivation?	0-700
Tracking and fencing	50	50	
Total	50	300-800	300-1,000

3.2 Planting stock

When selecting which planting stock to plant, the following options should be considered:

- Genetics (Libby 2002) quoted in the Redwood Growers Manual advises (pp23) potential growers "not to plant redwood seedlings from any open -pollinates source in NZ, while in the Farm Forestry Redwood Handbook pp25 forest growers are warned to " ensure they have the best genetic material available that has a proven track record in New Zealand". There have been a series of provenance and clonal trials installed across a range of NZ sites since the 1980's and these are starting to yield good information.
- Propagation method – Clonal forestry is expected to be very important to the production of good redwood stands that consistently provide the stand and wood qualities required to meet the American market from faster grown NZ redwood. Limited stocks of good quality clonal material are now available in NZ. Ref ?
- Nursery location and transport. Nurseries growing redwood??

3.3 Initial stocking rates and survival

Initial stockings for redwood plantations will depend upon the nature of the seedlings. Redwood stock is significantly more costly than radiata and clonal stock higher again.

- Elite clonal stock can be planted at a final crop stocking of 400 – 500 stem/ha Redwood Growers Manual advises (pp33) Such plantings will require planting in association with a nurse crop to control branching, provide shelter and drive height growth. The nurse crop trees will then be subsequently removed leaving just the redwood crop.
- If planted as a pure plantation of good genetic source seedlings, or a row by row seedling or nurse crop clone mix, initial stockings are typically in the range of 800 to 1,100 stems/ha or more to allow for subsequent selection of the best performing trees possible at time of pruning and/or thinning.

3.4 Planting

Specifically, for redwoods, it is recommended (Redwood Growers Manual advises pp38) that the planting technique be adjusted. Seedlings should be placed in a well 'worked' hole the diameter of the seedlings roots (in cultivated ground) or twice the diameter in uncultivated ground.

Costs for planting labour and management will usually vary on area, stocking rate, travel distance, terrain, access limitations (e.g. how closely you can have trees delivered) and land cover (scrub or cutover land being generally more expensive to plant than grass). The added requirements for planting redwoods will further add to the cost.

Supervision and quality control of planting operations is crucial to ensuring that trees are planted correctly, in the right locations, and at the appropriate stocking rates. Survival assessment is also usually undertaken in the months following planting. This helps to determine what areas may require "blanking" – restocking the following winter.

Labour shortages exist in many regions including Hawke's bay, primarily due to the seasonal nature of the task. Labour is also affected by reduced demand for other silviculture operations such as pruning.

3.5 Post-plant weed control

Redwoods will need releasing from competitive weeds for up to 18months. It is very important that weeds are controlled following planting.

3.6 Fertiliser

Fertiliser may be required depending on the location. Preliminary studies have shown high rates of success when fertiliser is applied (Nicholas, 2007)

The table below summarises expected costs for planting redwoods in Hawke's Bay.

Table 4: Indicative redwood planting costs

Cost Type	Planting cost ($ per hectare)		
	Low	**Medium**	**High**
Clonal cost (500 spha)	1,120	1,400	1,1960
Seedling cost (range of spha)	1,080	1,350	1,650
Labour cost (500 sph)	420	500	580
Fertiliser	?	?	?
Releasing	?	?	?
Operations management	100	150	200
Total (seedlings)	**1,600**	**2,000**	**2,430**

4. Silviculture and forest management

4.1Silviculture strategy

Elite clones can be planted at a stocking of 500 stems/ha (as opposed to the usual stocking of 800 or higher) to achieve a final crop of around 400 stems/ha. Elite clones already display desirable characteristics such as good stem form and fine branching, and therefore do not require the higher initial stocking to control branch size or form (Nicholas, 2007).

It is very important to have a clear objective in the silvicultural regime to be applied. There are significant premiums for clear grades of redwood and for heartwood. This drives a regime toward achieving relatively fast growth and pruning. However large branches >50mm, and bark encased knots are unwelcome in upper logs and will result in serious downgrade. Pruning is thus required if clearwood is to be achieved but the level and regularity of lifts requires careful monitoring along with thinning interventions to prevent the formation of dead branches or in the alternative, profuse epicormic production that undermines the whole investment in pruning. Redwood is relatively soft and plantation-grown trees of good genetics generally have small, well-spaced branches, so pruning is not difficult from an operational perspective. The bark of young trees can be easily damaged so care should be taken when pruning (Nicholas, 2007).

If a non-clearwood regime is to be contemplated, the imperative is to maintain stockings at a level that keeps branches < 50mm and alive for as long as possible. It is for this reason that the planting of genetic material with a proven small branching habit becomes important (Redwood Growers Manual advises pp42).

At this stage there remains a lack of robust data on the most appropriate regimes to balance the clearwood vs bark encased knot vs epicormic dilemma. However, advice to date, (Redwood Growers Manual advises pp41) is that a target Diameter over Stubs(DOS) of 120-150mm should be targeted, while in terms of timing advice, (Farm Forestry Redwood Handbook pp33), is that severe pruning should be avoided, should be delayed until bark is thickening and should be undertaken in autumn to minimise the formation of epicormics.

Table 5: Indicative redwood silvicultural costs

Cost Type	Silvicultural cost ($ per hectare)		
	Low	**Medium**	**High**
Pruning cost - Lift 2.2m	1080	1200	1320
Pruning cost - Lift 4m	880	980	1080
Pruning cost - Lift 5.6m	780	870	960
Thinning (clones)	250	300	350
Thinning (seedlings)	750	850	950
Total (clones)	**2990**	**3350**	**3710**
Total (Seedlings)	**3490**	**3900**	**4310**

4.2 Silvicultural systems

The redwoods are a relatively shade tolerant species (Redwood Growers Manual pp41). Combined with the capability to coppice form the stump after felling, redwood forests present and opportunity to be managed on a selection and small coupe or shelterwood silvicultural system in contrast to the normal clearfelling regimes practised with the more light demanding radiata that has formed the backbone of New Zealand forestry. These systems require skill to implement but can lend themselves to smaller farm scales of operation and would provide benefits to sediment and erosion mitigation especially on alluvial outwash zones and as a buffer species close to waterways. These are the main systems employed in private holdings in the USA ((Redwood Growers Manual pp42

The coppicing can eliminate some of the costs and disturbance involved in post clearfell management.

4.3 Forest management

Forest management requirements will depend usually on the scale of the forest resource and expertise of the owner. Very small forests may be managed with little effort by the owner, but owners with little spare time or experience, or with a large forest asset may choose to engage the services of forest manager. The specific forest management required will vary from forest to forest, but primary management roles and responsibilities can include:

- Preparation of budgets and work plans/schedules
- Contractor engagement and supervision of forest operations
- Mapping and stand record-keeping
- Cost tracking and reporting
- Consent application and administration
- Security, protection and infrastructure maintenance
- Health and Safety and Environmental (HS&E) compliance
- Professional and technical advice
- Liaison with regulatory bodies and other agencies, neighbours, iwi and affected parties as required

Costs for undertaking forest management activities will depend on agreed scope of responsibility, and will also vary based on forest location, scale and competition for services. The table below summarises some indicative forest management costs that could be expected for forests in Hawke's Bay.

Table 6: Indicative redwood forest management costs

Cost type	Cost ($ per hectare)		
	Low	Medium	High
Forest management	15	25	35
Administration	5	15	25
Protection and maintenance	10	20	30
Total	**30**	**60**	**90**

5. Pests, diseases and other risks

5.1 Wild animals

Coast redwood is highly susceptible to browsing mammals, goats, deer and possums which can destroy main shoots.

Control of wild animals is often as much for protection of biodiversity and environment as it is about protecting the tree crop. Wild animals can be vectors for disease such as bovine tuberculosis and can also predate on indigenous wildlife. Some wild animals have recreation value through hunting, and so control of these species may be achieved with little or no cost. The requirements for control of animal pests will vary from site to site. The primary animal pests that are likely to be encountered in Hawke's Bay forests are:

- **Possums** will eat young trees but are often not prolific on an ex-farm site due to prior land management. Possums tend to be controlled through poisoning, trapping or shooting.
- **Goats** are potentially the biggest risk in terms of animal pests, particularly in northern Hawke's Bay. Control is usually by shooting, and risk areas should be managed pre and post-planting.
- **Pigs and deer** are also prolific in certain parts of Hawke's Bay, and should be managed appropriately where deemed to be a risk to successful establishment.
- **Livestock** such as sheep and cattle can be problematic on ex-farm sites. Damage is usually through trampling rather than browsing and can be controlled simply through effective fencing.

5.2 Insect pests

Insects have only caused minor problems to date in redwood in New Zealand. Some anecdotal evidence exists suggesting that pruning can allow the entry of huhu beetles or a native longhorn borer into the tree, whose tunnels significantly reduce the value of the sawn timber. However, this risk has not been extensively quantified (Nicholas, 2007).

5.4 Diseases

The high content of tannin in redwood timber usually ensures a high degree of immunity to fatal attacks by insects or fungi (Knowles,1993). However, the canker fungus Botryosphaeria has been reported to cause extensive damage on redwood trees in Europe, but only minor damage on redwood in New Zealand (Nicholas, 2007).

5.5 Fire

Fire is a known risk for plantations in New Zealand. Older redwood are well protected from fire due to their very thick bark which does not burn easily, even under intense heat (Knowles, 1993).

Management of fire risk will post likely be a combination of protection operations and fire insurance. Forest design can also influence fire risk, by providing fire breaks and buffers of less flammable species in risk areas like road edges and powerline corridors.

5.6 Wind

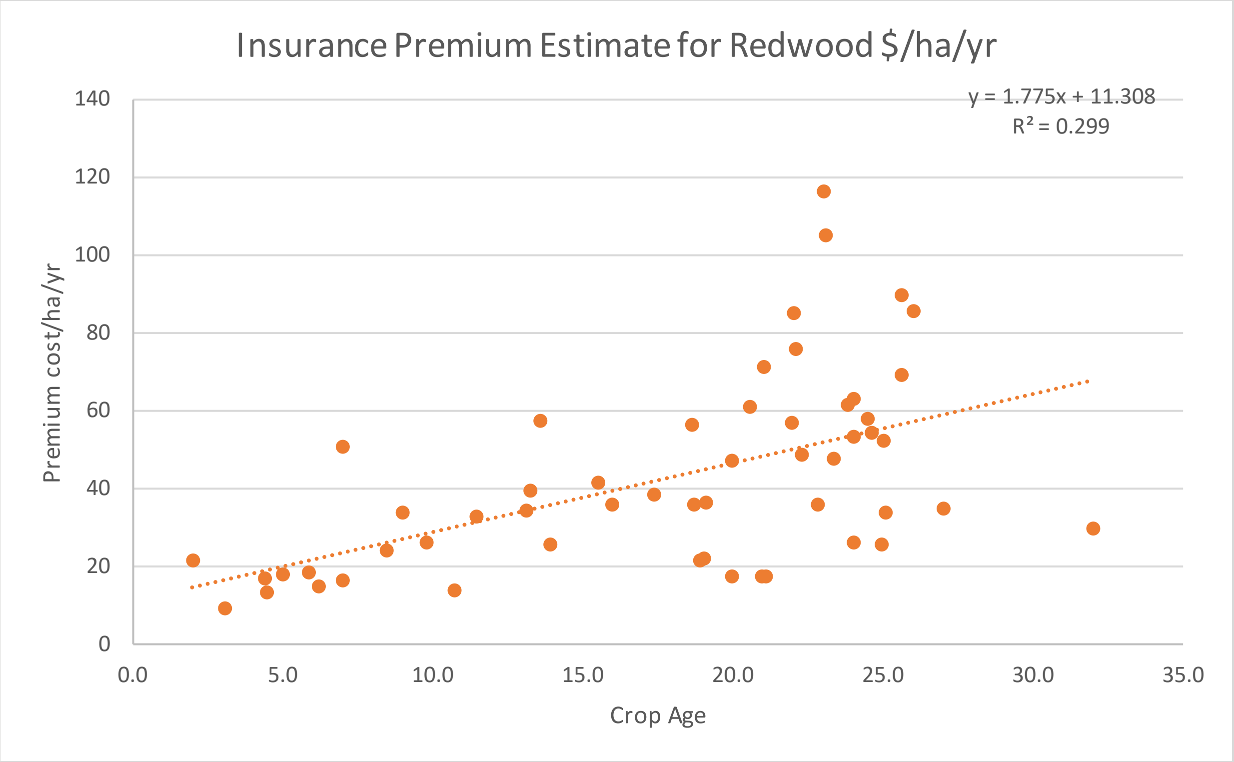
Wind is a known risk in Hawke's Bay, with severe damage caused to pine plantations across the north and east of the North Island when Cyclone Bola struck in March 1988. Conversely, redwood can be surprisingly tolerant of storm events, but does not do well in prevailing winds. Risk of wind damage will primarily depend on exposure, and age of the trees. Management of wind risk will often include a combination of methods, such as:

- Site selection
- Treestock quality
- Timing and intensity of silviculture (especially thinning)
- Harvest planning and scheduling
- Insurance
- Windthrow salvage

5.7 Insurance

Risks associated with fire and wind damage can usually be mitigated through appropriate insurance cover. Insurance will usually compensate a proportion of the current tree crop value, and often also provides compensation for the costs of clearing and replanting land.. The chart below summarises indicative tree crop insurance cover costs for an average Hawke's Bay non radiata pine forest. An additional $1 per hectare per year could be assumed for including public liability cover.

Table 7: Indicative insurance costs, annual rate over first 35 years



5.8 Wilding spread risk

Redwood is not a prolific regenerator, as seed production is strongly site dependent. Germination rates are variable and frequently very low, even though mature trees on good sites produce significant quantities of seed. However, redwood has a strong ability to coppice from stumps when harvested.

The following table compares DSS1 scores for spreading vigour and palatability with common conifer species planted in New Zealand.

Table 8: Species comparison of DSS1 spreading vigour and palatability scores

Species	**DSS1 score (/5)**	
	Spreading vigour	**Palatability**
Redwood, cedar, spruce	0	N/A[1]
Radiata pine	1	1
Douglas-fir (Nth island)	1	3
Larch	2	0
Corsican pine	3	4
Douglas-fir (Sth island)	4	3
Pinus contorta	5	2

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[1] Palatability not scored as spreading vigour of zero means very low risk of spread

6. Productivity

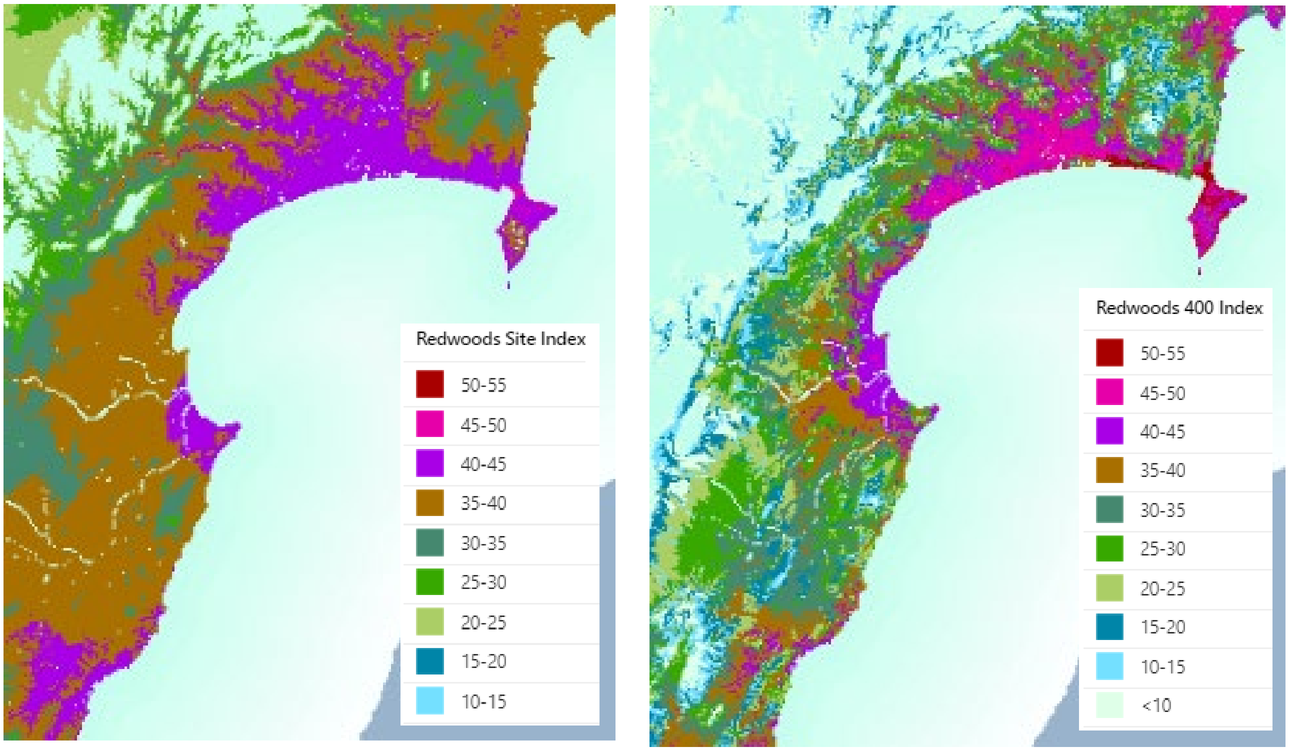
6.1 Productivity rating systems

Productivity of sites for redwood growth in New Zealand are generally characterised using two indices, being Site Index and 400 Index.

Site Index is a measure of height productivity and is defined as the height of the 100 largest diameter trees per hectare at a given reference age. For redwood that reference age is 20 years. The average Site Index in Hawke's Bay approximates 30-35m, with an overall range of 10-55m (Palmer, et al., 2010).

400 Index is a measure of volume productivity and is defined as the mean annual volume increment (MAI), at an age of 30 years, for a final crop stocking of 400 stems/ha. The average 400 Index for Hawke's Bay approximates 25-30/ha/year, with an overall range of 10-55m^3/ha/year (Palmer, et al., 2010).

Figure 1: Site Index and 300 Index productivity surfaces for Hawke's Bay



These indices are valuable inputs to growth and yield predictions, and the table below summarises estimated values for typical high, medium and low productivity sites in Hawke's Bay.

Table 9: Site index estimates for low, medium and high productivity classification

Class	Productivity index	
	Site Index (m)	400 Index (m^3/ha/yr)
Low	15	15
Medium	30	30
High	50	50

6.2 Growth models

Growth modelling is required to predict future yields, as this information is crucial to cashflow forecasting. Some information is available surrounding redwood growth models, however permanent sample plots have only recently been established. Care should be taken when using this information, as some predictions have been taken from stands established with genetically unimproved seed and are therefore likely to underestimate (Nicholas, 2007).

6.3 Rotation length

The 2017 NEFD reported the area-weighted average harvest age of radiata pine in New Zealand as 28.4 years, with a typical range of 26 to 32 years. There is insufficient such data for other species in New Zealand. Historically a minimum of 45 years was recommended for most alternative species. However, this has been revised in recent years for many species due to genetic improvement and advances in silviculture.

Table10:-Recommended rotation lengths for redwoods in Hawke's Bay.

Regime	Rotation length (years)
Clearwood (pruned)	35 minimum
Carbon	indefinite

6.4 Expected lifespan

In the context of a redwood plantation, the expected lifespan of the species is entirely dependent upon the objectives of management. Within a plantation clearfell regime redwood will have an optimal "economic rotation" which is the culmination of the interactions between growth rate, log qualities and quantity, costs and interest rates.

If a plantation is established for the ultimate management under a selection or small coup shelterwood systems the notion of an "optimal rotation" is much less clear and will be driven predominantly by site productivity once the planted forest has reached a stage where harvesting with regular physical returns to the forest becomes feasible.

If a plantation has been established for Carbon sequestration, then redwood which is a very long lived species is an ideal species and can live for many hundreds of years while the stand can be maintained naturally through the coppicing of fallen trees and natural seeding.

7. Log production

7.1 Harvest systems

There are two primary systems or configurations employed for harvesting commercial forestry plantations in New Zealand, ground based and cable hauler systems. Both systems, in addition to standard clearfelling, could, with the right variations in equipment and skilled harvest crews, be deployed to enable the harvesting of redwoods under shelterwood and small coupe systems. Selection systems would be better aimed at forests on gentle terrain.

Any harvesting system that does not involve clearfelling will see daily harvesting productivity decline and harvesting costs rise significantly if equipment, like for like, with that employed in clearfelling was used. It is very important therefore to understand equipment options if non-clearfell operations were to be considered as lower productivity (and cost) options may be better suited.

The generic harvesting configurations are:

Ground-based logging utilises wheeled or tracked machinery such as skidders, tractors and excavators to extract felled stems to processing sites. These systems are usually restricted to flatter terrains, although new technology such as tethering or remote / tele-operation is enabling machines to operate on steeper slopes in certain areas. Tree felling is also usually undertaken using machinery in this easier terrain.

Hauler logging involves specialised machinery suspending cable systems over the ground to haul logs to processing sites. These systems are usually required on steeper terrain, or where sensitive ground conditions or access problems prevent the use of ground-based systems. In general hauler systems are significantly more expensive to run, as more machinery and manpower is usually required, but productivity is usually lower than for ground-based systems.

Helicopters are sometimes employed for logging, but this is relatively rare in radiata pine, as the cost of such an operation usually outweighs the value of the logs produced. It may prove more cost-effective for redwood, depending on specific conditions.

In addition to terrain, other considerations that may influence harvest system and machinery requirements could include:

- Stream locations and sizes
- Infrastructure locations (eg. roads and processing sites)
- Resource consent conditions
- Ground conditions and expected weather
- Contractor availability
- Ecological or archaeological constraints

A robust harvest planning process is essential to identify these considerations well ahead of harvest, to ensure that infrastructure is fit for purpose, and harvest operations can be completed in a safe, efficient and environmentally friendly manner.

7.2 Harvest productivity and cost

In addition to harvest system requirements, there are several other factors that can affect the productivity and therefore costs of a harvest operation. Such factors include (but are not limited to):

- Piece size – smaller trees are costlier to handle and process. Very large trees can also be more expensive to harvest, especially if they are too big to handle with normal size machinery.

- Haul distance – if trees need to be extracted long distances to processing sites, this will affect productivity and therefore cost. Reducing haul distance usually is a trade-off as it inevitably requires more cost in terms of infrastructure.
- Remoteness – if the forest requires significant travel or accommodation for harvest crews, this will affect productivity and/or cost. Costs associated with transporting machinery and equipment will also be affected.
- Complexity – jobs that have complicated requirements will usually cost more to harvest. This could include traffic management, power lines, archaeological sites, access restrictions or multiple land-uses and the silvicultural / harvest system being employed.
- Competition – There is generally a shortage of experienced harvesting contractors across New Zealand, including in Hawke's Bay. This lack of competition is having an adverse effect on harvest costs as forest owners try to secure contractors for their forests.

Harvesting of redwood in New Zealand has typically been at small scale and there are no reliable datasets of harvesting rates across various terrains and piece sizes. Here we have assumed harvesting rates of radiata pine plus \$10/m^3 for additional processing costs including managing bark removal.

The following table summarises harvest costs that could be expected for a range of harvest systems and factors that would commonly be encountered in Hawke's Bay.

Table 11: Indicative redwood harvest costs

Harvest type	**Harvest cost ($ per m^3)**		
	Low	Medium	High
Ground-based	29	33	40
Hauler	43	50	65
Small coupe -Ground based	50	65	NA

7.3 Infrastructure requirements

Harvesting of plantation forests will usually require the design, installation, maintenance and rehabilitation of a network of forest roads and processing sites. Stream crossings, entranceways, fences and gates may also be required.

Infrastructure requirements and costs are very site-specific. Detailed harvest planning and engineering design work will often be required to properly quantify requirements. This process will normally consider the implications of:

- Existing infrastructure location and condition
- Topography and climate
- Soil types and erosion potential
- Regulatory requirements
- Health, safety and environmental best practice
- Trade-offs between harvest costs and infrastructure costs
- Harvest systems and productivity
- Landowners, neighbours, iwi and other affected party considerations
- Aggregate sources

Below is a table summarising some expected ranges of infrastructure costs that could be expected for typical forests in Hawke's Bay.

Table12: Indicative redwood infrastructure costs (first rotation, ex farm)

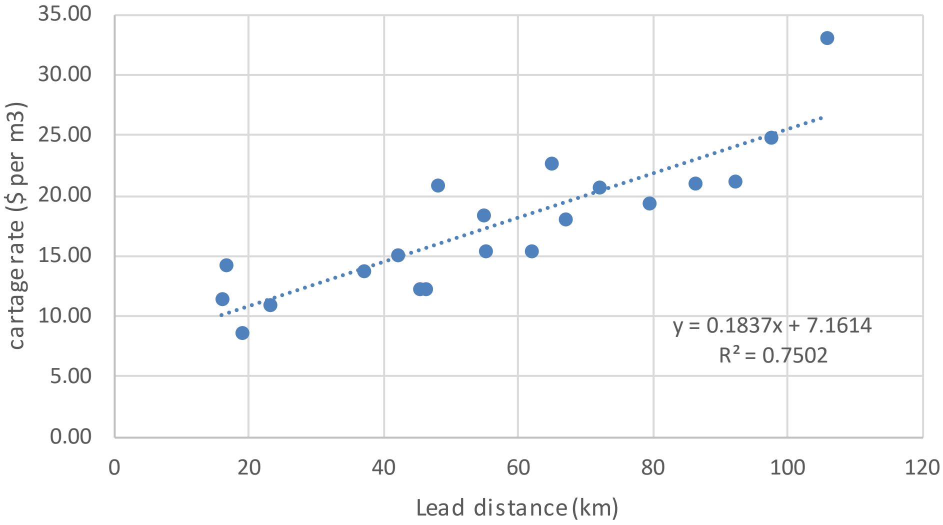
Cost Component	**Infrastructure cost ($ per m^3)**		
	Low	Medium	High
Road and Skid Construction	3.00	6.00	10.00
Maintenance	0.50	1.00	1.50
Post-harvest rehabilitation	0.50	1.00	1.50
Total	**4.00**	**8.00**	**13.00**
Small coupe -Ground based	**??**	**??**	**NA**

7.4 Log cartage

Transporting logs from forest to customer in Hawke's bay has historically been by road and rail. Currently rail transport is limited to logs moving north to Napier port from the Manawatu / Whanganui region, but funding is in place to re-open the Napier – Wairoa rail line to facilitate log transport south to Napier. This has the potential to reduce transport costs and improve safety for road users on State Highway 2.

Log cartage costs will usually have a fixed component, and a variable component based on lead distance, as this is the key factor in determining cartage costs. Regression analysis can be used to compare actual cartage rates and lead distances, to develop a formula for predicting cartage rates. Below is a graph showing regression analysis for log cartage in the Southern North Island over 2017-2018. This analysis shows that cartage costs over this period can be approximated by using the formula ***Cartage cost ($/m3) = $7.16 + ($0.18 x Lead distance)***.

Figure 2: Cartage rate analysis for Southern North Island, July 2017 - June 2018 (Source: PF Olsen).



Fuel prices have a significant impact on cartage rate, with approximately 20% of cartage costs being attributed to diesel consumption. Diesel prices across the analysis period above averaged $1.26 per litre[2]. Diesel prices since this period (up to October 2018) have increased by approximately 20%, and this is likely to have resulted in cartage costs increasing by around 4%. It is worth noting that this increase would also likely be felt in harvest costs, where diesel costs have a similar influence.

Factoring the increased fuel component, the cartage formula that best approximates current cartage costs would be:

Cartage cost ($/m^3) = $7.45 + ($0.19 x Lead distance)

Table 5: Indicative cartage costs

Lead distance (km)	Cartage cost ($/m^3)
25	$12.20
50	$16.95
100	$26.45
150	$35.95

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[2] Discounted retail price – Source: https://www.mbie.govt.nz/info-services/sectors-industries/energy/liquid-fuel-market/weekly-fuel-price-monitoring

7.5 Other costs of production

Management of harvesting operations by a suitably qualified individual or company will usually be required. Management tasks include:

- Harvest planning
- Contract and contractor management
- Health & safety and environmental compliance monitoring.
- Production monitoring
- Log value recovery and quality control
- Log marketing
- Reporting and documentation
- Weighbridge fees and consumables (paint, stencils etc)

Post-harvest clean-up may be required on some sites, and can include slash management, fence repairs, drainage works and erosion control works.

The Commodity Levies (Harvested Wood Material) Order 2013 imposes a levy on all harvested wood material from plantation forests in New Zealand. Levies are payable to the Forest Growers Levy Trust and the levy is currently set at **\$0.27 per m^3** or tonne and cannot exceed \$0.30 per m3 or tonne during the six-year levy period. The levy period ends in 2019, at which point forest growers will hold a referendum to decide whether to continue for another six years. The levy was introduced to provide funding for the following categories:

- Research, science and technology (64%[3])
- Forest health and biosecurity (13%)
- Health & safety (10%)
- Promotion (9%)
- Fire (1%)
- Forest resources and environment (1%)
- Transportation (1%)
- Small and medium forest enterprises (0.1%)

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[3] Source: Forest Growers Levy Trust 2017 Annual Report

8. Log markets and wood availability

8.1 Domestic processing capacity

At present, redwood is not processed domestically on any great scale. However, were a focus of planting new forests in a region to achieve a local scale of 2-3000ha across age classes, such a scale may be enabling for a locally based solid wood processing capability. While such an organised 'smooth' planting is unlikely in reality, the potential to achieve a local enabling scale is not at all impossible.

8.2 Wood availability

Because it is not grown or harvested in large numbers, availability is limited to supply from small (including portable) sawmills or private sellers.

8.2 Log exports

One of the most promising arguments for redwood expansion lies in the Californian marketplace, where demand is growing and supply is dwindling. It is thought that New Zealand redwood (if well-managed) can provide timber of a similar quality to that currently found in the second growth forests of the USA which are now effectively the only ongoing supply in that region.

There may also be other overseas and domestic markets that warrant future investigation and development, based around the specific features of the timber which are its natural durability without treatment, its attractive colour and suitability for cladding and outdoor above ground applications.

Over the New Zealand forest industry as a whole, over50% of log production is exported at present, and there are two export ports that can handle logs from Hawke's Bay forests: Napier Port in Napier and Eastland Port in Gisborne. As the following table shows, substantial increases in log exports have occurred over recent years, and both ports have development plans to ensure that infrastructure is able to withstand continued growth.

Table 6: East coast log exports 2015-2018

	Log exports (tonnes)	
Financial Year	Napier	Gisborne
2014/15	1,108,000	2,200,000
2015/16	1,207,000	2,265,000
2016/17	1,630,000	2,500,000
2017/18	2,000,000*	2,982,000

Sources: Napier Port and Eastland Group annual reports 2015-2018. *estimate

It is worth noting that a proportion of the log volume exported from Napier originates from outside the Hawke's Bay region, with a regular rail service bringing logs from the Manawatu-Whanganui region, trucks carting logs north from the Tararua district, and some forests around Taupo being marginally closer to Napier than Tauranga.

8.2 Log prices

Because redwood is used as an appearance wood, it differs from radiata pine in that lumber price is driven by knot characteristics rather than diameter. A high differential between clear and knotty lumber prices (pruned and unpruned logs), drives the recommendations that pruning should be a goal for redwood plantations where growth rates are good. Sawlogs tend to be sawn down to either 10cm or 15cm in order to avoid wastage, as there is no market for redwood chip logs.

Table 15 shows indicative redwood prices that have been determined by an independent Registered NZIF consultant,(Pers Comm S Rapley NZ Redwood Company) They are believed to be conservative as the pruned price listed is lower than a standard unpruned price in California.

Table 7: Redwood timber prices (at wharf/mill gate)

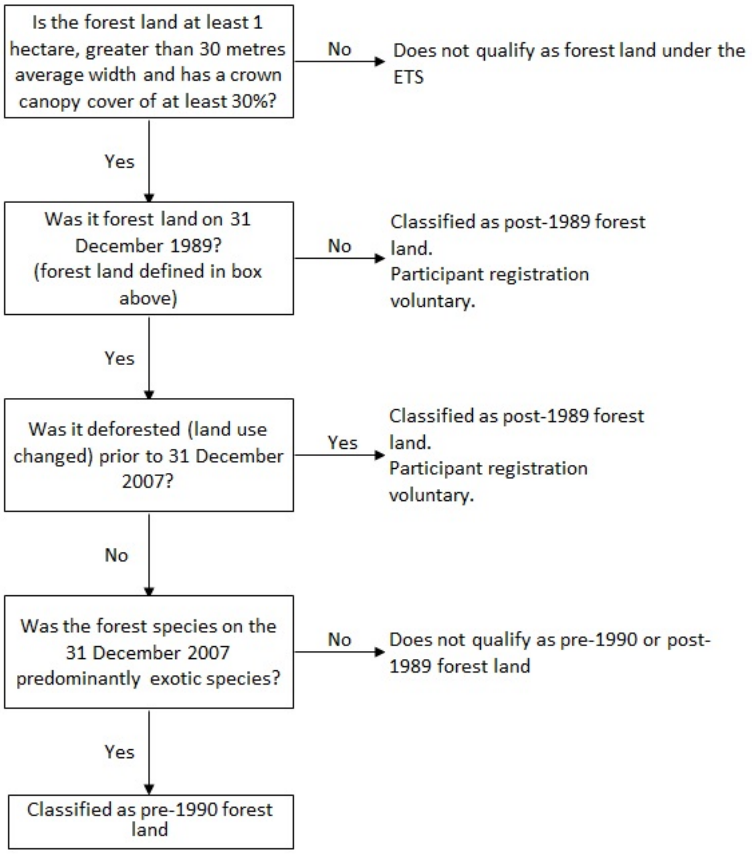
Grade	Price ($/m^3)
Pruned	225
Unpruned	147

9. Carbon forestry

9.1 ETS eligibility

In order to enter the Emissions Trading Scheme (ETS) and claim credits for the carbon sequestration of a forest, the forest must reside on Post-1989 eligible forest land. This means that the land must not have been forest land on the 31st December 1989 and must also meet minimum size requirements. Land that **was** forest at the end of 1989 is only eligible for entry into the ETS if it was converted to another land-use prior to 31 December 2007. The following flowchart summarises the process for determining ETS eligibility of forest land.

Figure 3: ETS Eligibility assessment process



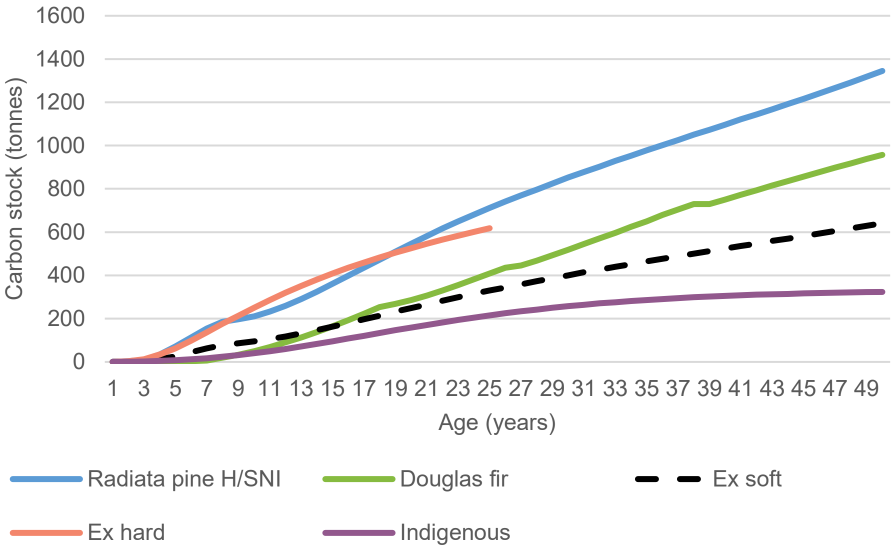
Although land may be deemed as eligible Post-1989 forest land, it does not automatically enter the ETS. A landowner (or forestry right holder) is required to apply to have their land added to the ETS. MPI will assess the application, including eligibility, legal ownership and mapping accuracy, prior to approving entry into the ETS.

As HBRC is interested in encouraging afforestation, we assume that land considered for planting will generally be Post-1989 eligible forest land. In saying this, in most cases there are small areas of ineligible land in a parcel that is assessed for eligibility. This is often due to patches of scrub being deemed as ineligible, or areas of patchy survival being assessed as not meeting the definition of forest land. Offsetting this is the fact that ETS mapping standards can allow certain gaps to be closed up and future crown growth around boundaries to be factored, often resulting in slightly more area being accepted into the ETS. From recent experience, the ETS eligible area of a newly planted forest is often around **5% less** than the net stocked area.

9.2 Carbon sequestration

Redwood carbon sequestration rates published in the ETS lookup tables are generally lower than most other commercial species in New Zealand, as it falls into the generalised exotic softwood category. The following graph compares MPI generic look-up tables for coast redwood (ex soft) in the Hawke's Bay / SNI with national averages for other species groups.

Figure 3: MPI generic look-up tables for different species groups.



The sequestration rates shown are applied to ETS participants with a total ETS registered area of less than 100 hectares. For those participants with larger areas registered, permanent sample plots must be installed and measured each reporting period to derive participant-specific look-up tables (PSTs). It is generally accepted that the lookup tables have a higher level of conservatism than participant-specific tables. However, further analysis regarding redwood sequestration rates should be carried out, and a conservative approach to modelling sequestration is usually recommended because there are many variables that can impact actual sequestration rates for a participant. Recent observations of genetically improved redwood stock are demonstrating productivity level far in excess of the lookup table and in some instances is approaching the productivity of radiata pine.

While over a shorter period of 30-50 years, redwood under the look-up tables has a relatively low sequestration rate, the longevity of the species does mean that as a carbon only forest, or a production forest managed under other silvicultural systems, sequestration can continue to accumulate to very large amounts. Participant specific tables would probably be warranted in such situations.

9.3 Carbon strategies

When considering how best to generate carbon revenue, there are some different strategies that can be employed, and the choice will come down to factors such as risk profile, resource profile silvicultural system and carbon price assumptions. It will also depend on whether the forest is intended to be harvested or not.

Averaging strategy needs to be explained here

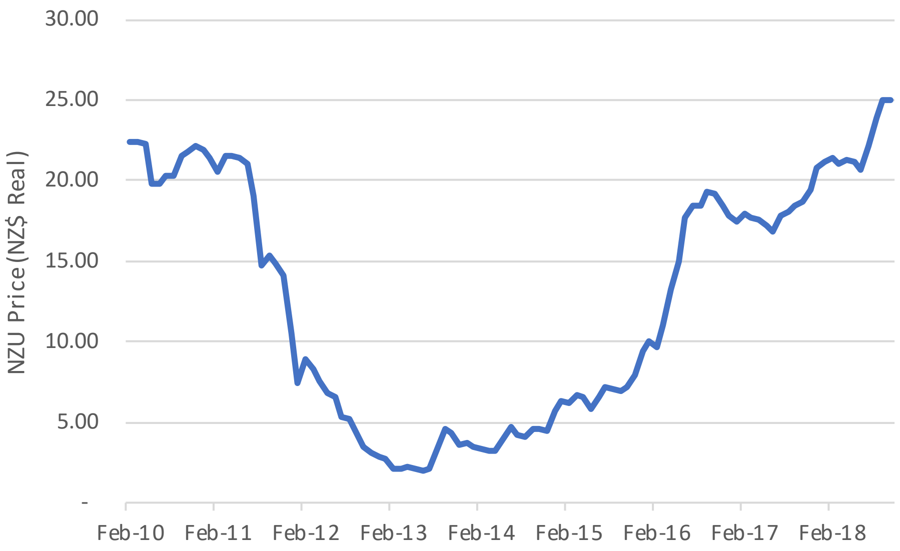
9.4 Carbon pricing

Carbon pricing can be somewhat volatile, and is influenced by several factors including (but not limited to):

- Industrial emissions levels
- Regulatory changes and political influences
- The $25 Fixed Price Option (FPO) available to emitters in lieu of acquiring units for surrender
- Market access and liquidity
- Seasonality of demand
- International trends

The following graph shows the trend in NZU pricing since 2010. The large price drop that occurred in late 2011 was primarily due to the introduction of cheap European units into the ETS market. Low prices were maintained through to 2014 when the Government blocked use of these cheaper units. Prices have since slowly recovered and are now trading around the $25.00 mark, with market prices being heavily influenced by the $25.00 FPO option available to emitters. The Government has announced an intention to review the nature and level of the existing price cap, and a number of reports have noted that considerably higher carbon prices may be required to trigger meaningful emissions reductions in the future.

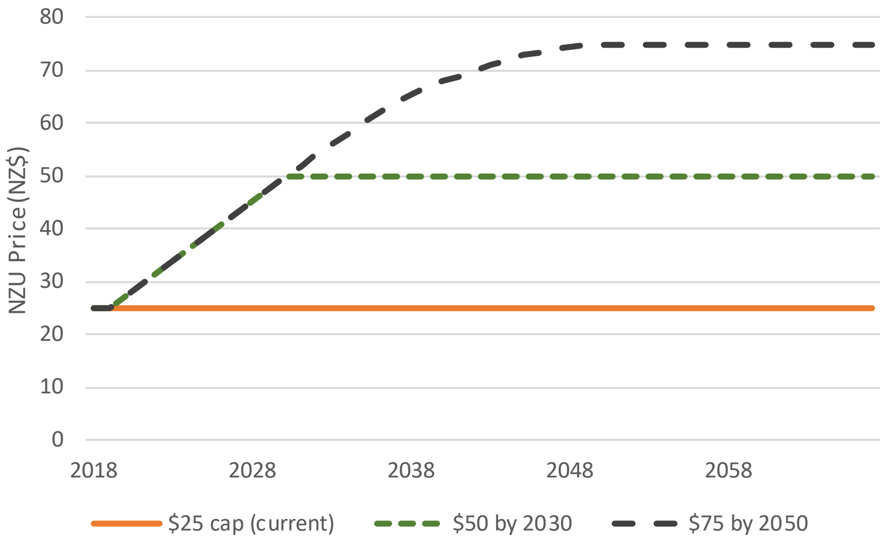
Figure 4: NZU price history, 2010 - 2018.



Forecasting future carbon prices is difficult and very dependent on future carbon policy, emissions reduction goals and international linkages. A report produced for the Parliamentary Commissioner for the Environment (PCE) in 2010 projected that NZ carbon prices could be in the range of $50-$150 per tonne by 2030 (COVEC, 2010). Since then New Zealand has signed up to the Paris Accord, and agreed a Nationally Determined Contribution (NDC) of reducing GHG emissions to 30% below 2005 levels, by 2030. The Productivity Commission recently released their final report on a transition to a “low-emissions economy”. Modelling for this report suggests that carbon prices may need to rise to between $75 and $152 a tonne by 2050 (New Zealand Productivity Commission, 2018) to achieve desired emissions outcomes.

It is recommended that modelling of carbon price should use a baseline of $25.00 remaining static into the future, as this is the current pricing, and reflects the current known price cap mechanism.

Figure 5: Example future carbon price scenarios



9.5 ETS costs

ETS participation will usually incur initial set up costs such as planning, mapping, preparing applications and associated MPI fees. There will also be ongoing costs associated with emissions return preparation and submission, record keeping and Field Measurement Approach (FMA) plot measurement and data processing (if >100 hectares). The following table summarises expected costs for redwood ETS participation. It is assumed that for small areas (<20ha) the forest owner would complete most work themselves, while for larger areas a forestry expert would be engaged. FMA costs are assumed to be $350 per plot for measurement, management and data processing.

Table 8: Estimated ETS costs

	ETS Cost ($ per hectare per year)	
ETS Cost	0-99ha	100ha+
Planning, mapping and registration	$40	$20
Administration	$10	$5
FMA measurement	-	$10
Total	**$50**	**$35**

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RIGHT TREE, RIGHT PLACE

HAWKE'S BAY AFFORESTATION PROGRAMME (HBAP)

Species assessment – Radiata pine

1. Introduction

Radiata pine (*Pinus radiata* D.Don) originates from a small area on the west coast of the United States, where it is referred to as Monterrey pine. In its natural habitat, radiata pine is not considered to be a significant commercial species due to its sparse population and generally poor form.

Radiata pine was first introduced to New Zealand around 1859 (Burdon and Miller 1992), and planting "booms" in the 1920s, 1960s and 1990s have led radiata pine to become the dominant commercial forest species in this country. There are currently 1.16 million hectares of Radiata pine planted in New Zealand, making up 90 percent of planted production forest area (MPI 2017).

Globally, radiata pine is the most extensively planted exotic softwood species, with approximately 4.2 million hectares equating to 3% of total plantation forests worldwide (Mead 2013). Chile (1.5 million hectares) and Australia (0.8 million hectares) are, along with New Zealand, the countries with the largest land holdings of Radiata pine.

2. Site Requirements

2.1 Climate

- **Temperature** affects many aspects of growth. Radiata pine prefers cool night temperatures of about 5°C, while the effect of day temperatures is small, except the extremes of range (Rook 1979). A study in 2011 found that optimum productivity was reached with mean annual air temperatures from 12-15°C (Kirscbaum and Watt 2011). Frost studies suggest that radiata pine seedlings may tolerate temperatures as low as -12°C to -14°C in winter (Mead 2013). Frost damage can be lessened through land preparation and removing vegetation from around trees.
- **Rainfall** is also an important consideration. Productivity of radiata pine tends to fall off as rainfall drops below 1,000mm (Burdon and Miller 1992). Commercial plantations require a minimum annual rainfall in the range of 600-750mm (Mead 2013). Severe drought can cause establishment problems for new plantings. Very high rainfall, resulting in near continuous leaf-wetness can increase the risk of foliar diseases such as Dothistroma needle blight (Gadgill and Bulman 2008). Radiata pine prefers a dry summer environment, but severe drought can cause survival issues for newly established crops.
- **Wind** can have an adverse effect on radiata pine survival, form and wood quality. Younger trees (age 2 to 3) are particularly susceptible to toppling, usually due to inadequate vertical root development (Mason 1988). Appropriate management and silviculture strategy can allow radiata pine to be successfully grown on windy sites, but planting may best be avoided on very exposed ridges, or where wind funnels between mountains. Radiata pine is reasonably tolerant to salt spray (Mead 2013), and so normal coastal winds are not often a limiting factor.
- **Snow** can limit the suitability of radiata pine to some sites. Planting on snow-prone sites, particularly the leeward side of ridges, should be avoided (Mead 2013).

Generally, radiata pine is suited to a wide range of climates found in New Zealand, including that of the majority of Hawke's Bay. The following table summarises the optimal climate conditions for radiata pine.

Table 1: Climate profile for radiata pine.

Climate variables	P.radiata preferred	Hawke's Bay actual (Chappell 2013)
Mean annual air temperature (°C)	12.0 – 15.0	8.0 - 13.5
Mean winter minimum air temperature (°C)	~5.0	2.0-7.0
Frost limit (°C)	-14.0	-6.0 to -12.0
Mean annual rainfall (mm)	650 – 2,000	707 - 2,000+
Snow at low levels?	None	Rare (1-2 days per 10 years)

2.2 Topography

- **Elevation** has effects on tree growth, primarily due to its modification of climatic variables such as temperature and snow (see above). The maximum recommended altitude for commercial radiata pine in the central North Island (latitude 38°S to 39°S) is 1,000m (Mead 2013), but a more conservative limit used by forest companies in the region is 800m. Basic wood density is likely to reduce as altitude increases, with a rule of thumb being a reduction of 7kg/m3 per 100m of elevation gain (Cown 1999).
- **Slope** is a limiting factor for commercial radiata plantings, primarily for health and safety and environmental reasons. With increasing focus on safety of planting operations, some very steep slopes may not be planted due to unacceptable risk for workers. Slope also affects the cost and complexity of harvest operations, and the susceptibility to erosion.
- **Aspect** has a reasonable impact on productivity, as it alters the pattern of radiation. North-facing slopes are warmer than south-facing slopes. North-westerly aspects are often more exposed to high winds in the region. Aspect is not generally a limiting factor for establishment of radiata pine.

Table 2: Topography requirements for radiata pine.

Topography variables	P.radiata preferred
Maximum altitude (m)	800

2.3 Soils

- **Soil moisture** is very important to success of radiata pine plantings. This is dependent on rainfall in the area, and depth and texture of the soils. Radiata pine performs poorly on waterlogged soils, instead preferring deep, well-drained soils (Mead 2013). Very dry summer soil conditions can affect establishment success.
- **Nutrient supply** is crucial to all plants, and identifying nutrient deficiency is usually completed through foliar analysis. The most important nutrients controlling radiata pine growth are the concentrations of phosphorus and nitrogen. It is likely that N and P deficiencies will be very site-specific, based on previous land management and fertiliser programmes. Although deficiencies in these nutrients can be corrected reasonably simply through fertiliser application, there may be some restrictions placed on their use (Nitrogen fertiliser use is being capped

already in some areas). On some farm sites, there could be excess N, which can cause problems with form and density. Other nutrients such as magnesium and boron can be deficient in some soils. Calcium borate fertilisers are commonly used to correct boron deficiency.

- **Compaction** can reduce rooting density of radiata pine. Soil strength (penetration) of > 3,000kpa should be avoided (Madgwick 1994). Another measure of compaction is air-filled porosity, and measures of <10% can adversely affect growth (Payn 2005).
- **Erosion and soil stability** should also be considered when selecting sites for radiata pine establishment. Sites that have already suffered significant slipping or mass movement may be inappropriate for establishment in a commercial radiata pine crop, as growth and eventual harvest of this crop may accelerate movement. Radiata pine has been used in the past for isolated erosion control plantings, but there may be better performing alternatives on severely degraded land.

2.4 Access and infrastructure

If establishing a radiata pine crop for eventual harvest, access to the crop will need to be guaranteed in the future. The following should be considered before establishing a radiata pine forest:

- **Distance to market** (is there a viable customer located within a reasonable distance of the site?)
- **Legal access** (can the site be accessed without encumbrance?)
- **Infrastructure requirements** (can the site be accessed for planting and ongoing management; can roads and skids be installed to get produce off the site profitably?)
- **Harvest requirements** (can the crop be harvested profitably using available harvest systems?)

3. Establishment and early growth

3.1 Land preparation

Land preparation is undertaken to promote early growth, control weed competition, and promote wind firmness. Preparation activities are usually undertaken using hand tools, machinery, fire, chemicals or animals (grazing). The specific type of land preparation will depend on the condition of the land.

- **Ex-grazing land.** Land preparation requirements for land that is primarily grass are relatively little. The most efficient pre-plant preparation will be hard grazing prior to planting. If grazing is not possible prior to planting, an aerial broadcast application of herbicide may be required.

  Boundary fences will likely need to be installed or modified, and internal fences may need to be removed to avoid future hindrance.
- **Scrub or brush land.** On sites with high incidence of scrub, gorse, blackberry or other brush species, an aerial application of brushkiller may be required. If this brush is dense or > 2m in height, it may also require some mechanical clearance too, either via roller crushing, or line cutting.
- **Cutover land**. Prior to replanting land following harvest, it is often necessary to complete some form of mechanical land preparation, to clear away logging slash. This is especially so on flatter areas that have been harvested using mechanised systems. Usually machines will heap slash up into windrows to clear space for the new crop.

  A desiccation spray is also usually required to supress weed growth prior to replanting.
- **Spot mounding.** To prevent frost damage to young trees, frost-prone areas will often be spot mounded. This lifts the tree up out of the frost hollow. Spot mounding is also used to aid establishment in areas of high soil compaction.

The following table shows some indicative land preparation costs that could be expected for operations undertaken in the Hawke's Bay region.

Table 3: Indicative land preparation costs

Operation type	**Operation cost estimate ($/ha)**		
	Ex-grazing land	**Scrub / brush land**	**Cutover land**
Grazing	0		
Aerial spraying		250	300
Roller crushing / line cutting		0-500	
Windrowing /Spot mounding			0-700
Tracking and fencing	50	50	
Total	50	300-800	300-1,000

3.2 Planting stock

When selecting which planting stock to plant, the following options should be considered:

- Genetics

  Open-pollinated (OP) seeds are produced from purposely established seed orchards using grafts of elite trees selected from intensive breeding programs. The seeds are GF™ certified and most OP treestocks planted today are GF 19. OP seeds are often in short supply as most of the older OP seed orchards have been demolished and new generation OP seed orchards are still too young to produce seed. The identity and breeding of the female parent is known, but the genetics of the male parent are inherently less certain.

Stand Select™ Open-Pollinated (SSOP) seeds are usually collected from GF 25 to GF 28 forest stands and are used to fill the market gap caused by shortages of OP seed. The seeds are collected from trees that have excellent growth and form. Because SSOP seed has a higher uncertainty concerning its exact parentage, SSOP seed and seedlings produced from it are not GF™ or GF Plus™ certified.

Control-pollinated (CP) seeds are ~~also~~ produced from purposely designed seed orchards. In controlled pollination, female cones are bagged and pollinated using pollen from a donor clone so that both male and female parents are known. In this case, genetics can be recombined using the best of our knowledge to produce families with the most desirable traits. CP seeds are GF Plus™ certified and have indicative GF Plus values for six important traits - growth, straightness, branching, Dothistroma resistance, wood density and spiral grain. CP seeds are more expensive to produce, and their price is higher than OP seed. However, CP seed can offer higher levels of genetic gain in the important growth, form and wood quality traits.

Clonal treestocks are multiple copies of single trees that are first propagated by tissue culture and are then further 'bulked-up' as rooted cuttings harvested from nursery stoolbeds. Trees of the same clone are initially generated from single seeds developed from CP crosses among top breeding parents. The clones are all stored in frozen condition (a process called 'cryopreservation') to maintain their juvenility. Copies of the clones are then grown in field trials designed to compare their performance for growth rate and wood quality against that of OP and CP seedlots. The best 1-5% of clones tested are selected and extracted from 'cryostorage' for nursery production. Trees of the same clone are genetically identical and clonal treestocks have the highest degree of uniformity and genetic improvement. Clonal treestocks are very expensive to produce, and production capacity is very limited at present.

- Propagation method

Bareroot treestocks are grown in nursery beds and are usually larger in size and cheaper to produce. Because their roots, especially the nutrient-absorbing fine roots, are trimmed back during lifting, the trees spend their first year redeveloping their root systems after planting. Skilled planting (cultivate, open, drop and pull up) is required for planting bareroot treestocks. Due to their larger size and reduced root mass, bareroot treestocks should only be planted during the relatively wet winter season.

Containerised treestocks are grown in a special medium mix in plastic trays. The root plug remains intact during lifting and as a result the root systems are not disturbed. Containerised trees are usually smaller, but they continue to grow after planting without any setback. The planting season can be extended if containerised treestocks are used. Other advantages are reduced planting shock by having a “packed lunch”, and easier transport, storage and planting.

Cuttings can be produced from stoolbeds in a nursery as a means of bulking up scarce and expensive CP seed of clonal material, by hedging young plants in the nursery for several years so that each plant produces many dozens of cuttings. Cuttings taken from 1-year old plants have little advantage over seedlings, but cuttings from 2 and 3-year-old plants often result in trees with straighter stems, less malformation, lighter branching and less taper (NZFFA 2005).

- Nursery location and transport

Hawkes Bay has no forest nurseries producing planting stock for the restocking of harvested areas and establishment of new forests. The most significant and closest forest nursery is the Arborgen Australasia nursery at Puha in the Gisborne District, although tree stocks are also sourced from nurseries in the central North Island and further afield, such as Murray’s Nurseries at Woodville (MAF 2008). Logistics of delivering treestocks from nursery to planting site need to be considered carefully due to the time-critical nature of transplanting. Increased demand for treestocks may necessitate development of nursery capacity within the Hawke’s Bay region.

- Hybrids

  Some radiata pine hybrids have been developed and are beginning to be established at a commercial scale in New Zealand. The most common hybrids at present are *Pinus radiata x P.attenuata* and *Pinus attenuata x P.radiata var cedrosensis*. These hybrids have been developed primarily for southern conditions, where they are hoped to be more snow tolerant, and less prone to wilding spread than radiata pine. These hybrids are not seen to be of any material advantage in the typical Hawke's Bay growing environment.

Recommended planting stock

PF Olsen recommend containerised seedlings produced from CP seed for most commercial radiata pine plantings in Hawke's Bay. This is due to the generally high-quality planting sites, risk of dry winter weather, and relatively long distances from nurseries. On poorer quality sites where there is less emphasis on wood quality, there may be justification for utilising cheaper OP/SSOP bare-rooted seedlings.

The following table provides indicative costs of radiata pine treestocks supplied to the Hawke's Bay region. Costs shown include RPBC levies and transport to Hawke's Bay.

Table 4: Indicative radiata pine treestock costs

	Trees stock cost ($ per 1,000 trees)		
Genetics type	**Bareroot (ex Gisborne)**	**Containerised (ex Sth Auckland)**	**Clonal (ex Bay of Plenty)**
OP – GF19	405	430	-
SSOP	375	400	-
CP – GF+	515	550	1,600[1]

3.3 Initial stocking rates and survival

It is most common to plant more radiata seedlings than are required at harvest, for the following reasons:

- Isolated mortality can be compensated for
- Selection of best performing trees is possible at time of pruning and/or thinning
- Trees influence the growth of their neighbours, so planting close together can result in improved straightness, smaller branching, and better early height growth (Maclaren, Radiata pine growers' manual - FRI bulletin No.184 1993)

With improved genetics, trends have been towards lower initial stockings over the last few years. Many foresters are using a standard of 833 stems per hectare, being a spacing of 4m between rows, and 3m between trees. In areas where lower quality genetics are employed, or survival is expected to be poorer than normal, stocking rates of 1,000 to 1,200 stems per hectare may be employed.

Supervision and quality control of planting operations is crucial to ensuring that trees are planted safely correctly, in the right locations, and at the appropriate stocking rates. Survival assessment is also usually undertaken in the months following planting. This helps to determine what areas may require "blanking" – restocking the following winter.

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[1] Note – this is an indicative price - clonal treestocks are not currently available on the open market (as at October 2018).

3.4 Planting

Being a temperate species that prefers wet winters and dry summers, radiata pine is usually planted between late autumn and early spring. Planting of radiata pine is almost always a manual operation, with planting crews using spades to cultivate the spot before hand planting the seedling. Labour shortages exist in many regions including Hawke's bay, primarily due to the seasonal nature of the task. Labour is also affected by reduced demand for other silviculture operations such as pruning.

Costs for planting labour and management will usually vary on area, stocking rate, travel distance, terrain, access limitations (e.g. how closely you can have trees delivered) and land cover (scrub or cutover land being generally more expensive to plant than grass).

The table below summarises expected costs for planting radiata pine in Hawke's Bay.

Table 5: Indicative radiata pine planting costs

	Planting cost ($ per hectare)		
Cost Type	**Easy**	**Medium**	**Hard**
Labour cost (833 sph)	420	500	580
Operations management	100	150	200
Total	**520**	**650**	**780**

4. Silviculture and forest management

4.1 Post-plant weed control

The objective of post-plant herbicide application is to allow the seedling enough time to over-top the surrounding vegetation. Once the tree has gained dominance, it will compete favourably for light and water (Maclaren, Radiata pine growers' manual - FRI bulletin No.184 1993). Although pre-plant spraying is often not required on pasture sites, a post-plant release spray is usually applied. Application can be broadcast from an aircraft, or can be spot-applied via a knapsack sprayer. Chemicals such as terbuthylazine are effective against pasture weeds but do not harm radiata pine, so can be sprayed directly over trees. Manual releasing using hand tools is an alternative to chemical use, but results are often more variable, and costs are much higher. Manual releasing is usually only undertaken if there is a factor preventing the application of herbicide.

Releasing is usually completed in the spring while soil moisture is high and soil temperatures are starting to rise, but before seedlings are actively growing. Trees should not be sprayed if seedlings are stressed, e.g., during drought (Maclaren, Radiata pine growers' manual - FRI bulletin No.184 1993). Costs will vary based on the method, and type and quantity of chemical required. Some indicative costs are provided in the table below.

Table 6: Indicative radiata pine releasing costs

	Releasing cost ($ per hectare)		
Cost type	**Chemical – Aerial**	**Chemical - knapsack**	**Manual**
Labour / equipment cost	90-120	200-250	500-700
Chemical cost	100-160	20-35	-
Operations management	40	60	70
Total	**230-320**	**280-345**	**570-770**

4.2 Fertiliser

In general, it is not expected that radiata pine grown in Hawke's bay will need to be fertilised, unless there is a very site-specific nutrient deficiency.

4.3 Silviculture strategy

The primary considerations when developing a silviculture strategy for radiata pine in Hawke's Bay is whether to prune, and whether to thin. Pruning is the removal of lower branches at a young age, which allows future diameter growth to be free of knots. The resulting "clearwood" is of considerably higher value when the trees are harvested. Thinning is the removal of a selection of trees to a target "final stocking" which allows the best trees more space to grow in height and especially diameter. This is especially important for a pruned strategy, as clearwood development relies on a trees ability to put on diameter growth.

A valid silviculture strategy may be to neither prune or thin, which would often result in very high biomass. This would only normally be recommended for a non-harvest strategy (e.g. carbon forestry), as the logs produced at maturity would be very small if stockings are kept high.

Strategy choice will depend on site factors, distance and nature of log markets, and financial and risk profiles (Maclaren and Knowles, Silviculture of radiata pine 2005), and will also depend on personal preference so we will analyse three common and comparable silvicultural strategies.

1. Clearwood strategy – prune and thin
2. Framing strategy – thin only
3. Carbon strategy – no prune or thin

4.4 Pruning

Pruning of lower branches is completed when trees are relatively young, as this helps to minimise the “defect core” - the interior section of a pruned log that contains knotty timber. It is also easier and cheaper to prune trees when their branches are still relatively small. Given that costs are substantial, pruning is usually undertaken in a maximum of two “lifts”.

The first lift is usually to a target height of 3.0-3.5 metres, and is ideally timed for a diameter-over-stubs (DOS) of 18-19cm, when the trees are 6-7 metres tall, and 3-4 metres of green crown is remaining after pruning. In Hawke’s Bay growing conditions, this usually equates to an age of 4-5 years.

The second lift is usually to a target height of 5.5 metres, and is timed for when DOS is again in the 18-19cm range. Trees are usually around 9-10 metres tall, to ensure that 3-4 metres of green crown is maintained. In Hawke’s Bay this usually equates to an age of 6-7 years.

Table 7: Indicative radiata pine pruning costs

Cost type	Cost ($ per hectare)		
	Easy	Medium	Difficult
1st prune (375 sph to 3.5m)	1,200	1,300	1,400
2nd prune (350 sph to 5.5m)	700	850	1,000
Operations management (per lift)	80	120	160
Total	**2,060**	**2,390**	**2,720**

4.5 Thinning

Given that more trees are planted than will likely be required for the final crop, there will be a need for at least one thinning. Decisions on thinning will usually be based on answering the following questions:

- What to do with thinned stems?

  Waste thinning assumes that any cut trees are left where the fall, to decay over time. **Production thinning** involves extracting felled stems and merchandising into logs for sale. Production thinning of radiata pine in New Zealand is relatively uncommon, as it requires favourable terrains, early installation of infrastructure and access to markets for young, small logs. Production thinning can also increase risk of windthrow (as trees are generally older when thinned), and often results in damage to final crop trees through the extraction process. Production thinning is therefore not generally recommended for Hawke’s Bay forests.

- When and how often to thin?

  Timing of thinning will be determined by whether the trees are to be pruned or not (thinning will usually occur after pruning), and how big the trees are (small trees are cheaper to thin than large trees). Thinning should occur once the benefit of close competition on branch size has been realised, but before canopy closure starts to have an impact on growth rates of the final crop trees. A single waste thin is usually sufficient, undertaken when trees reach a Mean Top Height[2] (MTH) of 12 metres. If trees have been pruned, timing is usually within 12 months of the completion of pruning.

- What residual stocking?

  Clearwood regimes aim to grow diameter over the pruned section of the tree, to add value through clearwood production. Final crop stocking tends to be relatively low to encourage diameter growth, usually within a range of

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[2] Mean Top Height is defined as the height predicted by the Petterson height/dbh curve for a dbh corresponding to the quadratic mean dbh of the 100 largest trees per hectare (based on dbh) in a stand (Goulding 2005).

350 – 380 stems per hectare on a productive site. On lower productivity sites a stocking of 300 – 340 stems per hectare may be more appropriate.

Framing regimes do not require as much focus on diameter growth, and so higher stocking rates can be applied. Final crop stocking chosen will again depend somewhat on the productivity of the site, but a stocking of 450 – 600 stems per hectare is considered sufficient to produce logs of a marketable size at maturity.

Table 8: Indicative radiata pine thinning costs

Cost Type	Cost ($ per hectare)		
	Easy	Medium	Difficult
Waste thin FR (833>550)	600	750	1,000
Waste thin CW (833-350)	700	850	1,100
Operations management	80	120	160

4.6 Forest management

Forest management requirements will depend usually on the scale of the forest resource and expertise of the owner. Very small forests may be managed with little effort by the owner, but owners with little spare time or experience, or with a large forest asset may choose to engage the services of forest manager. The specific forest management required will vary from forest to forest, but primary management roles and responsibilities can include:

- Preparation of budgets and work plans/schedules
- Contractor engagement and supervision of forest operations
- Mapping and stand record-keeping
- Cost tracking and reporting
- Consent application and administration
- Security, protection and infrastructure maintenance
- Health and Safety and Environmental (HS&E) compliance
- Professional and technical advice
- Liaison with regulatory bodies and other agencies, neighbours, iwi and affected parties as required

Costs for undertaking forest management activities will depend on agreed scope of responsibility, and will also vary based on forest location, scale and competition for services. The table below summarises some indicative forest management costs that could be expected for forests in Hawke's Bay.

Table 9: Indicative radiata pine forest management costs

Cost type	Cost ($ per hectare)		
	Low	Medium	High
Forest management	15	25	35
Administration	5	15	25
Protection and maintenance	10	20	30
Total	**30**	**60**	**90**

5. Pests, diseases and other risks

5.1 Wild animals

In general, radiata pine is not especially palatable to browsing mammals, but is sometimes damaged by wild or domestic animals (Maclaren, Radiata pine growers' manual - FRI bulletin No.184 1993). Radiata pine is most susceptible to damage when young, as trees are reasonably well defended once their branches have grown to protect the stem. Control of wild animals is often as much for protection of biodiversity and environment as it is about protecting the tree crop. Wild animals can be vectors for disease such as bovine tuberculosis, and can also predate on indigenous wildlife.

Some wild animals have recreation value through hunting, and so control of these species may be achieved with little or no cost.

The requirements for control of animal pests will vary from site to site. The primary animal pests that are likely to be encountered in Hawke's Bay forests are:

- **Possums** will eat young trees but are often not prolific on an ex-farm site due to prior land management. Possums tend to be controlled through poisoning, trapping or shooting.
- **Goats** are potentially the biggest risk in terms of animal pests, particularly in northern Hawke's Bay. Control is usually by shooting, and risk areas should be managed pre and post-planting.
- **Pigs and deer** are also prolific in certain parts of Hawke's Bay, and should be managed appropriately where deemed to be a risk to successful establishment.
- **Livestock** such as sheep and cattle can be problematic on ex-farm sites. Damage is usually through trampling rather than browsing and can be controlled simply through effective fencing.

5.2 Insect pests

Although many species of insect are known to affect radiata pine, most have not caused widespread damage through outbreak. Below is information on some insects that are known to favour pines and significant damage in certain conditions. There is a very low likelihood that any of these insect pests would impact growth or health of radiata pine planted in Hawke's Bay.

- **Sirex wood wasp** (*Sirex noctilo*) is one of the few insects in New Zealand that can attack live radiata pine (Bain, Sopow and Bulman 2012), laying eggs in living trees and depositing mucus and fungus into the wood. The mucus causes the foliage to wilt and makes conditions in the tree suitable for the spread of the fungus. Susceptible trees may die. The larvae tunnel through the fungus-infected wood, and the adults make round exit holes when emerging. Resin may ooze from egg-laying (oviposition) holes drilled by Sirex. Even if the attack is unsuccessful, degrade of the timber may occur because of resin accumulation or killed zones in the wood (NZFFA 2009).

  Sirex first established in New Zealand in 1900, most likely through imported European timber. An outbreak in the 1940s killed many individual trees in stands covering 120,000ha in the central North Island. It generally only affected trees that were stressed from overcrowding, aggravated by unusually dry summers (Mead 2013). A combination of introduced natural enemies and better silviculture has led to excellent control of Sirex and today it is regarded as a minor pest (Bain, Sopow and Bulman 2012).
- **Wood borers and Bark beetles** can be a problem in some radiata pine forests. The main species prevalent in New Zealand are *Hylastes ater*, the black pine beetle, and *Hylurgus ligniperda*, the golden-haired bark beetle. Hylastes and Hylurgus are generally found feeding on the cambium of recently felled logs and fresh stumps. Seedlings can also be damaged by Hylastes and it can lead to sapstain fungi infection (Mead 2013). This is primarily a risk of second rotation plantings.

  The primary economic impact of bark beetle infestation is that log importers require either debarking or fumigation to avoid introduction of these insects to their countries. Currently Methyl bromide is used to fumigate radiata pine logs at export ports, although its use is expected to cease due to health and environmental concerns. Alternative fumigants are currently being investigated.

Beetles in the genus *Dendroctonus* and *Ips* are generally considered to be the most serious insect pests of coniferous forests in the Northern Hemisphere. *Dendroctonus ponderosae*, the mountain pine beetle has devastated millions of hectares of Canadian forest in the last 15 years. It has primarily attacked *Pinus* species, although there have been some isolated attacks on douglas-fir and spruce. Beetle populations do not persist long-term on non-pine hosts (Natural Resources Canada 2017). Although these outbreaks have occurred primarily in the native regions of mountain pine beetle (E. Brockerhoff 2009), radiata pine is likely to be a suitable host. *Dendroctonus* species have been intercepted alive at New Zealand ports, and some are known invaders. However, *D. ponderosae* is probably a weak invader, and therefore it is considered a significant threat but a low risk (Brockerhoff and Bulman 2014).

- **Pine wooly aphid** (*Pineus pini*) is a sap-sucking insect that primarily targets unhealthy or less vigorous trees. Dry sites and high stockings are most vulnerable, so good silvicultural practice will generally prevent significant infection. There are also numerous natural predators to the Pine wooly aphid in New Zealand, so overall the impact on tree growth is minimal (NZFFA 2009).
- **Pine shoot moth** (*Rhyacionia buoliana*) is a problem in Chile, where larvae invade radiata pine shoots, causing breakage, malformation and reduced growth (Mead 2013). An introduced parasite has been used successfully as a biological control. Pine shoot moth has not been recorded in New Zealand, and the likelihood of future introduction is relatively low.

5.3 Diseases

There are a number of diseases that can specifically effect radiata pine, primarily through fungal pathogens. Below is a summary of the main diseases known to exist in New Zealand, along with diseases that could cause significant problems to radiata pine were they to be introduced to this country in the future.

- **Dothistroma needle blight** is caused by the fungus *Dothistroma pini and* causes needle cast of conifers. It was first identified in New Zealand in the mid-1960s, and Radiata pine is considered highly susceptible. Severity of infection depends on temperature, leaf-wetness period, and spore density (L. S. Bulman, et al. 2004). Dothistroma prefers warm, wet spring weather conditions, and in general the risk of infection in Hawke's Bay is low, with northern parts of the region most at risk. Infection is unlikely to materially impact on stand growth until defoliation is greater than 25% of current foliage. At this point of infection treatment would usually be recommended, being an aerial application of copper fungicide in October. Ground and aerial surveys should be used to identify stands requiring treatment.

  Pruning removes infected foliage and lowers available inoculum, and so can slow new infection. Thinning can also help by improving air circulation to reduce leaf wetness. Tree breeders have also focussed efforts on developing Dothistroma resistant stock.
- **Cyclaneusma needle cast, Red needle cast (RNC) and Physiological needle blight (PNB)** are other common needle diseases of radiata pine**.** These diseases can often look similar, but tend to proliferate at different times and different tree ages (Bulman and Gardner, Field assessment, control and identification of common foliage diseases of pine in New Zealand 2014). Cyclaneusma and RNC are caused by fungal infection, whereas PNB is thought to be a result of water stresses and humidity fluctuation (Gould, et al., 2008).

  Generally these diseases are not common in Hawke's Bay, although Cyclaneusma is more common in the Wairoa district (Bulman and Gardner, Field assessment, control and identification of common foliage diseases of pine in New Zealand 2014). Chemical treatment is generally cost-prohibitive for these diseases - the best control option available is to identify and remove susceptible trees during thinning operations. RNC is a relatively new disease to New Zealand being first detected in 2008. Early trials of chemical controls suggest that phosphite may be effective in controlling RNC, but more work needs to be completed to understand optimal dosages and timing.

- ***Sphaeropsis sapinea*** is an opportunistic fungal pathogen attributed to several diseases including **Diplodia dieback, Diplodia whorl canker, Diplodia shoot blight** and **Diplodia crown wilt**. Radiata pine is recognised as highly susceptible to attack by *S.sapinea.* Diplodia is found throughout New Zealand and attacks are most commonly found with pre-existing conditions such as animal/insect damage, drought stress or nutrient imbalance. Pruning wounds are also a common source of infection (M. Dick 1999). There is no effective chemical control available, so management is usually focussed on prevention through good silviculture practices and tree-breeding for resistance. *S. sapinea* is also often responsible for sapstain of logs, timber and woodchips.
- ***Armillaria* root rot** is a fungus that attacks roots of radiata pine and can cause growth loss and mortality. It colonises stumps so is most common on sites once occupied by indigenous forest, and second rotation pine forests where old stumps are still present. Control is generally not required on land that has been in pasture. For land that has been in stocked in woody species, the best control is stump removal, though this will often not be cost-effective. A trichoderma biological control has been developed, which is nursery-applied and can result in 30% less mortality from *Armillaria* (Hill, et al. 2005). Research is also looking at introduction of competing fungi that could colonise stumps before *Armillaria* therefore reducing potential for spread (Hood 2015).
- **Canker diseases** such as *Peniophora* and Nectria flute canker are present in New Zealand, but are not deemed to be of significant economic importance. Nectria currently only occurs in the South Island.

  Pine pitch canker (caused by the fungal pathogen *Fusarium circinatum*) is considered to be a major threat to plantations around the world and infects all ages and parts of radiata pine, at any time of year (Mead 2013). It is not currently present in New Zealand forests, although the disease has been detected on quarantined douglas-fir material imported from California (M. Dick 2004). Risk of introduction to New Zealand persists as climatic conditions are considered to be favourable, but there are few vector insects here that could cause the necessary wounding so likelihood of significant damage is considered to be low at present (Ganley 2007).
- **Western gall rust**, caused by the fungus *Peridermium harknesii*, is a serious disease of many pines in North America including radiata pine. The pathogen has never been recorded in New Zealand and the probability of invasion is considered to be very low, however if it were to establish here the long-term effects may be large (Ramsfield, et al. 2007).

5.4 Fire

Fire is a known risk for plantations in New Zealand, with over 40,000 hectares burned in the last 60-70 years. This equates to an annual loss of 0.12% per year, although recently losses have been somewhat lower at 0.03% per year due partly to better fire management and preparedness (Pearce, et al. 2008). The principal causes of fire are arson, escaped burns, forestry operations, spontaneous combustion, vehicles and campsites. Fires started outside the forests usually pose the biggest risk (Mead 2013).

Management of fire risk will post likely be a combination of protection operations and fire insurance. Forest design can also influence fire risk, by providing fire breaks and buffers of less flammable species in risk areas like road edges and powerline corridors.

5.5 Wind

Wind is a known risk in Hawke's Bay, with severe damage caused to pine plantations across the north and east of the North Island when Cyclone Bola struck in March 1988. Risk of wind damage will primarily depend on exposure, and age of the trees. Timing of silviculture (especially late thinning) and quality of planting and treestocks can also influence risk of damage (Somerville, et al. 1989). Management of wind risk will often include a combination of methods, such as:

- Site selection
- Treestock quality
- Timing and intensity of silviculture (especially thinning)
- Harvest planning and scheduling
- Insurance

- Windthrow salvage

5.6 Insurance

Risks associated with fire and wind damage can usually be mitigated through appropriate insurance cover. Insurance will usually compensate a proportion of the current tree crop value, and often also provides compensation for the costs of clearing and replanting land. Public liability cover is also usually included. The table below summarises indicative insurance cover costs for an average Hawke's Bay radiata pine forest.

Table 10: Indicative radiata pine insurance costs, average of first 28 years.

	Cost ($ per hectare)	
Cost type	**Pruned**	**Unpruned**
Fire	22	16
Wind	22	16
Public Liability	1	1
Total	**45**	**33**

5.7 Wilding spread risk

Radiata pine is known to naturally regenerate through wind-borne seed in New Zealand. It will primarily colonise grass, tussock and shrub environments, where animal browsing is absent or restricted. It is generally considered to be a low risk species, with scores of 1/5 for spreading vigour and palatability in the DSS1 wilding spread risk calculator (Paul 2015). Radiata pine would therefore need to be located in wind-exposed areas with receptive vegetation types and little or no grazing to be considered a significant wilding risk. The following table compares radiata pine DSS1 scores for spreading vigour and palatability with other common conifer species planted in New Zealand.

Table 11: Species comparison of DSS1 spreading vigour and palatability scores

	DSS1 score (/5)	
Species	**Spreading vigour**	**Palatability**
Redwood, cedar, spruce	0	N/A[3]
Radiata pine	1	1
Douglas-fir (Nth island)	1	3
Larch	2	0
Corsican pine	3	4
Douglas-fir (Sth island)	4	3
Pinus contorta	5	2

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[3] Palatability not scored as spreading vigour of zero means very low risk of spread

6. Productivity

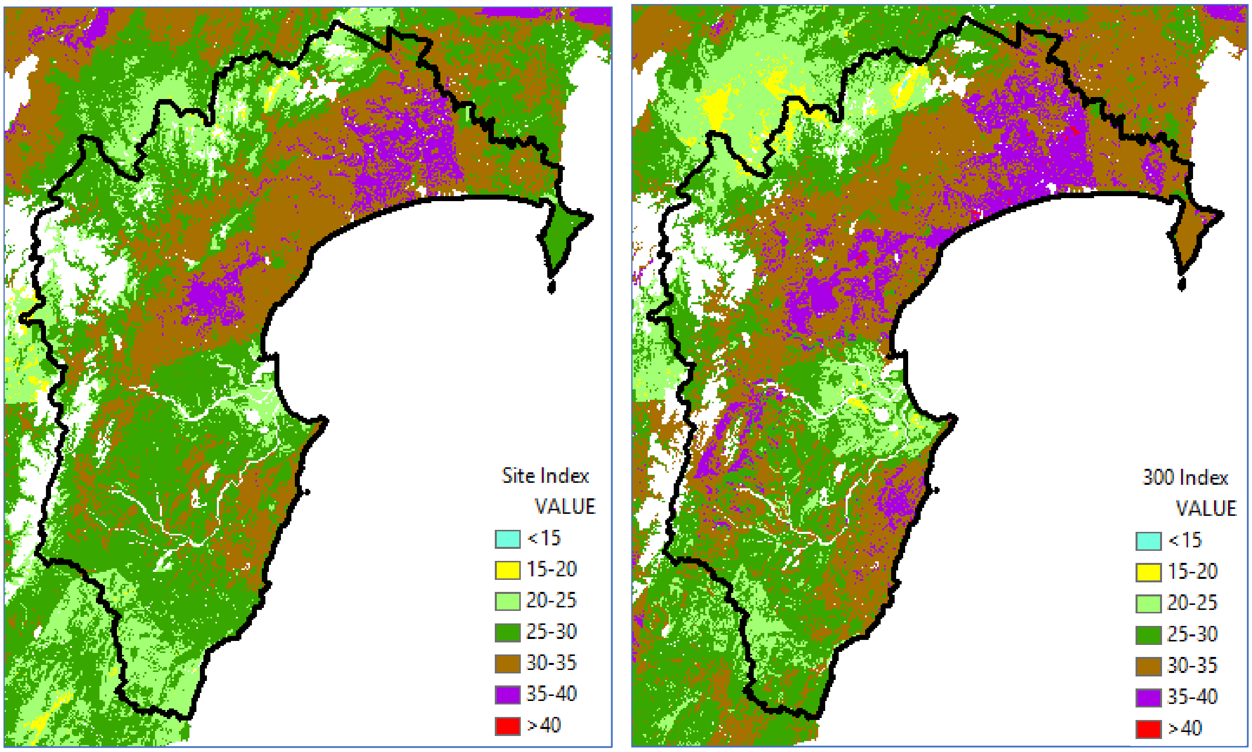
6.1 Productivity rating systems

Productivity of sites for growth or radiata pine are generally characterised using two indices, being Site Index and 300 Index.

Site Index is a measure of height productivity and is defined as the height of the 100 largest diameter trees per hectare at a given reference age. For radiata pine that reference age is 20 years. The average Site Index in Hawke's Bay is 30.9m, with an overall range of 15.7-38.6m (Palmer, et al. 2010).

300 Index is a measure of volume productivity and is defined as the mean annual volume increment (MAI), at an age of 30 years, for a final crop stocking of 300 stems/ha. The average 300 Index for Hawke's Bay is 31.3m^3/ha/year, with an overall range of 13.5-41.9m^3/ha/year (Palmer, et al. 2010).

Figure 1: Site Index and 300 Index productivity surfaces for Hawke's Bay



These indices are valuable inputs to growth and yield predictions, and the table below summarises estimated values for typical high, medium and low productivity sites in Hawke's Bay.

Table 12: Site index estimates for low, medium and high productivity classification

Class	Productivity index	
	Site Index (m)	300 Index (m^3/ha/yr)
Low	28.7	27.4
Medium	31.7	34.5
High	35.3	37.8

6.2 Growth models

Growth modelling is required to predict future yields, as this information is crucial to cashflow forecasting. There are two primary models used for growth and yield prediction of radiata pine in Hawke's Bay.

NAPIRAD

The NAPIRAD model was developed in the early 1980s using PSP data extracted from 207 plots across Wharerata, Patunamu, Mohaka, Esk, Kaweka and Gwavas forests. Known limitations for this model are as follows:

- There was limited data from poorer sites, i.e. Kaweka (11 plots).
- Very few unthinned stands are represented, so modelling of unthinned stands could be more inaccurate.
- The model will predict very little mortality.

300-Index growth model (I300)

The 300 Index Model is intended for use in any site in New Zealand. The growth model is calibrated for any given site using the two site productivity indices Site Index and 300 Index. It predicts yield from planting and has been found to perform well up to and beyond age 50 years for a wide range of site types. The 300 Index Model is a silvicultural model which is sensitive to different levels of stocking, and to thinning and pruning operations.

The model was developed from an initial dataset of 775 trial plots throughout New Zealand, with validation work performed using an additional 5,700 existing plots.

The 300-Index growth model is recommended for radiata pine in Hawke's bay, as it is more flexible and is based on more recent data.

6.3 Rotation length

The 2017 NEFD reported the area-weighted average harvest age of radiata pine in New Zealand as 28.4 years, with a typical range of 26 to 32 years. Hawke's Bay growing conditions would be considered as above average, and so the following harvest ages are deemed as appropriate for modelling future radiata pine plantations in the region.

Table 13: Typical rotation lengths for radiata pine in Hawke's Bay.

Regime	Rotation length (years)
Framing (unpruned)	26
Clearwood (pruned)	28

6.4 Expected lifespan

Expected lifespan is only relevant to non-harvest regime, as we know that there is radiata pine tends to thrive up to normal clearfell ages. Understanding how long a forest may live helps to determine how much sequestered carbon can safely be sold.

How long radiata pine will survive if left unharvested is somewhat unknown, as there have not been many stands left to grow very old in New Zealand, and we don't know yet what the effect of modern genetic improvement will be. It is reasonable to assume that radiata pine will continue to grow past 50 years, but it would be prudent to not assume any carbon revenue past this point. This is especially so if it was expected that a permanent pine plantation would eventually transition to native forest over a long period. It would be unlikely that mature native forest would store the same amount of carbon as a 50-year-old pine plantation, so even selling 50 years of carbon credits could result in some future carbon liability.

7. Log production

7.1 Harvest systems

There are two primary systems employed for harvesting radiata pine plantations in New Zealand.

Ground-based logging utilises wheeled or tracked machinery such as skidders, tractors and excavators to extract felled stems to processing sites. These systems are usually restricted to flatter terrains, although new technology such as tethering or remote / tele-operation is enabling machines to operate on steeper slopes in certain areas. Tree felling is also usually undertaken using machinery in this easier terrain.

Hauler logging involves specialised machinery suspending cable systems over the ground to haul logs to processing sites. These systems are usually required on steeper terrain, or where sensitive ground conditions or access problems prevent the use of ground-based systems. In general hauler systems are significantly more expensive to run, as more machinery and manpower is usually required, but productivity is usually lower than for ground-based systems.

Helicopters are sometimes employed for logging, but this is relatively rare in radiata pine, as the cost of such an operation usually outweighs the value of the logs produced.

In addition to terrain, other considerations that may influence harvest system and machinery requirements could include:

- Stream locations and sizes
- Infrastructure locations (eg. roads and processing sites)
- Resource consent conditions
- Ground conditions and expected weather
- Contractor availability
- Ecological or archaeological constraints

A robust harvest planning process is essential to identify these considerations well ahead of harvest, to ensure that infrastructure is fit for purpose, and harvest operations can be completed in a safe, efficient and environmentally friendly manner.

7.2 Harvest productivity and cost

In addition to harvest system requirements, there are several other factors that can affect the productivity and therefore costs of a radiata pine harvest operation. Such factors include (but are not limited to):

- Piece size – smaller trees are costlier to handle and process. Very large trees can also be more expensive to harvest, especially if they are to big to handle with normal size machinery.
- Haul distance – if trees need to be extracted long distances to processing sites, this will affect productivity and therefore cost. Reducing haul distance usually is a trade-off as it inevitably requires more cost in terms of infrastructure.
- Remoteness – if the forest requires significant travel or accommodation for harvest crews, this will affect productivity and/or cost. Costs associated with transporting machinery and equipment will also be affected.
- Complexity – jobs that have complicated requirements will usually cost more to harvest. This could include traffic management, power lines, archaeological sites, access restrictions or multiple land-uses.
- Competition – There is generally a shortage of experienced harvesting contractors across New Zealand, including in Hawke's Bay. This lack of competition is having an adverse effect on harvest costs as forest owners try to secure contractors for their forests.

The following table summarises harvest costs that could be expected for a range of harvest systems and factors that would commonly be encountered in Hawke's Bay.

Table 14: Indicative radiata pine harvest costs

Harvest type	**Harvest cost ($ per m^3)**		
	Easy	Medium	Hard
Ground-based	19.00	23.00	30.00
Hauler	33.00	40.00	55.00

7.3 Infrastructure requirements

Harvesting of radiata pine forests will usually require the design, installation, maintenance and rehabilitation of a network of forest roads and processing sites. Stream crossings, entranceways, fences and gates may also be required.

Infrastructure requirements and costs are very site-specific. Detailed harvest planning and engineering design work will often be required to properly quantify requirements. This process will normally consider the implications of:

- Existing infrastructure location and condition
- Topography and climate
- Soil types and erosion potential
- Regulatory requirements
- Health, safety and environmental best practice
- Trade-offs between harvest costs and infrastructure costs
- Harvest systems and productivity
- Landowners, neighbours, iwi and other affected party considerations
- Aggregate sources

Below is a table summarising some expected ranges of infrastructure costs that could be expected for typical forests in Hawke's Bay.

Table 15: Indicative radiata pine infrastructure costs (first rotation, ex farm)

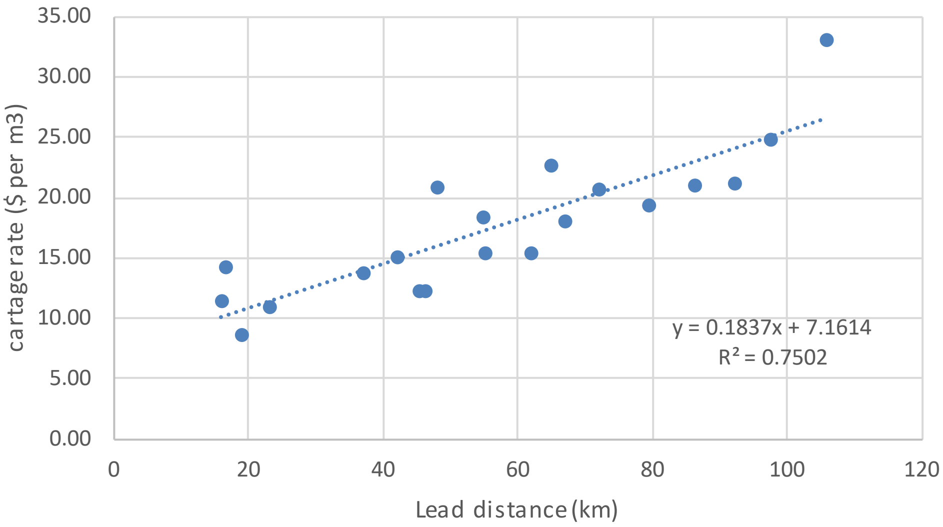
Cost Component	**Infrastructure cost ($ per m^3)**		
	Low	Medium	High
Road and Skid Construction	3.00	6.00	10.00
Maintenance	0.50	1.00	1.50
Post-harvest rehabilitation	0.50	1.00	1.50
Total	**4.00**	**8.00**	**13.00**

7.4 Log cartage

Transporting logs from forest to customer in Hawke's bay has historically been by road and rail. Currently rail transport is limited to logs moving north to Napier port from the Manawatu / Whanganui region, but funding is in place to re-open the Napier – Wairoa rail line to facilitate log transport south to Napier. This has the potential to reduce transport costs and improve safety for road users on State Highway 2.

Log cartage costs will usually have a fixed component, and a variable component based on lead distance, as this is the key factor in determining cartage costs. Regression analysis can be used to compare actual cartage rates and lead distances, to develop a formula for predicting cartage rates. Below is a graph showing regression analysis for log cartage in the Southern North Island over 2017-2018. This analysis shows that cartage costs over this period can be approximated by using the formula ***Cartage cost ($/m3) = $7.16 + ($0.18 x Lead distance)***.

Figure 2: Cartage rate analysis for Southern North Island, July 2017 - June 2018 (Source: PF Olsen).



Fuel prices have a significant impact on cartage rate, with approximately 20% of cartage costs being attributed to diesel consumption. Diesel prices across the analysis period above averaged $1.26 per litre[4]. Diesel prices since this period (up to October 2018) have increased by approximately 20%, and this is likely to have resulted in cartage costs increasing by around 4%. It is worth noting that this increase would also likely be felt in harvest costs, where diesel costs have a similar influence.

Factoring the increased fuel component, the cartage formula that best approximates current cartage costs would be:

Cartage cost ($/m^3) = $7.45 + ($0.19 x Lead distance)

Table 16: Indicative cartage costs

Lead distance (km)	Cartage cost ($/m^3)
25	$12.20
50	$16.95
100	$26.45
150	$35.95

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[4] Discounted retail price – Source: https://www.mbie.govt.nz/info-services/sectors-industries/energy/liquid-fuel-market/weekly-fuel-price-monitoring

7.5 Other costs of production

Management of harvesting operations by a suitably qualified individual or company will usually be required. Management tasks include:

- Harvest planning
- Contract and contractor management
- Health & safety and environmental compliance monitoring.
- Production monitoring
- Log value recovery and quality control
- Log marketing
- Reporting and documentation
- Weighbridge fees and consumables (paint, stencils etc)

Post-harvest clean-up may be required on some sites, and can include slash management, fence repairs, drainage works and erosion control works.

The Commodity Levies (Harvested Wood Material) Order 2013 imposes a levy on all harvested wood material from plantation forests in New Zealand. Levies are payable to the Forest Growers Levy Trust and the levy is currently set at **\$0.27 per m^3** or tonne and cannot exceed \$0.30 per m3 or tonne during the six-year levy period. The levy period ends in 2019, at which point forest growers will hold a referendum to decide whether to continue for another six years. The levy was introduced to provide funding for the following categories:

- Research, science and technology (64%[5])
- Forest health and biosecurity (13%)
- Health & safety (10%)
- Promotion (9%)
- Fire (1%)
- Forest resources and environment (1%)
- Transportation (1%)
- Small and medium forest enterprises (0.1%)

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[5] Source: Forest Growers Levy Trust 2017 Annual Report

8. Log markets and wood availability

8.1 Domestic processing capacity

Hawke's Bay has an established domestic processing base for radiata pine, with one large processor and several smaller operations located primarily in the northern half of the region.

Table 17: Hawkes Bay log processing capacity estimate

Mill	Estimated log intake capacity (m3)			
	Pruned / part-pruned logs	Unpruned saw logs	Pulp logs	Total
Pan Pac Whirinaki	450,000	300,000	350,000	**1,100,000**
Napier Pine Fernhill	60,000			**60,000**
Napier Pine Pandora	40,000			**40,000**
East Coast Lumber Wairoa	50,000			**50,000**
Kiwi Lumber Dannevirke	60,000			**60,000**
The Pallet Company Napier		35,000		**35,000**
Total	**660,000**	**335,000**	**350,000**	**1,345,000**

Pan Pac Forest Products Ltd

Pan Pac sawmill located at Whirinaki processes pruned, part-pruned and unpruned sawlogs into various timber products. Green sawn output is approximately 430,000m^3 per year, equating to log input of approximately 750,000m^3.

Pan Pac also operates a pulpmill at Whirinaki, producing Thermomechanical Pulp (TMP) and Bleached Chemi-thermomechanical Pulp (BCTMP) for the papermaking industry. The pulpmill processes approximately 750,000m^3 of chip annually, of which around half is sourced from logs. The remainder is sourced as chip from sawmills (including its own).

Pan Pac has a forest estate of around 35,000 hectares, but also sources its logs and chip from external parties across Hawke's Bay, Manawatu, Wairarapa and the Central North Island.

East Coast Lumber Ltd

East Coast Lumber is located in Wairoa and processes pruned logs for the appearance grade lumber market. It processes approximately 50,000 m^3 of logs per year.

Napier Pine Ltd

Napier Pine has two sawmills located in Fernhill (Hastings) and Pandora (Napier). It primarily processes pruned logs, and has capacity to produce up to 100,000m3 between the two sites.

The Pallet Company Ltd

The Pallet Company process unpruned sawlogs into timber for produce bin and pallet manufacture. They currently process around 35,000m3 of logs per year.

Kiwi Lumber Dannevirke

Although technically outside the Hawke's Bay region, Kiwi Lumber in Dannevirke routinely sources from forests in Hawke's Bay. The mill processes primarily pruned logs and has an annual log intake of around 60,000m^3.

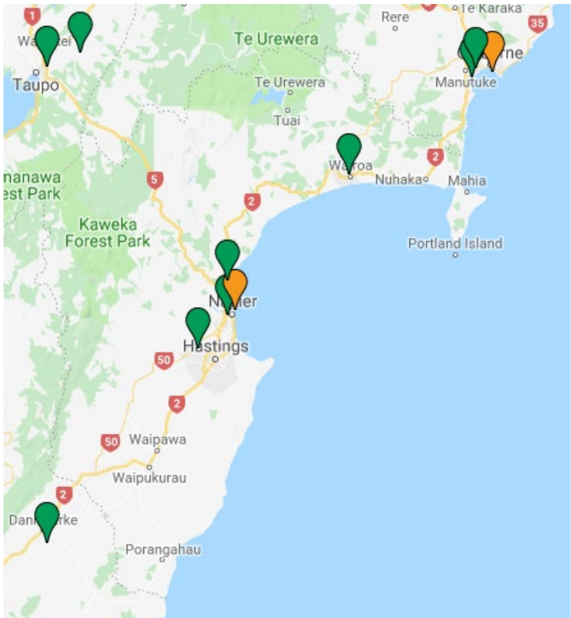
Inter-regional log flows

Other mills to procure logs from Hawkes Bay include Tenon Clearwood and PermaPine in Taupo, and various mills in Gisborne. This demand is usually limited to high value pruned logs.

Mill closures

Clyde Lumber in Wairoa closed in December 2012 and subsequently was placed in receivership. Waitane Mill in Napier was placed in liquidation along with its major shareholder Verda in August 2016. These two sawmills together processed approximately 100,000m3 of logs per year.

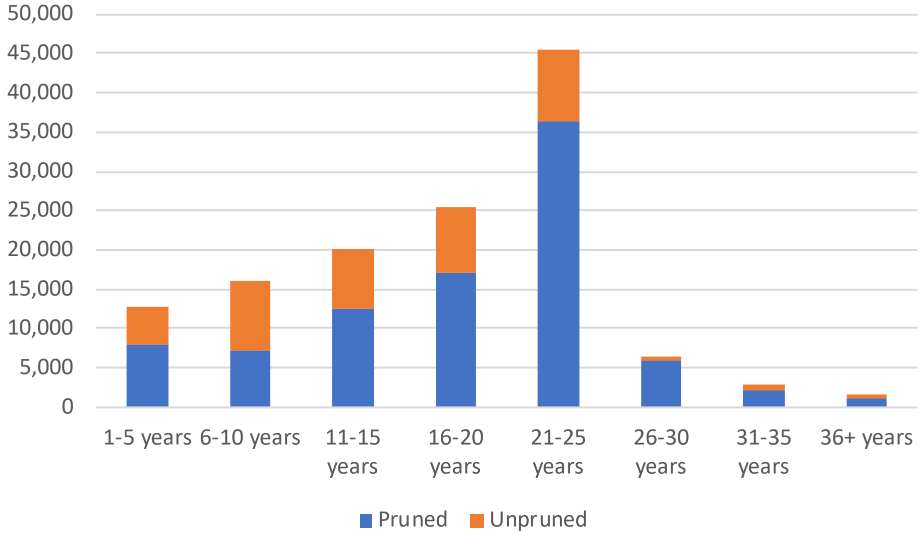
Figure 3: Location of domestic processors (green) and export ports servicing Hawke's Bay forests



8.2 Wood availability

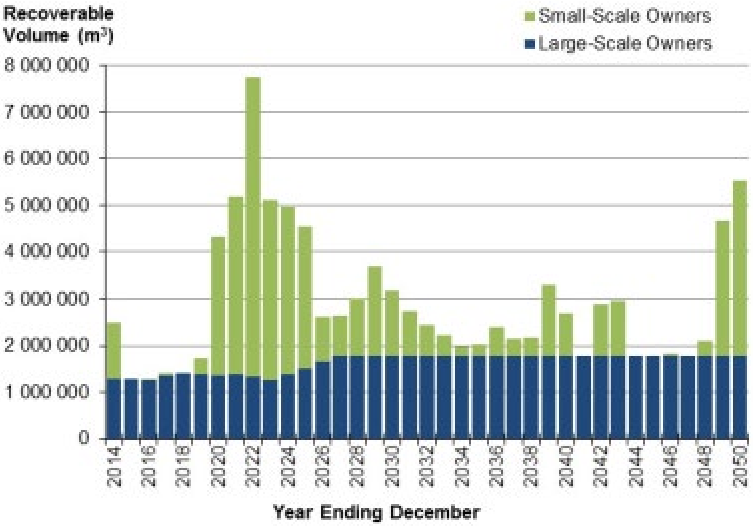
Hawke's Bay has 131,000 hectares of radiata pine plantation (MPI 2017), with approximately 47% located in the Hastings district, 41% in the Wairoa district and 12% in the Central Hawke's Bay district. The age-class profile of Hawke's Bay radiata pine is not evenly spread, as a significant proportion of forest is approaching harvest. Much of this upcoming harvest is owned by small-scale owners (ie. <1,000 hectares owned in the region).

Figure 4: Radiata pine age-class profile for Hawke's Bay (Source: NEFD 2017)



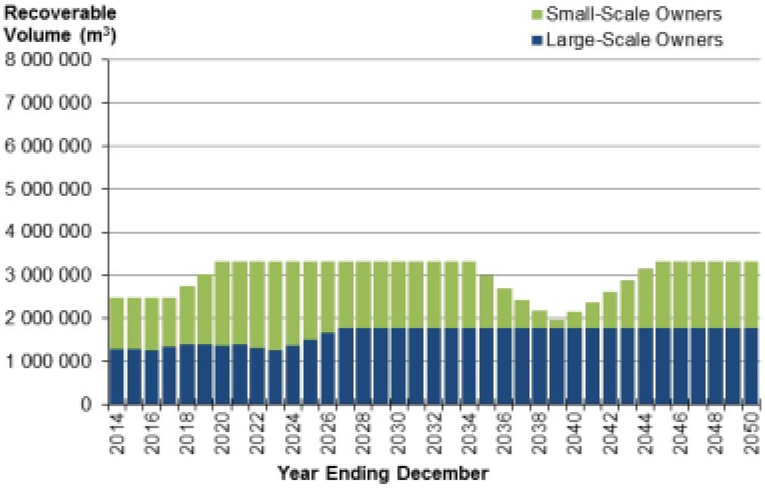
Wood availability forecasts for Hawke's Bay were produced by MPI in 2014 using several scenarios in terms of forest owner decisions. One scenario assumes that large scale owners (>1,000ha) maintain a somewhat consistent base volume, while small scale owners harvest at age 28. This scenario would result a 5-7 year period of significantly increased wood-flow.

Figure 5: Hawke's Bay radiata pine availability - Large owners fell at stated intention, small owners at age 28 (from MPI 2014 wood availability forecast).



Such a spike may not realistically be possible given limitations on infrastructure, and so a more smoothed increase may be necessary. An alternative scenario modelled by MPI involved a split non-declining yield (NDY) scenario, where in general a consistent volume was maintained, but a reduction in volume was allowed between 2035-2039 to match the resource. The following graph shows what wood availability might look like in this situation. Availability would build up to over 3,000,000m3 per year, and could be sustained for up to 15 years. Actual harvest age would need to vary considerably from year to year to achieve the target profile.

Figure 6: Hawke's Bay radiata pine availability - Split NDY scenario with target rotation 28 years (from MPI 2014 wood availability forecast).



Given that the current domestic processing capacity is approximately 1.4 million m3 per year, either scenario would result in availability being adequate to fulfil current processing capacity. If some level of woodflow smoothing was achieved, there could be opportunity for additional radiata pine processing capacity to be introduced. Alternatively, an ongoing and substantial export log programme could be expected.

The introduction of more radiata pine plantation to the region over the next 2-5 years would not fill the hole forecast in 2035-2039, unless trees were grown on a relatively short rotation of 17-21 years. It would be more likely to increase overall radiata pine availability in the years after 2045.

8.2 Log exports

Given that there is currently more volume being produced in the region than there is processing capacity, forest owners utilise export markets to sell large proportions of their logs. Radiata pine export markets are well established with China, Japan, South Korea and India all having strong demand for logs (and wood products). Over 50% of New Zealand log production is exported at present. There are two export ports that can handle logs from Hawke's Bay forests, being Napier Port in Napier and Eastland Port in Gisborne (see orange markers on Figure 3 above).

As the following table shows, substantial increases in log exports have occurred over recent years, and both ports have development plans to ensure that infrastructure is able to withstand continued growth.

Table 18: East coast log exports 2015-2018

	Log exports (tonnes)	
Financial Year	Napier	Gisborne
2014/15	1,108,000	2,200,000
2015/16	1,207,000	2,265,000
2016/17	1,630,000	2,500,000
2017/18	2,000,000*	2,982,000

Sources: Napier Port and Eastland Group annual reports 2015-2018. *estimate

It is worth noting that a proportion of the log volume exported from Napier originates from outside the Hawke's Bay region, with a regular rail service bringing logs from the Manawatu-Whanganui region, trucks carting logs north from the Tararua district, and some forests around Taupo being marginally closer to Napier than Tauranga.

8.2 Log prices

The graph below shows that while log prices have been shown to steadily increase over the long-term, prices can be very volatile in the shorter term, particularly for export logs. Export markets can be reactive to oversupply, and pricing can often fluctuate rapidly on the back of exchange rate and shipping cost fluctuations.

Domestically, pruned and structural prices have risen reasonably consistently over the past 5 years, while pulp log prices have remained virtually unchanged.

The recent trend for domestic log prices has been towards "export equivalence" – due partly to a reduction in long-term wood supply agreements. Mills that are located favourably when compared to a port will often be able to reap the cartage differential benefit in these circumstances.

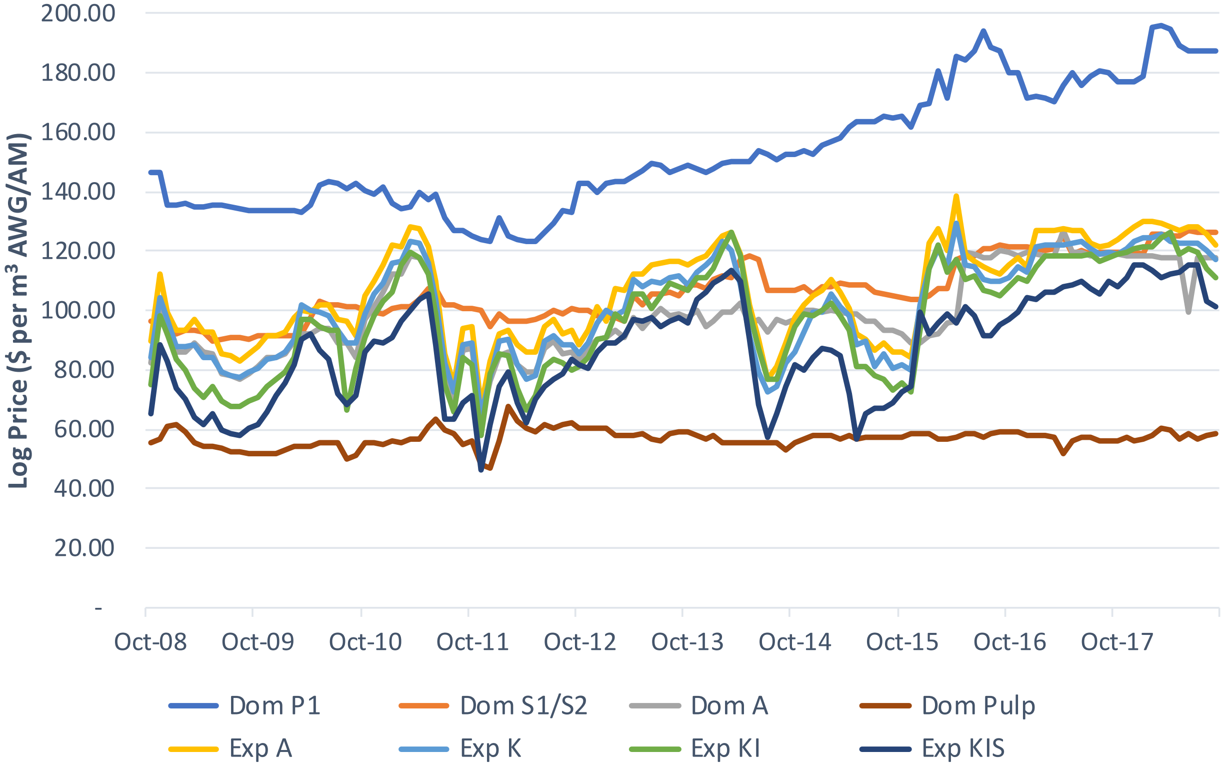


Table 19: Inflation-adjusted log prices to September 2018, Southern North Island (Source: Agrifax/AgriHQ, PF Olsen)

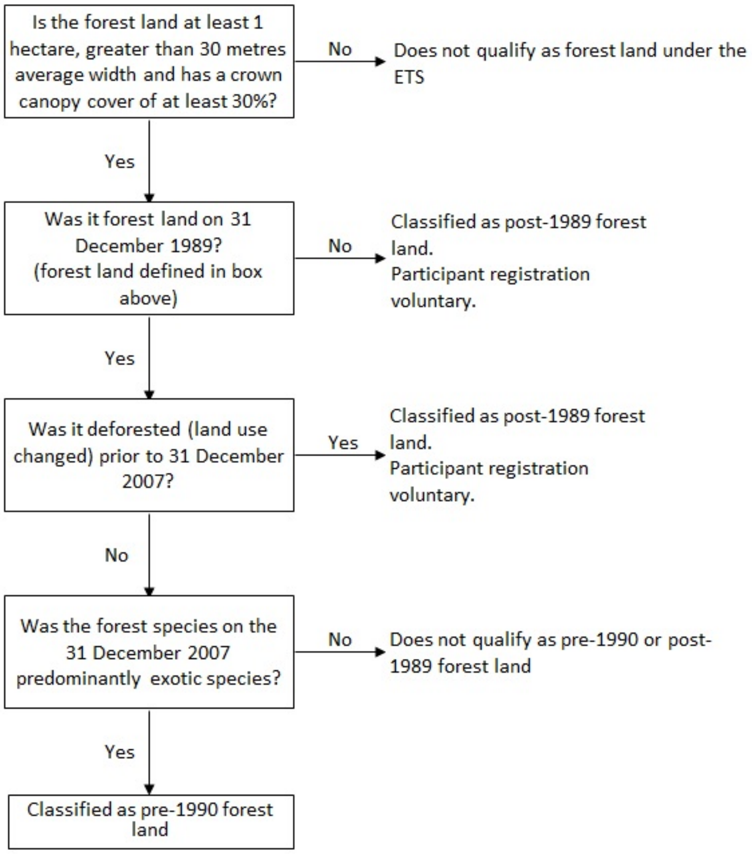
	Log price ($ per m^3)		
Grade	5-year average	3-year average	1-year average
Domestic Pruned P1	170	180	186
Domestic Structural S1/S2	115	119	124
Domestic A grade	107	113	117
Domestic Pulp	57	58	58
Export A	114	121	127
Export K	109	117	122
Export KI	107	113	120
Export KIS	95	103	111

9. Carbon forestry

9.1 ETS eligibility

In order to enter the Emissions Trading Scheme (ETS) and claim credits for the carbon sequestration of a forest, the forest must reside on Post-1989 eligible forest land. This means that the land must not have been forest land on the 31st December 1989 and must also meet minimum size requirements. Land that **was** forest at the end of 1989 is only eligible for entry into the ETS if it was converted to another land-use prior to 31 December 2007. The following flowchart summarises the process for determining ETS eligibility of forest land.

Figure 7: ETS Eligibility assessment process



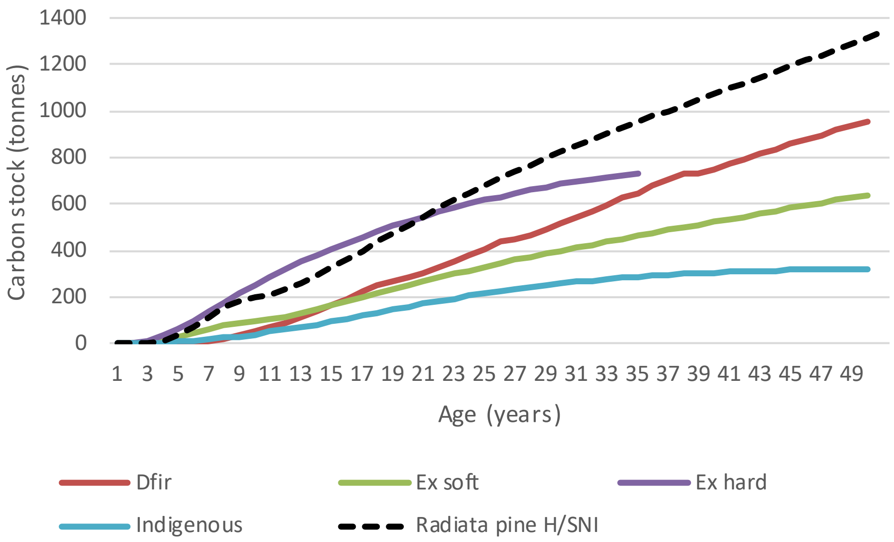
Although land may be deemed as eligible Post-1989 forest land, it does not automatically enter the ETS. A landowner (or forestry right holder) is required to apply to have their land added to the ETS. MPI will assess the application, including eligibility, legal ownership and mapping accuracy, prior to approving entry into the ETS.

As HBRC is interested in encouraging afforestation, we assume that land considered for planting will generally be Post-1989 eligible forest land. In saying this, in most cases there are small areas of ineligible land in a parcel that is assessed for eligibility. This is often due to patches of scrub being deemed as ineligible, or areas of patchy survival being assessed as not meeting the definition of forest land. Offsetting this is the fact that ETS mapping standards can allow certain gaps to be closed up and future crown growth around boundaries to be factored, often resulting in slightly more area being accepted into the ETS. From recent experience, The ETS eligible area of a newly planted forest is often around **5% less** than the nett stocked area.

9.2 Carbon sequestration

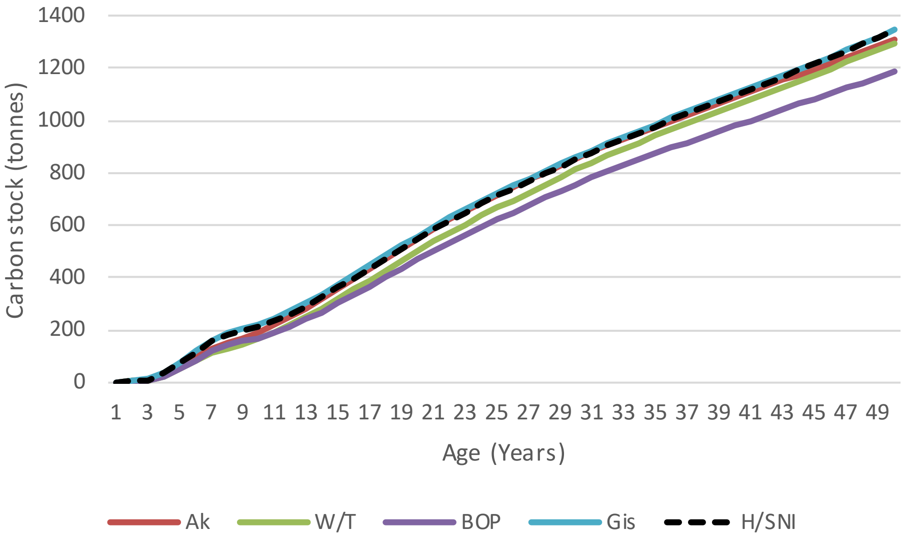
Radiata pine carbon sequestration rates are generally higher than most other commercial species in New Zealand. The following graph compares MPI generic look-up tables for radiata pine in the Hawke's Bay / SNI with national averages for other species groups.

Figure 8: MPI generic look-up tables for different species groups.



Hawke's Bay / SNI region also compares favourably with other parts of the country. Below is a chart comparing MPI generic tables for the North Island. South Island tables are lower for all regions. Hawke's Bay / SNI region's lookup table is second highest in terms of sequestration behind Gisborne.

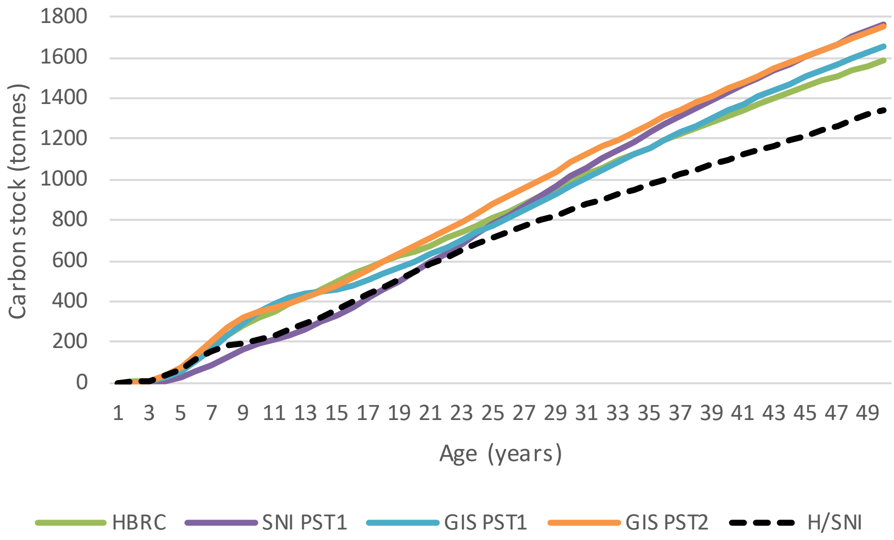
Figure 9: MPI generic look-up tables - North Island radiata pine



The sequestration rates shown in the figures above are applied to ETS participants with a total ETS registered area of less than 100 hectares. For those participants with larger areas registered, permanent sample plots must be installed and measured each reporting period to derive participant-specific look-up tables (PSTs).

Recent experience has shown that participant-specific tables for radiata pine usually result in greater sequestration rates than those provided by the generic tables, likely due to a higher level of conservatism being applied to generic tables for their widespread application. Below is a graph comparing the generic table for radiata pine in the Hawke's Bay / SNI region, with a selection of participant-specific tables from the Hawke's Bay / SNI and Gisborne regions. It shows that this sample of PSTs have calculated sequestration rates 10-20% higher than the generic table for Hawke's Bay / SNI.

Figure 10: Comparison of local PSTs and H/SNI generic lookup table



A conservative approach to modelling sequestration is recommended, as there are many variables that can impact actual sequestration rates for a participant. Therefore we recommend that the H/SNI generic lookup table is used in all scenarios, regardless of actual registered area and FMA status.

9.3 Carbon strategies

When considering how best to generate carbon revenue, there are many different strategies that can be employed, and the choice will come down to factors such as risk profile, resource profile and carbon price assumptions. It will also depend on whether the forest is intended to be harvested or not.

The three main strategies available currently are:

- **Sell carbon credits as they are earned, and surrender back upon harvest.** This enables a participant to take advantage of the time value of early positive cashflows versus later negative cashflows. The primary risk to this strategy is long-term carbon pricing, as many forecasts suggest that carbon pricing needs to increase substantially in the long-term to encourage emissions reductions. If carbon prices were to rise considerably over the course of a rotation, the cost of buying back credits for harvest surrender may far outstrip the time value of the early positive cashflows. Given the risk profile of this strategy, it is not generally recommended for small-medium sized forest owners.

- **Sell only the "safe" carbon**. "Safe" carbon is a term used to describe the long-term minimum carbon storage of a forest across multiple rotations. This minimum is only greater than zero if all carbon growth is accounted for, by having the trees entered into the ETS at a young age. The risks of this strategy are lower, but there is still some uncertainty as the "safe" level is only an estimate until after harvest and replant. It could also change again in the future if rotation lengths were adjusted or if there was a delay before replanting.
- **Sell carbon credits as they are earned, and don't harvest**. In establishing a permanent forest, it is possible to sell carbon credits as they are earned for the foreseeable future. As there is no harvest, there is no future liability for harvest emissions. Risk for this strategy is limited to the effects of crop maturity (ie. sequestration rates plateauing or declining), or damage through fire, wind or other events or incursions. This risk can be mitigated through insurance, or a type of "self-insurance" whereby a proportion (eg.10%) of earned credits are retained in case of a future surrender requirement.

The following figures compare example carbon flows and balances for the strategies mentioned above.

Figure 11: Example carbon stock balances by sales strategy (H/SNI lookup table, age 28 harvest)

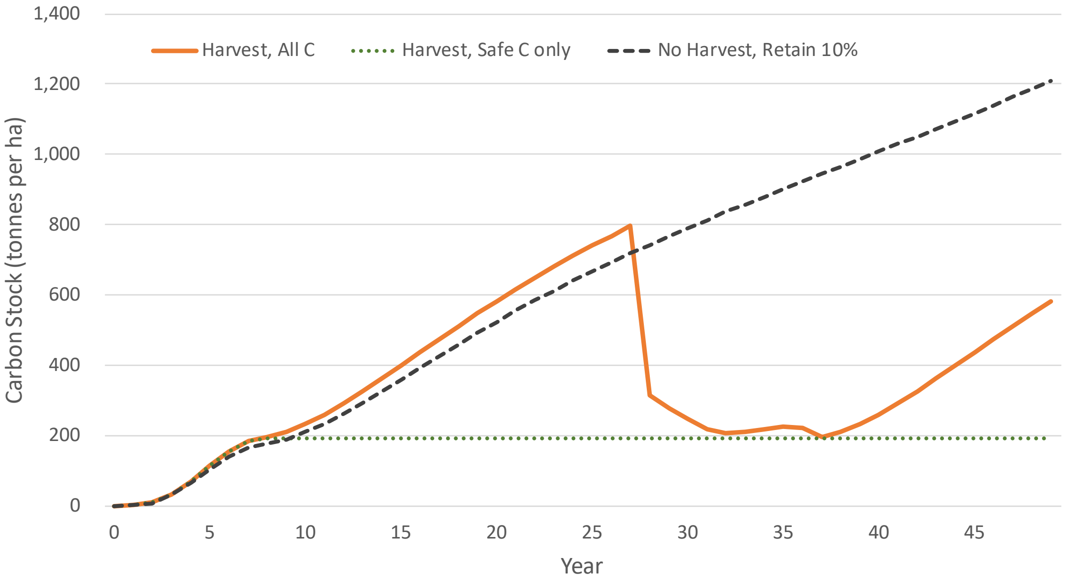
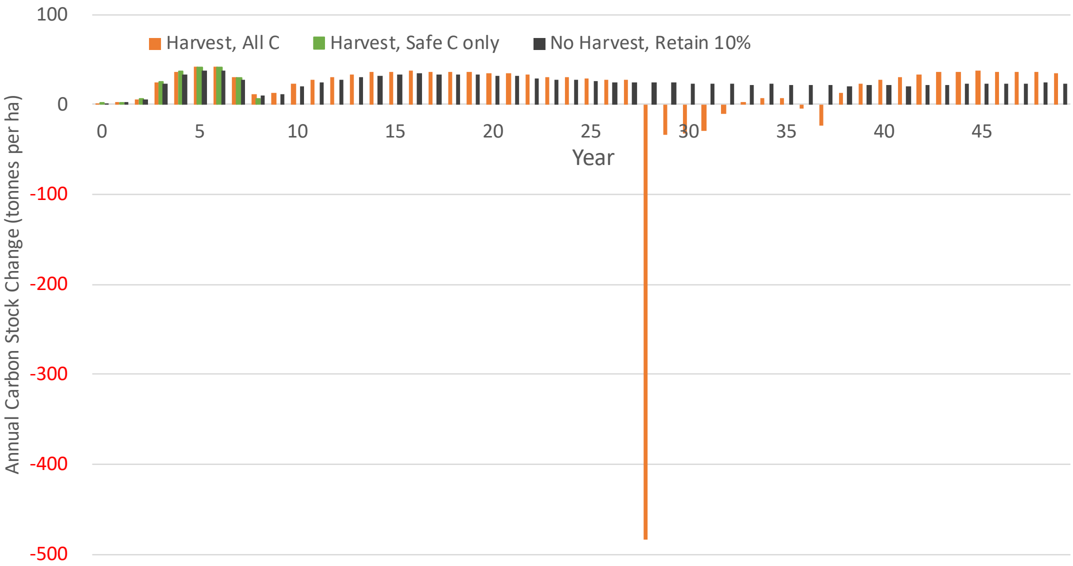


Figure 12: Example annual carbon flows by sales strategy (H/SNI lookup table, age 28 harvest)



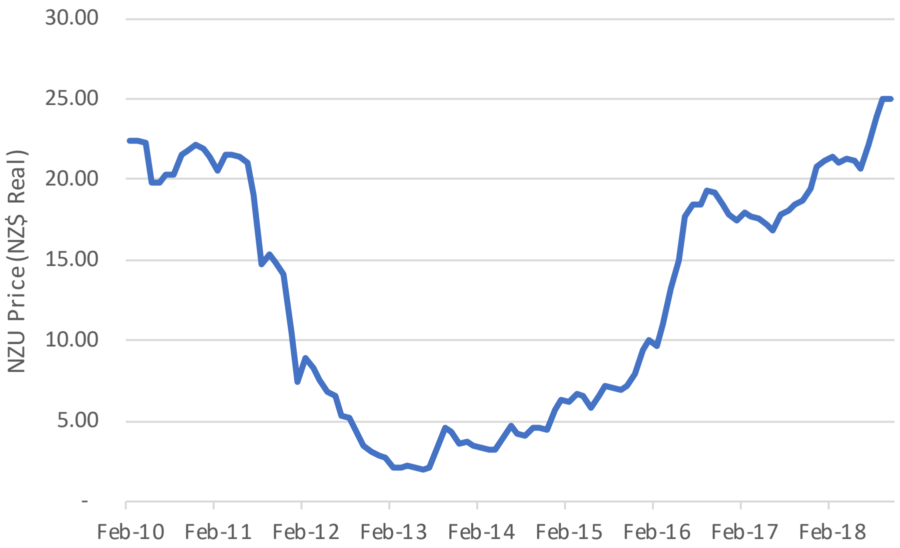
9.4 Carbon pricing

Carbon pricing can be somewhat volatile, and is influenced by several factors including (but not limited to):

- Industrial emissions levels
- Regulatory changes and political influences
- The $25 Fixed Price Option (FPO) available to emitters in lieu of acquiring units for surrender
- Market access and liquidity
- Seasonality of demand
- International trends

The following graph shows the trend in NZU pricing since 2010. The large price drop that occurred in late 2011 was primarily due to the introduction of cheap European units into the ETS market. Low prices were maintained through to 2014 when the Government blocked use of these cheaper units. Prices have since slowly recovered and are now trading around the $25.00 mark, with market prices being heavily influenced by the $25.00 FPO option available to emitters. The Government has announced an intention to review the nature and level of the existing price cap, and a number of reports have noted that considerably higher carbon prices may be required to trigger meaningful emissions reductions in the future.

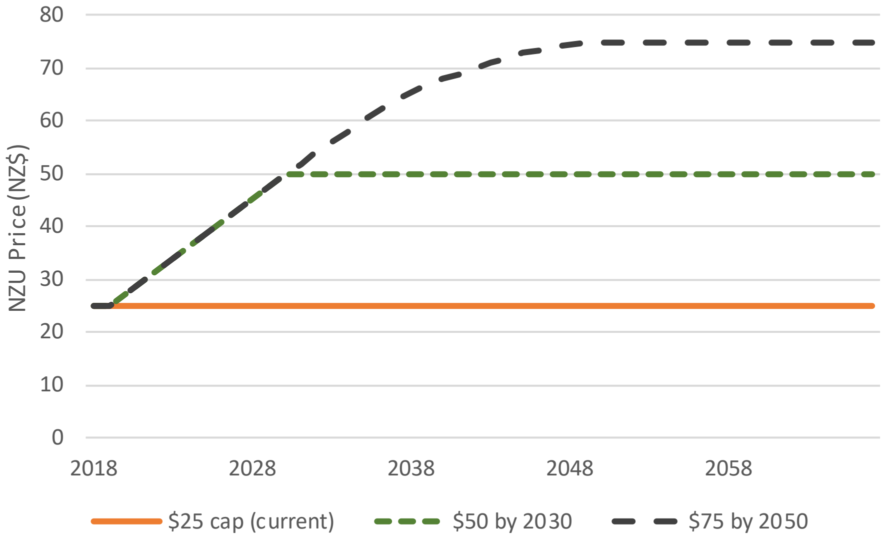
Figure 13: NZU price history, 2010 - 2018.



Forecasting future carbon prices is difficult and very dependent on future carbon policy, emissions reduction goals and international linkages. A report produced for the Parliamentary Commissioner for the Environment (PCE) in 2010 projected that NZ carbon prices could be in the range of $50-$150 per tonne by 2030 (COVEC 2010). Since then New Zealand has signed up to the Paris Accord, and agreed a Nationally Determined Contribution (NDC) of reducing GHG emissions to 30% below 2005 levels, by 2030. The Productivity Commission recently released their final report on a transition to a “low-emissions economy”. Modelling for this report suggests that carbon prices may need to rise to between $75 and $152 a tonne by 2050 (New Zealand Productivity Commission 2018) to achieve desired emissions outcomes.

It is recommended that modelling of carbon price should use a baseline of $25.00 remaining static into the future, as this is the current pricing, and reflects the current known price cap mechanism.

Figure 14: Example future carbon price scenarios



9.5 ETS costs

ETS participation will usually incur initial set up costs such as planning, mapping, preparing applications and associated MPI fees. There will also be ongoing costs associated with emissions return preparation and submission, record keeping and Field Measurement Approach (FMA) plot measurement and data processing (if >100 hectares). The following table summarises expected costs for radiata pine ETS participation. It is assumed that for small areas (<20ha) the forest owner would complete most work themselves, while for larger areas a forestry expert would be engaged. FMA costs are assumed to be $350 per plot for measurement, management and data processing.

Table 20: Estimated ETS costs

	ETS Cost ($ per hectare per year)	
ETS Cost	0-99ha	100ha+
Planning, mapping and registration	$40	$20
Administration	$10	$5
FMA measurement	-	$10
Total	**$50**	**$35**

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