The current and future potential of contingency species to mitigate biosecurity risk for the New Zealand forest sector

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Executive summary

The problem

In 1969 radiata pine made up 54% of the planted forest estate, including eucalypts, larch, Corsican pine, Ponderosa pine, Austrian pine, and Douglas-fir; today radiata pine comprises over 90%.

The Forest Growers Science and Innovation Strategy and the Forest Biosecurity Committee Forest Biosecurity Strategy to 2030 both recognise that the New Zealand forest industry is highly reliant on radiata pine and to a lesser extent, Douglas-fir. The biosecurity risk associated with a single species has not been evaluated, recently (e.g., MacLaren 2004), more focussing on the general biosecurity risks (Brockerhoff and Bulman 2014). This has resulted in uncertainty around the need for risk mitigations such as species diversification and the extent and timing of adoption of those mitigations.

As a result, the Herron et al. (2020) biosecurity report was commissioned and completed.

Forest Growers are now interested in understanding the availability and potential of contingency species for radiata pine as part of their risk analysis.

Client initiatives

The industry wants an evaluation of the current biosecurity risk facing the radiata pine and Douglas-fir estates and whether the risk is increasing compared with previous estimates.

This project

1. Identify potential contingency specie(s) in the event of a significant and serious biosecurity event impacting our commercial radiata pine and Douglas-fir forests that takes account of known performance in NZ, site limitations, silvicultural considerations, disease and pest limitations and ability to deal with changing climatic conditions. The selections should be further prioritised by consideration of wood properties, market uses and ability to fit into existing industrial scale market supply chains, potential for genetic improvement and lead times.

2. For the potential contingency species, undertake a stock take of genetic resources here in NZ, the security of the genetic resources, seed sources and a status summary of growing from nursery through to establishment including weed control and what would be needed to scale up to commercial scale plantings and timeframes. Hybrids in pines and other species should be included.

3. Other species have the potential to meet alternative market opportunities that cannot be satisfied with radiata or Douglas-fir – active research is currently limited to redwoods, cypress species and hybrids, *Eucalyptus nitens, Eucalyptus fastigata, Eucalyptus regnans* and the selection of naturally durable *Eucalyptus* species in the NZ Dryland Forests Initiative program. There is also research into native species establishment and totara management in Northland and a poplar breeding program run through Plant & Food Research that the industry has limited engagement with. Based on known performance in New Zealand, are there other species that should be added and are there any in the current research program that should be dropped? A similar stocktake of the security of seed sources, genetic improvement status, wood quality and end use/market demand/acceptance issues should be included.

4. The project will need to include input from other parties who have trials and knowledge of other species in New Zealand including Farm Forestry Association, NZDFI, NZ Redwood Company, Plant & Food Research and Tane's Tree Trust.

Key results

Several species that are at the stage of readiness have been identified for consideration as contingency species for radiata pine.

Other species able to produce different wood products than those that can be manufactured from radiata pine have been also identified. These have potential to expand the market opportunities for NZ's forestry industry.

We suggest that a workshop be convened to select the species for research and areas for development.

Species that are not selected for further development can be 'parked' by the establishment of genetic resource plantings across New Zealand, to safeguard sufficient material to (re-)initiate a species breeding and development programme, should it be necessary in the future.

Implications of results for the client

- Potential contingency species for radiata pine have been identified for discussion.

Further work

- An industry workshop is now needed to decide the industry outcomes required from the further development of a short-list of these species.
- A programme of research can then be developed based on these outcomes. This would ensure some continuity for the Specialty Wood Products Partnership (SWP), due to finish in 2022.
- Species of close secondary interest could also be planted in genetic resource plantings across New Zealand. This may also be considered for inclusion in the research programme to be developed.

The current and future potential of contingency species to mitigate risk for the New Zealand forest sector

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Background

The Forest Grower's science and innovation strategy review has identified that, as a result of climate change, increased trade and international tourism, there is likely to be an increased biosecurity risk to our mainstream commercial forestry species. As a consequence, New Zealand may need to have an increased focus and investment on contingency species for our current radiata pine and Douglas-fir commercial forest industry.

As a part of the Forest Research Committee strategic review, FRC have commissioned this report to identify potential contingency species in the event of a significant and serious biosecurity event impacting our radiata and Douglas-fir estates.

Potential contingency species

Contingency species for radiata pine are considered here in two tiers:

1) Species (or hybrids) that are capable of fitting into the same markets as radiata pine and;
2) Species that could create a reliable and marketable value chain but that sit outside the current radiata pine market context.

Option 1) directly addresses the biotic risk to radiata pine. Hybridising radiata pine with specie of greater resilience to pests and diseases is likely to be one of the options, integrating characteristics of other pine specie with reasonable growth, form and wood properties into the improved radiata pine genetic material already available. Pure pine species should also be able to be exploitable at scale.

Option 2) addresses the risk by diversifying beyond only pine species. This option has the potential of not only mitigating the biological risks but could also target key market opportunities that offer potential to strengthen the sustainability of the forestry industry, regional economies, and New Zealand's GDP (Gross Domestic Product).

All contingency species options considered here have not had the 70 years of intensive research and development that underlies the success of radiata pine forestry. Therefore, continuing investment in several other forestry options alongside continuing with radiata pine research will expand the market opportunities for NZ's forestry industry. However, any contingency species have also been assessed for the risk they pose of unwanted wilding spread.

The best options identified for contingency species are summarised in Table 1 below.

Table 1: Summary of the readiness of the sector to grow contingency species. Note: This table has been constructed largely on expert opinion. Further analysis with referencing may be necessary on a sub-set before finalising any decisions. If there was insufficient information the cell was left blank.

	Growing						Products		
Species	**Readiness of seed orchards and/or breeding programmes**	**Nursery**	**Siting**	**Silviculture**	**Disease/pest issues and wilding threat**	**Issues for climate change/expected fire risk**	**Wood properties**	**Market**	**Fit into current supply chains**
Pines									
Pinus radiata x P. attenuata hybrids	Seed orchard seed available.	Best practice known but could be optimised for cloning.	High altitude cold sites only.	Radiata pine silviculture. Some mounding may be necessary for frost.	Highly susceptible to Dothistroma needle blight. Full wilding potential not documented but expected to be low.	Areas of suitability may shrink as areas become warmer. Fire risk likely to be low due to planting in high altitude cold sites.	Limited data suggests hybrids may have lower wood density than radiata pine.	Would fit into radiata pine market.	Yes
Pinus greggii	Best provenances identified, but no seed orchards.	Clonal propagation techniques would be good to have.	Warm sites.	Not known, radiata pine standards likely OK.	Not as resistant as other spp to pine pitch canker; Full wilding potential not documented but expected to be low.	Fire risk not known in NZ.	Slightly better than radiata pine.	Would fit into radiata pine market.	Yes
Pinus muricata	Some grafted selections, very limited seed available.	Best practice known.	Correct provenance required.	Radiata pine.	Blue variety performs very badly with exposure. Full wilding potential not documented but expected to be low.	Wider natural range than radiata may be able to adapt to changing climate. Fire risk not known in NZ.	About the same as radiata pine.	Would fit into radiata pine market.	Yes
Pinus patula	No improved seed options at this time. Limited diversity.	Best practice needs confirmation for this spp.	Cooler sites.	Not known, radiata pine standards likely OK.	Dothistroma may be an issue depending on variety. Medium wilding potential in warmer areas.	Fire risk not known in NZ.	May be slightly less dense than radiata pine but more evidence is needed across sites.	Would fit into radiata pine market.	Yes
Pinus pinaster	Some seed orchard seed available. 2nd generation trials underway.	Best practice needs confirmation for this spp.	Warm sites.	Radiata pine.	Medium wilding potential in warmer areas but not well understood in New Zealand.	Fire risk not known in NZ.	Slightly less stiff than radiata pine but more evidence across sites needed.	Would fit into radiata pine market.	Yes
Pinus ponderosa	Best provenances identified but no seed orchards.	Best practice needs confirmation for this spp.	Low rainfall sites/Coastal.	Radiata pine.	Medium wilding potential in warmer areas but not well understood in New Zealand.Dothistroma may be an issue.	Fire risk not known in NZ.	May be slightly less dense than radiata pine but more evidence is needed across sites.	Would fit into radiata pine market.	Yes

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Pinus taeda	Best provenances identified, likely need to import seed.	Best practice needs confirmation for this spp.	Cooler sites.	Radiata pine.	Full wilding potential not documented but expected to be low.	Fire risk not known in NZ.	May be slightly more dense than radiata pine but more evidence is needed across sites.	Would fit into radiata pine market.	Yes
Southern pines (*Pinus elliottii, P. caribaea*)	Best provenances identified, likely need to import seeds.	Best practice needs confirmation *for this spp.	Warmer sites.	Not known, radata pine standards likely OK.	Full wilding potential not documented but expected to be low.	*P. caribaea* can be brittle and snap under high winds. Fire risk not known in NZ.	*P.caribaea* is more brittle and less dense, *P. elliottii* is more dense but has high resin content.	Would fit into radiata pine market.	Yes
Pine hybrids	Hybrid breeding is not currently undertaken at scale in NZ.	Clonal propagation techniques will be needed.	Hybrid dependent e.g. *P. attenuata x radiata* is for cold, dry sites free from the risk of Dothistroma needle blight.	Not known, radata pine standards likely OK.	Full wilding potential not documented but expected to be low and dependent on the type of hybrid.	Hybrid breeding will help mitigate climate risk for NZ by providing greater resistance to disease and drought in particular (hybrid dependent). Fire risk not known in NZ.	Appear to be equivalent to *P. attenuata*. More documentation and evidence in the public domain required.	Would fit into radiata pine market.	Yes
Other spp									
Abies grandis	Seed from provenance trials.	Requires 2-year-old seedlings for deployment.	Good soils and rainfall. Can tolerate colder climates.	More work needed.	Aphids. Full wilding potential not documented but expected to be low.	Resilience/site tolerance undefined across NZ. Fire risk not known in NZ but likely to be low.	Better stiffness than radiata pine but limited testing in NZ.	Sawn timber.	Potential to fit into some existing radiata pine markets but would need much work for a small existing population.
Abies spp.	Seed from provenance trials.	Requires 2-year-old seedlings for deployment.	More work needed. Colder climates.	More work needed.	Aphids. Full wilding potential not documented but expected to be low.	Fire risk not known in NZ.	Likely less dense but stiffer than radiata pine, limited testing in NZ.	Sawn timber.	Potential to fit into some existing radiata pine markets but would need much work for a small existing population.

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Acacia dealbata	4	Best practice known.	Warm dry sites.	More work needed.	High wilding risk on most sites.	Fire risk not known in NZ but likely to be low.	A hardwood with higher density than radiata pine.	Fibre crop.	Doesn't fit with radiata supply chain. Might fit into other existing global fibre supply chain but more work is needed.
Acacia melanoxylon	Best provenances identified but no seed orchards. Could collect from progeny trials.	Best practice known.	Warm sites with good rainfall.	Form pruning required.	Susceptible to psyllids. High wilding risk.	Fire risk not known in NZ but likely to be low.	Durable and appearance grade markets. Research needed to identify superior genetics.	Sawn timber.	Currently fits into its own niche supply chain.
Cedrus spp.	Limited import seed.	Seedlings or cuttings.	More work needed.	More work needed.	Full wilding potential not documented but expected to be low.	Fire risk not known in NZ.		Timber.	
Cryptomeria japonica	Limited some imported clones.	Seedlings or cuttings.	More work needed.	More work needed.	Full wilding potential not documented but expected to be low.	Fire risk not known in NZ.		Timber.	
Cupressus macrocarpa	Seed orchard seed available.	Seedlings or cuttings.	Best away from warm areas with high rainfall where canker is vigorous. Good soil is best.	~400 spha recommended. More research ideal, (Sayle and Dungey 2014). Pruning required for best returns.	Cypress canker serious impediment. Full wilding potential not documented but expected to be low.	Fire risk not known in NZ but likely to be moderate.	Class 2 durable classification for use in construction and furniture. Has the potential to be class 3 with grading and/or breeding/accurate wood classification.	Well developed markets into Asia. Bottleneck is supply and scale.	Does not fit into the current radiata pine value chain, but has well established NZ domestic supply chains and an international log trade into Asia but with an issue of scale and supply.
Cupressus lusitanica	Seed orchard seed available	Seedlings or cuttings.	Warmer sites with good soil and rainfall.	~400 spha recommended. More research ideal, (Sayle and Dungey 2014). Pruning required for best returns.	Cypress canker can be a problem for some families, but it is being addressed in the breeding programme. Full wilding potential not documented but expected to be low.	Fire risk not known in NZ but likely to be moderate.	Class 2 but can vary.	Sawn timber.	Current value chains for cypresses exist into Asia but with an issue of scale and supply.

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Cypress hybrids	Stoolbeds of hybrids in place at several Nurseries, limited production.	Cuttings.	Warmer sites with good soil and rainfall.	~400 spha recommended. More research ideal, (Sayle and Dungey 2014). Pruning required for best returns.	Full wilding potential not documented but expected to be low.	Fire risk not known in NZ but likely to be moderate.	Some hybrid combinations likely to be durable.	Sawn timber.	Current value chains for cypresses exist into Asia but with an issue of scale and supply.
Cypresses – other species		Seedlings or cuttings.	Warmer sites with good soil and rainfall.	~400 spha recommended. More research ideal, (Sayle and Dungey 2014).	Cypress canker can severely affect some species.	Fire risk not known in NZ but likely to be moderate.		Sawn timber.	Current value chains for cypresses exist into Asia but with an issue of scale and supply.
Pseudotsuga menziesii (Douglas-fir)	Seed orchard seed available.	Seedlings.	Wide range of sites. Currently limited by wildings and local resource requirements.	Well understood.	Swiss needle cast in warmer areas. Already has a significant issue of wilding spread in cooler hill country and mountain lands.	Fire risk not known in NZ but likely to be low.		Sawn timber.	Douglas-fir is one of the most widely traded conifers in the world. Does not fit the current radiata pine market.
Eucalyptus bosistoana	Best provenances (growth and wood properties) identified, seed orchard seed and clones available.	Seedlings. Research underway with cuttings.	Requires high fertility.	Best practice known.	Defoliating insects. Full wilding potential not documented but expected to be low.	Fire risk not known in NZ but likely to be moderate.	Class 1 durable; 21 GPa; ~1000 kg/m^3; seasons well.	Alternatives ground-durable posts for agricultural industries; high MoE veneers for LVL; sawn timber.	Existing domestic wooden posts industry and strong demand for naturally durable posts in agricultural sector; existing domestic LVL industry with capacity and demand for high stiffness veneers; existing domestic speciality timber market.
Eucalyptus delegatensis	Limited.	Seedlings.	Prefers colder sites.	Standard eucalypt silviculture.	*Mycosphaerella.* Full wilding potential not documented but expected to be low.	Fire risk not known in NZ but likely to be moderate.	Poor.	Sawn timber.	

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Eucalyptus globoidea	Best provenances (growth and wood properties) identified, seed orchard under development.	Seedlings.	Frost tolerance: Minus 5 degrees (avoid very cold sites). Rainfall min and max: 800 - 2500 mm/year. Soil type/drainage: Suited to a wide range of soils except skeletal and stony soils.	Best practice known.	Full wilding potential not documented but expected to be low.	Fire risk not known in NZ but likely to be moderate.	Class 2 durable; 17 GPa; ~900 kg/m^3.	Naturally durable products/ alternatives ground-durable posts for agricultural industries; high MoE veneers for LVL; sawn timber.	Existing domestic wooden posts industry and strong demand for naturally durable posts in agricultural sector; existing domestic LVL industry with capacity and demand for high stiffness veneers; existing domestic speciality timber market.
Eucalyptus fastigata	Limited seed orchard seed available.	Best practice known.	Sites warmer than -6 degrees celcius or on a slope for cold air drainage. Rainfall sufficient for early survival.	Forking in some seedlots has been overcome by the breeding programme and the new seed available.	Full wilding potential not documented but expected to be low.	Fire risk not known in NZ but likely to be moderate.		Fibre.	Currently used for pulp, but with potential for solid wood. Does not fit with current radiata pine market.
Eucalyptus microcorys	Limited.	Seedlings.	Warmer, more sheltered areas of the North Island.	Standard eucalypt silviculture.	Full wilding potential not documented but expected to be low.	Fire risk not known in NZ but likely to be moderate.		Sawn timber.	Does not fit with current radiata pine market. Very small amount grown for local sawn timber.
Eucalyptus nitens	Seed orchard seed available.	Best practice known.	Colder sites, mostly in the South Island.	Standard eucalypt silviculture.	Significant pest and disease issues. Full wilding potential not documented but expected to be low.	Fire risk not known in NZ but likely to be moderate.		Fibre.	Does not fit with current radiata pine market. Current market is international short fibre pulp.
Eucalyptus obliqua	Limited.	Seedlings.	Cooler sites.	Standard eucalypt silviculture.	Full wilding potential not documented but expected to be low.	Fire risk not known in NZ but likely to be moderate.		Sawn timber.	Does not fit with current radiata pine market.

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Eucalyptus pilularis	Best provenances identified, no seed orchard seed available.	Best practice known.	Frost free sites.	Standard eucalypt silviculture.	Full wilding potential not documented but expected to be low.	Fire risk not known in NZ but likely to be moderate.		Sawn timber.	Does not fit with current radiata pine market. Very small amount grown for local sawn timber.
Eucalyptus quadrangulata	Best provenances (growth and wood properties) identified, clones available.	Best practice known.	Frost tolerance: Minus 6 degrees. Rainfall min and max: 1000 - 2500 mm/year. Soil type/drainage: Prefers fertile well drained soils; grows well on a wide range of soils except skeletal and stony soils. Wind tolerance: Suited to sheltered sites only.	Standard eucalypt silviculture.	Defoliating insects. Full wilding potential not documented but expected to be low.	Fire risk not known in NZ but likely to be moderate.	Class 2 durable; 18 GPa; ~1000 kg/m^3.	Ground-durable posts for agricultural industries; high MoE veneers for LVL; sawn timber.	Existing domestic wooden posts industry and strong demand for naturally durable posts in agricultural sector; existing domestic LVL industry with capacity and demand for high stiffness veneers; existing domestic speciality timber market.
Eucalyptus regnans	Limited seed orchard seed available.	Best practice known.	Cooler sites with deep soils, shelter and good rainfall.	Standard eucalypt silviculture.	Can get foliage disease on wet sites but breeding has helped mitigate this. Full wilding potential not documented but expected to be low.	Fire risk not known in NZ but likely to be moderate-low, as siting for this species in normally on damper sites.		Sawn timber/fibre.	Currently used for pulp, but with potential for solid wood. Does not fit with current radiata pine market.
Eucalyptus saligna	Best provenances identified, likely need to import seed.	Best practice known.	Warm sites.	Standard eucalypt silviculture.	Can suffer from intense insect pest damage on warmer sites. Full wilding potential not documented but expected to be low.	Fire risk not known in NZ but likely to be moderate.	Durable heartwood.	Sawn timber.	Does not fit with current radiata pine market. Very small amount grown for local sawn timber.

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Eucalyptus sphaerocarpa	Limited.	Seedlings.	More work needed, but warmer sites with good rainfall.	Standard eucalypt silviculture.	Full wilding potential not documented but expected to be low.	Fire risk not known in NZ but likely to be moderate.	Durable heartwood.	Durable timber.	No existing market known, but could be grown for sawn timber.
Larix spp.	Best provenances identified, no seed orchards.	Seedlings.	Prefers sheltered slopes and good rainfall.	Radiata pine basic silviculture OK but more later-age work needed.	Full wilding potential not documented but expected to be low.	Fire risk not known in NZ but likely to be low.	Good wood stiffness and density similar to Douglas-fir.	Timber.	Various markets. Possibility to grow for radiata market, with longer rotation lengths.
Native spp. at scale	Not known. Mānuka breeding does occur with some commercial companies.	Generally, seedlings some cuttings.	Various.	Weed control in early years.	Some species are susceptible to animal browsing.	Most native spp are low-to-medium fire risk with the exception of some e.g. manuka.	Varies with Spp.	Timber; various end uses.	Various markets. Possibility to grow for radiata market, with longer rotation lengths.
Picea spp.	Seed from provenance trials.	Seedlings must be grown over 2 years.	Deep, moist, fertile well-drained soils.	Can be damaged by Swiss needle cast.	Spruce aphid has caused failure on many sites. Full wilding potential not documented but expected to be low.	Fire risk not known in NZ but likely to be low.	Good stiffness; moderate to low density. More dimensionally stable than radiata.	Internal low-risk framing and mouldings.	Various markets but not currently tested in NZ. Possibility to grow for radiata market, with longer rotation lengths.
Poplars	Poles available from several Nurseries.	Poles, 1-year rooted cuttings.	Fertile sites.	Silviculture for wood production has not been well developed.	Poplar sawfly may be an issue. Full wilding potential not documented but expected to be low.	Drought tolerance of clones is not known. Fire risk not known in NZ but likely to be low.	More information needed.	Timber, fibre.	Various markets internationally. Does not fit current radiata pine market.
Quercus spp.	Limited.	Seedlings.	High quality sheltered sites.	Wider spacing with pruning.	Can be susceptible to puriri moth, pin-hole borers and a number of beetles.	Drought may be an issue; low fire risk expected but not quantified under NZ conditions.	Most spp suitable for high-value furniture.	Timber.	Very small scale in NZ. Does not fit current radiata pine market.

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Sequoia sempervirens (Coast redwood)	Known seed sources available. Some seed importing.	Seedlings or cuttings.	Good within-company knowledge.	Good within-company knowledge.	Good within-company knowledge. Tree stumps do not die so will persist in the landscape. Wildings from seed are low risk.	Fire risk not known in NZ but likely to be moderate.	Durability.	Used for decking and cladding.	Good within-company knowledge. Currently fits into the local and international (California) sawn timber markets.
Thuja plicata	Best provenances identified no seed orchards.	Seedlings.	Cooler wetter climates with good quality soil.	Best practice able to be adopted from Canada.	Butt rot recorded in NZ trees https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5187347.pdf. Full wilding potential not documented but expected to be low.	Fire risk not known in NZ but likely to be low.	Highly durable for construction – particularly cladding.	Timber is known for its durability and quality.	Valuable internationally traded timber for cladding. Over and above the radiata pine market.

Pine hybrids

Pine hybrids offer potential to improve radiata pine by further improving their growth, wood properties, as well as resilience to biotic and abiotic risk (e.g. pitch canker, Hodge et al. 2000; Roux et al. 2007). In some cases, pine hybrids may even out-perform both parent species (see Dungey et al. 2003 and references therein; examples not including radiata, Kanzler et al. 2014).

Pine hybrids are already planted commercially in South Africa, Australia, USA, China and South Korea (Dungey et al. 2001, Kanzler et al. 2014). Most hybrid pines were developed to mitigate the pine pitch canker. Other hybrid pines have been developed for growing in specific environments e.g. *Pinus caribaea* x *Pinus elliottii* hybrids in South-Eastern Queensland. These hybrids perform at least as well as the mid-parent value and can show heterosis for at least one trait. For New Zealand conditions, they offer a rapid pathway to adapt existing genetically improved radiata pine to the risks of climate change, particularly to disease tolerance (Hodge et al. 2000; Roux et al. 2007; Kanzler et al. 2014).

Hybrids between *P. attenuata* and *P. radiata* are being commercially deployed into the drier areas in the central South Island. This hybrid is clearly superior at age on cold, high-altitude sites in the South Island and offers greater tolerance to wet snow damage. This niche is limited and likely to diminish with climate change. Use of this hybrid will, however, be confined to those cooler and drier sites which are less suitable for growth of the *P. radiata* parent species, and which are likely to remain free of disease caused by Dothistroma needle blight.

Several hybrid crossing programmes have been attempted (Dungey et al. 2003). These include hybrid attempts among radiata pine and *Pinus greggii*, *P. patula*, *P. oocarpa, P. tecunumanii,* and *P. pringleii.* While viable seed has been produced for some combinations, none have been confirmed to be hybrids using DNA marker evidence (e.g., SNP Chips). Several stands containing putative hybrids exist in forest industry trial blocks (Paul Watson Pers. Comm.).

Table 2: Summary of the likely best target combinations and justification for hybrids with radiata pine (adapted from Dungey et al. 2003).

Potential parent species for hybridisation	Key contributing factors
Pinus greggii	Would contribute drought resistance, the chance of some improved wood properties, and improved resistance to Dothistroma needle blight.
Pinus muricata	Wood properties are similar to radiata pine; more resistant to damage by Dothistroma needle blight; less susceptible to western gall rust; marginally more resistant to pitch canker; easily marketable under the same umbrella as *P. radiata*. Provenance selection is important.
Pinus oocarpa	Would contribute pitch canker resistance, improved wood properties (density, and pith-to-bark density profile), and enhanced propagation ability to a hybrid with *P. radiata* in New Zealand, targeted directly at the warmer areas of the North Island, particularly Northland. Can be susceptible to wind throw.
Pinus pringlei	Could contribute the following to a hybrid with *P. radiata*: improved wood characteristics as this appears to be more dense, diplodia dieback and drought tolerance, and resistance to pitch canker.
Pinus tecunumanii	Would contribute pitch canker resistance and improved wood properties (density, stiffness and pith-to-bark density profile); targeted at the warmer areas of the North Island.

The fertility of inter-specific crosses has been and will remain a major limiting factor for the utilisation of most inter-specific crosses (except with *P. attenuata*). The potential benefits are likely to call for persistent attempts, particularly with the continued advances in vegetative multiplication offering a rapid pathway to deployment.

Current research in species other than radiata pine

Forest Growers research on species other than radiata pine is predominantly undertaken by the Specialty Wood Products Partnership, a government and industry-funded research and development partnership aimed at increasing the productivity and profitability of specialty species (https://fgr.nz/programmes/alternative-species/ ; https://fgr.nz/wp-content/uploads/2018/04/SWP-Programme-Description.pdf).

The species included in this research programme and in other active programmes include:

Conifers

Douglas-fir

Douglas-fir is the world's most traded softwood and has good wood properties for large-scale beams and is used often for house construction, and even cladding. Douglas-fir is a better structural wood than radiata pine and is more moisture resistant. For growers, Douglas-fir is the species of choice for higher elevation sites with winter snowfall, although it is prone to malformation on very exposed sites. Its ability to spread from windblown seed is a drawback on some South Island sites, where naturally seeded wildings result in environmental and landscape concerns. This may be mitigated through gene editing to induce sterility if this technology can be used in the future. Selection to deliver gains for improved volume production, improved wood quality and improved tolerance to Swiss needle cast, which limits the success of the species warmer areas, are underway within the programme. A Douglas-fir thinnings OEL™ scoping study has also been undertaken.

Douglas-fir seed is available from several seed orchards, at Proseed and at Ettrick (Ernslaw One).

Cypresses

Cypresses are grown for their timber which are renowned for their fragrance, appearance, stability and durability. The wood of these species is particularly popular in New Zealand as a replacement for rimu, as well as in Asia.

Cypress breeding has been underway at Scion since 1984 (Dungey et al. 2009). *Cypressus macrocarpa* and *C. lusitanica* are the main species with good breeding programmes (2nd and 3rd generation respectively), but there are also hybrids under development, particularly with Alaskan/Yellow Cedar (*Chamaecyparis nootkatensis*), which produces very high durability timber. Hybrid production has focused on improving timber durability and canker-resistance through creating new hybrids and producing clonal planting stock.

Seed is available of *C. lusitanica* and *C. macrocarpa* through a seed orchard hosted by Proseed. While selections for canker-tolerant *C. macrocarpa* have been undertaken, a final round of field testing is underway to confirm the tolerance of the families.

Cypresses are, in general, easy to propagate clonally, and there are several existing trials where new hybrids are being tested with the best being easily propagated at scale.

Hardwoods

Durable eucalypts

There are many durable eucalypts in the >700 species within the *Eucalyptus* genus. In New Zealand the active breeding programmes are run by the New Zealand Dryland Forests Initiative (nzdfi.org.nz), focussed primarily on *E. bosistoana, E. globoidea* and *E. quadrangulata* (https://nzdfi.org.nz/grower-information/growing-ground-durable-eucalypts/nzdfi-selected-species/). Species of secondary interest include *E. argophloia, E. cladocalyx, E. macrorhyncha, and E. tricarpa.* Since 2009 NZDFI have established extensive breeding populations (progeny trials) and over 30 species demonstration trials. Early selections have been made for most of these species and 1st generation seed orchards (hosted by Proseed) and seed stands of *E. bosistoana* and *E. globoidea* are now producing seed. These species were chosen specifically for their timber properties, or their ability to hybridise; with the criteria:

- Class 1 or 2 durability (Australian standard)
- Good growth
- Good stiffness and strength properties
- Drought resistance
- Relatively good frost tolerance
- Ability to coppice
- Established timber potential from experience in Australian markets
- Tolerance and/or resistance to a range of environmental stresses

Within the Specialty Wood Products (SWP) Programme, the focus is on *E. bosistoana, E. globoidea,* and *E. quadrangulata* with some work on *E. argophloia* and *E. tricarpa.* SWP has supported research of site species matching; growth and heartwood modelling and on phenotyping these species. Improved (growth / wood properties) planting stock will be planted in 2021 produced from clones and seed orchards as well as seed stands. Significant markets for the wood have been identified and quantified.

Scion has older research trials of stringybark eucalypts (including *Eucalyptus globoidea*) established to test the suitability of a range of species over a range of sites (Shelbourne et al 2003). Data collected from these trials can identify suitable provenances and siting recommendations. These data have also been used to establish growth and yield models for E. globoidea (Salekin et al. 2020).

Industrial eucalypts

This group of eucalypts has historically been grown due to their high productivity and good form to produce hardwood wood chip for pulp and paper production. Some of these species have the potential to be sawn for solid wood applications, peeled and deconstructed before reconstructing (e.g. OEL). SWP (Specialty Wood Products) has been contributing to research in this area, with successful new flooring, thermal modification, and new seed orchards tailored to solid wood outcomes.

The two industrial eucalypts under research in SWP are *E. nitens* (4th generation, good gains in growth and internal checking) and *E. fastigata* (2-3rd generation, 15% gain for growth and form). *Eucalyptus regnans* breeding is continuing through Scion support, with some SWP support during 2020. This eucalypt was removed from the SWP programme during the mid-term review. This species is in its 3rd generation, with an expected 31% genetic gain for DBH.

All these species are available through seed orchards that are hosted by Proseed and Southwood Export Ltd. There are many other species in New Zealand and the genetic resources of these are summarised in Appendix 1.

Other options

Acacias
Timber from a range of *Acacia* species has an international reputation as a premium decorative timber. Initially promoted in the 1980's by the former NZ Forest Service, *Acacia melanoxylon* was widely planted in small woodlots and a specialist group formed within the Farm Forestry Association who promote this species (AMIGO). Future plantings are unlikely to be large scale, as high-quality sites are required, along with higher pruning costs to produce clearwood. There have been several provenance introductions and testing for an array of *Acacia* species. The best provenances have been identified including data for tolerance to psyllid attack (Shelbourne et al.1996). Improved seed could come from converting research trials to seed stands.

Coast redwoods
Coast redwood has potential to benefit New Zealand, although it is not currently included in the SWP research programme. Approximately 10,000 ha of redwood has been planted (FGR 2020), an area that is likely to be sufficient to supply future NZ markets once the stands mature in approximately 40-50 years. Larch and redwood are included in MPI statistics which show a total planted area of 23,381 ha for softwoods other than radiata, Douglas-fir and cypresses (MPI 2019). The median age of this resource is relatively young, at approximately 15 years (http://www.nzwood.co.nz/forestry-2/redwood/).

Increased plantings would be for export and it would seem there is strong global demand (Simon Rapley, pers. Comm.). Coast redwood cannot replace *Pinus radiata* in existing supply chains. The processing systems and end uses are different, and redwood has distinct wood properties, being a dimensionally stable, naturally durable decorative timber. Coast redwood timber is not commonly used in house construction in New Zealand and could be used structurally by using larger dimension timber. Lower-grade timber could be used to manufacture pallets and packaging.

Poplars
Poplars are an option that is often overlooked, as in New Zealand they are often considered as only trees for farms, although they could be managed for timber production (https://www.poplarandwillow.org.nz/documents/brochure-5-poplars-for-the-farm.pdf). Poplars are used for soil conservation in New Zealand, stabilizing pastoral hill country and riverbanks, and providing shelter and shade on farms. The programme of variety development is run by the Crown Research Institute, Plant & Food Research, and several varieties for different purposes are available. New Zealand grown poplar timber has been sawn and used for truck and trailer decking, stockyards, battens and, when treated, for fence posts. Their lack of resins and gums make them suitable for interior wood products, food packaging and gift packs. Overseas, poplar is used for pulp and paper products, furniture making, as a packaging material and in veneers and panel products.

Indigenous species
New Zealand indigenous tree species are also overlooked in New Zealand as there is a wide-held belief that their growth will be inadequate for planted forests (e.g., Steward et al. 2014 and references therein). Development and planting of indigenous forests fall under the Treaty of Waitangi and are subject to a Treaty Claim – Wai262, which is yet to be fully resolved but relates to the special relationship that Māori have with tāonga species. For this reason, solutions for planting indigenous species should be co-developed with tangata whenua.

All New Zealand indigenous timbers are now sourced from privately owned forests (http://www.nzwood.co.nz/forestry-2/rimu-2/). These forests must be managed to rigorous standards under detailed long-term sustainable management plans. Every forest managed for timber on a sustainable basis has its own individual Ministry of Primary Industries- approved Sustainable Forest Management (SFM) Plan or SFM Permit. All plans and permits are approved and registered under the relevant sustainable forest management provisions of New Zealand law, being Part 3A of the Forests Act 1949 (amended in 1993 to bring an end to unsustainable harvesting and clear felling of indigenous forest) and the Resource Management Act 1991.

Approximately 25,000 m^3 (standing tree volume) or less are felled annually, comprising podocarp like rimu, beech and tawa, all species that are high-quality furniture and finishing timbers. There is an approved annual sustainable harvest of beech (particularly red and silver beech) that is significantly higher than the present national production of about 15,000 m^3 (http://www.nzwood.co.nz/forestry-2/sustainable-forest-management-of-native-tree-species-in-new-zealand/).

A summary of key indigenous species likely to be amenable for future large-scale planting is given in Appendix 2. At this stage, none of the indigenous species are currently ready for large-scale deployment.

Pest and disease risk of key radiata pine contingency species

All species have one or more insect or pathogen challenges of varying degrees of seriousness. These are discussed below, ranked in order of risk starting with the species considered least at risk.

Douglas-fir is affected by Swiss needle cast, caused by *Nothophaeocryptopus gaeumannii*. This defoliating disease was first recorded in the central North Island in 1959. Within a few years it was causing a measurable decline in growth. After 15 years, cumulative reduction in volume increment was 35% in the North Island and 23% in the South Island. The pathogen has spread to wherever Douglas-fir is grown but is not as damaging in areas with cool winters such as Southland and Otago. Red needle cast, caused by *Phytophthora pluvialis*, causes serious defoliation of Douglas-fir in some regions. Nelson and the central North Island are particularly affected. This species is also moderately susceptible to the root rot pathogens *Armillaria* and *Phytophthora cinnamomi*. Overseas, there are several root rot fungi, a bark beetle and some defoliating pathogens that could cause damage if introduced to New Zealand. There have been very few damaging root rot pathogens or bark beetles introduced over the past 60 years and the risk of introduction of a serious pest or pathogen is considered low.

Cypresses are affected by the branch and stem canker fungi *Seiridium cardinale*, *S. neocupressi*, *S. cancrinum* and *S. unicorne*. These pathogens are more damaging on *Cupressus macrocarpa*; *Chamaecyparis lawsoniana*, × *Cupressocyparis leylandii* are moderately susceptible; and *C. sempervirens*, *Thuja plicata* and *Cupressocyparis leylandii* are less susceptible. No insect pests cause significant damage, although the juniper scale *Carulaspis juniperi* and the aphid *Cinara fresai* may reach high populations on individual trees occasionally. The most serious overseas threats to cypresses are *Phytophthora lateralis* that mainly affects *Chamaecyparis lawsoniana* and has killed many trees in their natural range in the Pacific Northwest. Root rot caused by *Armillaria* and various *Phytophthora* diseases have been recorded overseas causing sporadic and localised damage. The cypress aphid, *Cinara cupressi*, has caused serious damage to commercial and ornamental plantings and native stands of *Cupressus* and other cypresses in Europe, Africa, South America and the Middle East. It is the most serious insect threat to cypress in New Zealand. Only two serious cypress pathogens and no serious insect pests have established in New Zealand since cypresses were introduced, as with Douglas-fir the risk of introduction of a serious cypress pest or pathogen is considered low.

It is more difficult to evaluate pest and disease risk to pine hybrids because they are not commonly planted and may not have been deployed on sites where they would come under pest or pathogen pressure. *Pinus radiata* x *P. attenuata* hybrids have been planted in areas suitable for Dothistroma needle blight development and have proved extremely susceptible to that disease. In contrast, hybrids that include *P. tecunumanii* may be resistant (Hodge et al. 2000; Dungey et al. 2003; Roux et al. 2007). *Pinus attenuata* is considered the most susceptible host of *Dothistroma* and this pathogen has ruled out its deployment on sites other than those that are extremely dry and cold. *Pinus* species that are a plausible contingency for *P. radiata* have a wide range of pest and disease risk. *Dothistroma* curtailed planting of *Pinus nigra* var. *laricio* and *P. ponderosa* in most of New Zealand after its arrival in the early 1960s. *Pinus strobus* is very susceptible to the root pathogens *Leptographium* spp. The southern pines (i.e., *P. elliotii*, *P. taeda*), *P. muricata* and *P. pinaster* are resistant to Dothistroma needle blight, but may be susceptible to *Fusarium circinatum*, the pitch canker pathogen. Given pines and pine hybrids comprise such a large and diverse group, it is difficult to make general conclusions other than a damaging new pest or pathogen to *Pinus radiata* may not necessarily be as damaging to other *Pinus* species or *Pinus* hybrids, so this group is promising as a contingency to *Pinus radiata.*

Pest and disease risk of alternative species

Acacia spp are widely established in the Southern Hemisphere outside their native range and have been subjected to a number of pest and disease issues (Wingfield et al 2011). The Australian *Acacia* psyllids *Acizzia acaciae*, *A. uncatoides* and *A. albizziae* are common on *Acacia melanoxylon* and cause malformation and multi-leadering resulting from damage to shoot tips. In New Zealand there are eight rust species in the *Uromycladium* genus affecting Acacia to varying degrees. *Uromycladium alpinum* has caused considerable losses in *A. dealbata* and *A. mearnsii* nursery seedlings. *Uromycladium notabile* forms large galls on branches and stems that cause dieback, and sometimes tree death on *A. dealbata* and *A. mearnsii*. *Uromycladium robinsonii* has been recorded causing severe dieback on *Acacia melanoxylon*. An introduced tortoise beetle, *Dicranosterna semipunctata*, found to cause defoliation on *Acacia melanoxylon*, was first recorded in New Zealand in 2006. Given the number of Australian pests and pathogens on *Acacia* in New Zealand, and New Zealand's proximity to Australia and the opportunity for more pests to be introduced without their natural enemies, the pest and disease risk to *Acacia* would seriously inhibit their usefulness as a contingency species.

The ongoing use of *Eucalyptus* species as plantation trees in regions outside their native range is threatened because of Australian insect pests. Hurley et al. (2016) state that the rate of introductions increased nearly fivefold since the 1980s, and that has doubled the number of exotic eucalypt insect pests outside of Australia in less than three decades. Pests in the natural *Eucalyptus* range are controlled by a range of predators and parasitoids but often those natural enemies do not spread between continents. Burgess and Wingfield (2016) stated most of the introduced pathogens affecting eucalypts outside of Australia are foliage pathogens. Of those in New Zealand and South Africa, many have high genetic diversity suggesting multiple introductions over a long time.

Hood and Bulman (2018) evaluated the biosecurity risk of *Eucalyptus* and came to similar conclusions. *Eucalyptus globulus*, *E. macarthurii* and *E. viminalis*, ash group eucalypts (*E. regnans*, *E. delegatensis* and to a lesser extent, *E. fastigata*), and *E. nitens*, have all suffered from introduced pests and pathogens. Breeding programmes that include health as a key selection criterion are already mitigating damage from existing pests. This approach does, however, require investment and knowledge that is not available for new, or recently deployed species. Experience within New Zealand indicates that introductions of harmful insects and fungi will continue, and eradication is expensive in relation to unknown gains and the high likelihood of further introductions. Nevertheless, some successful biocontrol introductions have been achieved, with a more recent example of *Eadya daenerys* to control the eucalyptus tortoise beetle in New Zealand. Since that report was written in late 2018. Due to the high pest and disease risk, *Eucalyptus* spp. are not favoured as contingency species.

The focus of the current *Eucalyptus* forest health research plan for dryland eucalypts, including the three key species *E. globoidea, E. bosistoana* and *E. quadrangulata,* is on insect pests rather than pathogens. Although pathogens are extremely important, to-date insects have been the main challenge to eucalypt plantation health. Pathogens will be given due consideration if new pathogen threats are identified. In particular, Myrtle rust is 'on the radar' and work on host susceptibility if a pathogen becomes established in New Zealand in the near future can be implemented swiftly. The current work objectives are 1) selection of pest tolerant planting stock in the breeding programme, 2) development of evidence-based recommendations for the monitoring and sustainable management of established pests; 3) identifying biocontrol agents and 4) determining site factors contributing to health plantations (tree health varies greatly between (local) sites with some sites having all key pests presents but in healthy

Leaf rust is the most serious disease of poplars, with species of *Melampsora* and *Septoria* posing a risk to poplars in New Zealand. *Melampsora* leaf rust can cause premature leaf fall and reduce growth, and *Septoria* leaf spot and canker can cause defoliation and stem breakage, and result in the complete loss of susceptible poplar clones. *Melampsora laricis-populina* from Eurasia is present in New Zealand, and selection for resistance is included in the poplar breeding programme at Plant & Food Research. The North American species of *Melampsora* leaf rust and *Septoria* leaf spot and canker are not present in New Zealand or Europe. In North America, selecting for resistance to *Melampsora* leaf rust and *Septoria* leaf spot and canker are included in the poplar breeding programmes.

The *Xanthomonas* bacterial canker is one of the most damaging diseases of poplars in Europe, resulting in branch and stem cankers and dieback. It is not present in New Zealand or North America. In Europe, selection for resistance to *Melampsora* leaf rust and *Xanthomonas* bacterial canker are included in the poplar breeding programmes.

Poplars and willows are affected by four insect pests of potential concern, the poplar sawfly, two sawflies on willows and the giant willow aphid. The giant willow aphid arrived in New Zealand in 2013, and the poplar sawfly was first discovered in 2019. The giant willow aphid has caused significant economic loss to the honey industry and is a pest because the honeydew it produces causes black sooty mould and high wasp populations. It can cause death of some willow species through repeated annual infestation and defoliation. The parasitoid wasp *Pauesia nigrovaria* was released in 2020 to control the giant willow aphid. It is too early to gauge if the poplar sawfly will become a serious pest.

Overseas, rust pathogens that are not currently present in New Zealand, cause defoliation and introductions of these may compromise the successful breeding programme for resistance to the rust species currently present. There are scale insects and mealy bugs that produce honeydew and cause problems similar to those caused by the giant willow aphid.

Poplars bred in New Zealand after 1974 were selected for rust resistance and hybrid poplars are still being developed.

Coast redwood (*Sequoia sempervirens*) is a naturally healthy tree. There are no known pests or disease that can cause death of redwood trees. It is a host for a number of insects and fungi, but none have caused lasting or serious damage.

There is only one New Zealand record of the cypress canker fungus *Seiridium unicorne* on coast redwood. In its natural range in coastal zones of central and northern California, it is reported to have fewer foliar pathogens than any of the other major tree species, although Botryosphaeriaceae fungi have been associated with decline in urban areas. In the nursery, some damage to *Botrytis* can be important and production cultivars must be resistant. Silviculture treatments are used to control any insect damage.

Stocktake of genetic resources

Genetic resources are family-based collections that of the variation within a tree species. These collections aim to capture the range-wide variation of a species. In some cases, it may be a collection from an area of interest. Such a ‘baseline’ collection can involve stands, grafts, cuttings, cryopreserved material and/or seed in seed banks. These collections are important reserves of genetic material and genetic variation and are used as “banks.” These banks can be used to search for traits of interest in the future (e.g., disease resistance), or to initiate breeding and development programmes for commercial use.

On-ground genetic resources are important for New Zealand as our strict biosecurity rules make it quite difficult to import new genetic resources. If species are not already present in New Zealand, this can be even more difficult. An example of this is that the exchange of radiata pine resources into New Zealand is currently not possible via seed, pollen, or any scion material. If New Zealand is to consider species’ development where genetic resources are small, consideration and effort will be needed to unlock the importation pathways.

The last significant review of the genetic resources of species other than radiata was carried out by Gerry Vincent in 1999 (Vincent 2000). This report compared the provenance and progeny testing results from many sources and identified a list of 33 species that had already been grown successfully or had the potential to be used as a contingency species. The main driver of the report was to identify stands of these species with suitable genetics in ex-Forest Service forests, to raise their profile and initiate discussions around seed collections when they were scheduled to be felled, so replacement stands could be planted to maintain the resource. A small number of seed collections have taken place to date and new stands were established. The status of the remaining stands could be ascertained if the species or species group is in the shortlist by asking the current owners of the respective forests if they are still standing, enabling the report to be updated, once the workshop has taken place.

A stocktake of the current PSPs for species other than radiata pine is given in Appendix 1. This stocktake was done based on records only, and it is possible that several of the older stands are no longer in existence. For the purposes of further species’ development, stands/resources will need to be verified before relying on their existence.

From these initial trials, and other research and knowledge of existing eucalypt stands in New Zealand, five key species were selected as the focus for tree improvement work: ***E. bosistoana, E. globoidea, E. quadrangulata, E. argophloia*** *and* ***E. tricarpa****.* All these species are established in the NZDFI’s network of breeding trials.

These breeding populations are located at thirteen different sites. Seven in Marlborough, three in Wairarapa and one in each of Hawkes Bay, Horizons region and Canterbury as shown in the map below. Each breeding population is replicated at three different sites.

In addition, a further six species were established in the NZDFI’s demonstration trial network: *E. camaldulensis, E. cladocalyx, E. eugenioides, E. longifolia, E. macrorhyncha and E. notabilis.*

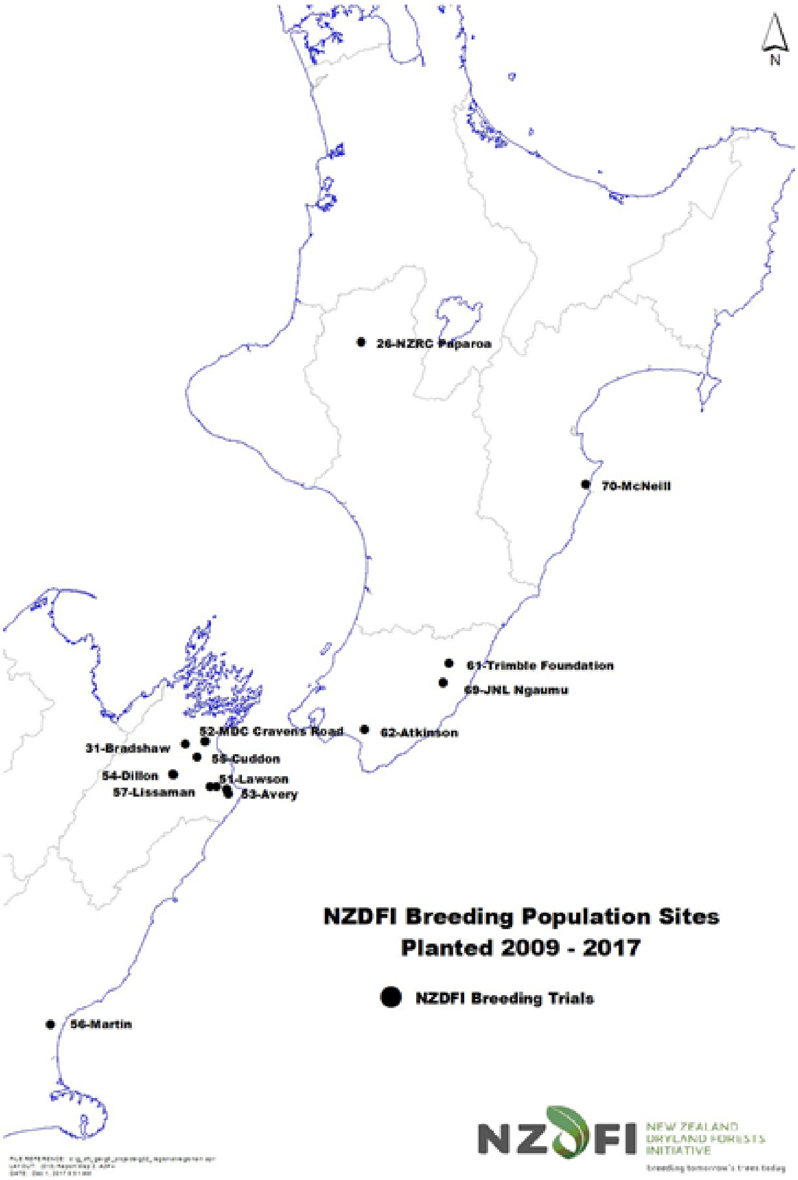

Figure 1: The NZDFI breeding population sites established between 2009 and 2018.

Poplars

Poplars are propagated using clonal propagation from stem cuttings. Plant & Food Research maintain a poplar collection of coppiced stools at Palmerston North, and commercial poplar clones are managed as coppiced stools to produce poles in regional council and private poplar nurseries. Plant & Food Research have 25 poplar species and hybrids in the poplar collection in Palmerston North, comprising 260 poplar clones. Bulking up from the poplar collection would take time unless undertaken rapidly in tissue culture (approximately one year), but for commercial poplar clones there are thousands of stools in nurseries, so planting these at scale could be quickly done in one year or less.

Recommendations and conclusions

Several species that are at the stage of readiness have been identified for consideration as contingency species for radiata pine, from both a biosecurity as well as market risk perspective.

We suggest that a workshop among forest growers and processors representatives should select the final species for further research and development.

We recommend that any work with indigenous trees is in partnership with Māori.

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Appendix 1. Summary of genetic resources

Note – this has been extracted from the PSP system, or contributed by NZDFI. The list is indicative of what may be available, and confirmation that the resources still exist is pending. There will be gene resource stands and trials not captured in this list. An extended review may be needed for species of interest prior to launching into the next steps.

Species			PSP sites	Collection rating (good, medium, poor)	Minimum age	Max age	Comment	Provenance/progeny trials	Breeding programme	N generations of breeding	Seed orchard	Ready to go	5-10 years	10-15 years	15+
Acacias															
Acacia dealbata	Silver wattle	AADLB	7	M	12	34		N	N			*	**	***	***
Acacia melanoxylon	Blackwood	AAMEL	207	G	9	114	many small plots as well	Y	Stalled	0	N	*	***	***	***
Acacia mearnsii	Black wattle	AAMNI	2	P	20	20	High tannin content	N	N					*	*
Indigenous															
Agathis australis	Kauri	AGAUS	78	Native	10	153	Indigenous and taonga	N	N				*	**	***
Podocarpus totara	Totara	PCTOT	60	Native	7	171	Indigenous and taonga. Natural stands & some planted	Y	N				*	**	***
Cyresses/Cedars															
Cedros deodar	Himalayan Cedar	CEDEO	51	M	32	65	Native to the himalayas	N	N				*	*	**
Chamaecyparis lawsonii	Port Orford Cedar	CHLAW	4	P	22	61	Limited but FFA favoured	N	N						
Chamaecyparis obtusa	Hinoki	CHOBT	1	P	24	24	Seed stand	N	N		Y	**	**	***	***
Cryptomeria japonica	Japanese Cedar	CRJAP	49	P	33	67	Mostly on private land	N	N						
Cupressus arizonica		CUARZ	22	P	42	62	Mostly on private land	N	N						
Cupressus leylandii		CULEY	11	P	23	38	Mostly on private land	N	N						
Cupressus lusitanica		CULUS	237	G	11	89	Variety of plots across landowners	Y	Y	3	Y	***	***	***	***
Cupressus macrocarpa		CUMAC	334	G	8	84	Variety of plots across landowners	Y	Y	4	Y	***	***	***	***
Cupressus mixed spp		CUMIX	38	M	11	18	Mostly forest blocks	N includes hybrids	Y	0-2	Y	**	***	***	***
Cupressus ovensii		CUOVI	30		7	17	Variety of plots across landowners	N a hybrid	Y	1		***	***	***	***
Eucalypts															
Eucalyptus argophloia		EUARG	?	M	?	?	Secondary breeding programme NZDFI	Y	Y	0-1	See below	?	?	?	?

Species		PSP sites	Collection rating (good, medium, poor)	Minimum age	Max age	Comment	Provenance/progeny trials	Breeding programme	N generations of breeding	Seed orchard	Ready to go	5-10 years	10-15 years	15+
Eucalyptus bosistoana	EUBOS	?	G	~8	Not known	Progeny trials/breeding programme	Y	Y	0-1	Y	**	***	***	***
Eucalyptus cladocalyx	EUCLA	?	M	?	?	Secondary breeding programme NZDFI	Y	Y	0-1	See below	?	?	?	?
Eucalyptus delegatensis	EUDEL	35	P	35	66	Not likely to be extant	N	On hold	0			*	*	**
Eucalyptus fastigata	EUFAS	98	G	7	53	Older sites not likely to be extant; breeding programme Scion	Y	Y	3-4	Y	***	***	***	***
Eucalyptus nitens	EUNIT	190	G	6	44	Older sites not likely to be extant; breeding programme Scion	Y	Y	2-4	Y	***	***	***	***
Eucalyptus regnans	EUREG	69	G	11	62	Older sites not likely to be extant; breeding programme Scion	Y	Y	4	Y	*	***	***	***
Eucalyptus fraxinoides	EUFRA	9	P	26	54	Small collection status unknown	N	N					*	*
Eucalyptus globoidea	EUGLA	29	P	17	38	Small collection (Scion), breeding programme (NZDFI)	Y	Scion:On hold NZDFI: Y	0-1	Y	***	***	***	***
Eucalyptus globulus series	EUGLO; EUMAI	25 GLO; 49 MAI	M	16	29	Small collection	Y	N				*	*	**
Eucalyptus quadrangulata	EUQUA	1	P	18	18	Small collection (Scion), breeding programme (NZDFI)	Y	Scion:On hold NZDFI: Y	0-1	Y	**	***	***	***
Eucalyptus macrorhyncha	EUMAC	?	M	?	?	Secondary breeding programme NZDFI	Y	Y	0-1	See below	?	?	?	?
Eucalyptus microcorys	EUMIC	2	P	24	28	Small collection	Y	N				*	*	*
Eucalyptus muelleriana	EUMUL	10		22	36	Some	Y	On hold				*	**	**
Eucalyptus pilularis	EUPIL	17	G	22	58	Good for warmer sites	Y	On hold	0-1?	Y	*	**	**	***
Eucalyptus saligna	EUSAL	60	M	13	64	Older sites not likely to be extant	Y?	On hold	0	Y	*	**	**	***
Eucalyptus tricarpa	EUTRI	?	M	?	?	Secondary breeding programme NZDFI	Y	Y	0-1	?	?	?	?	?
Miscellaneous														
Juglans nigra	JUNIG	67	P	49	31	Mostly on private land; some seed source trials	N	N				*	*	**
Pseudotsuga menzeisii	PSMEN	685	G	6	155	Douglas-fir	Y	Y	0-1	Y	***	***	***	***
Sequoia sempervirens	SQSEM	205	Unknown	7	119	Coast redwood- managed usually as clones	?	Clonal tests		Y	clonal			
Salix various	SX	14	M	x15	15	Private	?	N				*	**	**

Species		PSP sites	Collection rating (good, medium, poor)	Minimum age	Max age	Comment	Provenance/progeny trials	Breeding programme	N generations of breeding	Seed orchard	Ready to go	5-10 years	10-15 years	15+
Larix spp; L. eurolepis; L. decidua; L. kampferi	L.DEC; L.KAE; L.MIX; L.EUR	9	P	39	105	Small collections; some hybrids	Some	N					*	*
Picea sitchensis; P. abies; P. magnifica; P. omorika	NO PSPs					Prov collection; would need to check still extant; omorika not likely to be extant.	Y	N					*	*
Abies spp; A. grandis; A. concolor; A. magnifica; A. procera	NO PSPs					Plots of diff spp some provenance trials	Some	N				*	*	*
Robinia pseudoacacia	NO PSPs					Needs checking on status	Some	N				*	*	*
Liriodendron tulipifera	NO PSPs					Needs checking on status	Some	N				*	*	*
Cunninghammii lanceolata	NO PSPs					Needs checking on status	Some	N				*	*	*
Chamaecyparis thyoides	NO PSPs					Needs checking on status	Some	N				*	*	*
Alnus spp; A. rubra; mix	NO PSPs					Needs checking on status	Some	N				*	*	*
Pines														
Pinus contorta	P.CON	1	P	59	59	Not welcome in areas of wilding risk	N?	N				**	***	***
Pinus ayacahuite	P.AYA	2	P	52	52	For felling some seed collected	Some	N				*	*	**
Pinus attenuata and attenuradiata	P.ATE	132	M	5	5	High cold sites only; includes hybrids	Provenance test felled some selections available	Y some but involved in hybrids with radiata			**	**	***	***
Pinus brutia	P.BRU		P	39	39	Dry sites. 2 small trials only.	Some	N				*	**	***
Pinus douglasiana	P.DOU		P	58	58	Observation plots	N	N					*	*
Pinus durangensis	P.DUR		P	60	58	Prov trial small collection	Y	N					*	*
Pinus greggii	P.GRE		P	57	57	Observation plots; selected grafts	Some	N			*	*	**	***
Pinus hartwegii	P.HAR		P	56	57	Observation plots	Some	N				*	*	*
Pinus lambertiana	P.LAM		P	?	61	Observation plots	N					*	*	*
Pinus lawsonii			P	58	58	Observation plots	N						*	*
Pinus leiophylla			P	57	57	Observation plots; likely felled	N						*	*
Pinus massoniana			P	57	57	Observation plots	N						*	*
Pinus michoacana			P	56	58	Observation plots	N							*

Species		PSP sites	Collection rating (good, medium, poor)	Minimum age	Max age	Comment	Provenance/progeny trials	Breeding programme	N generations of breeding	Seed orchard	Ready to go	5-10 years	10-15 years	15+
Pinus montezumae			P	56	60	Observation plots + some provenance	Some	N					*	*
Pinus muricata	P.MUR		M	7	37	Planted stands/plots	Y	N			*	**	***	***
Pinus nigra	P.NIG	65	M	27	77	Some small collections	Some	N					*	*
Pinus patula	P.PAT		P	58	58	Observation plots	Some	N					*	*
Pinus pinaster	P.PIN		M	12	19	Progeny trials exchange NZ/France	Y	N				*	**	***
Pinus ponderosa	P.PON	30	P	27	92	Some provenance collections	Some	N				*	**	***
Pinus pseudostrobus			P	52	61	Observation plots	N	N					*	*
Pinus rudis			P	52	57	Observation plots; likely felled	Some	N					*	*
Pinus taiwanensis			P	57	57	Observation plots	N	N					*	*
Pinus teocote			P	56	57	Species trial	Some	N					*	*
Pinus virginiana			P	58	58	Observation plots	N	N					*	*
Pinus sylvestris	P.SYL	1	P	83	83	Single stand	N	N						*

Sources: SWP website (https://fgr.nz/programmes/alternative-species/ ; https://fgr.nz/wp-content/uploads/2018/04/SWP-Programme-Description.pdf); Scion PSP database; www.nzdfi.org.nz; https://www.poplarandwillow.org.nz/documents/brochure-5-poplars-for-the-farm.pdf;

+Note, this Appendix is based on PSPs and does not include trial series. There are extensive trial series of Douglas-fir, eucalypts, and other species. Further details of these will need to be determined once the final species shortlist is determined. Such trial series include the Scion/FFA stringybark trials that included species such as *E. baxteri, E. blaxlandii, E. cameronii, E. globoidea, E. laevopinea, E. longifolia, E. macrorryncha, E. maculate, E. microcores, E. muelleriana, E. obliqua, E. pilularis, E. youmanii* and *E. fastigata* and other controls. In addition there is a trial series that includes *E. globulus* and its subspecies.

Species	No. of PSPs	Collection rating (not clear)	Min age as at 2020	Max age as at 2020	Comment	Provenance/progeny trials	Breeding programme	N generations of breeding	Seed orchard	Ready to go Seed available but not for 5000ha/annum	5-10 years	10-15 years	15+
NZDFI species of interest													
E. argophloia	31		6	10		Yes	Yes	1					
E. blaxlandii	1		14	14	Unpedigreed, mixed or single provenance								
E. bosistoana	93		2	17		Yes	Yes	1	CSO, SSO	Yes	Yes	Yes	Yes
E. camaldulensis	48		6	9	Unpedigreed, mixed or single provenance								
E. cladocalyx	51		2	13	Unpedigreed, mixed or single provenance								
E. cornuta	5		9	9	Unpedigreed, mixed or single provenance								
E. eugenoides	28		9	9	Unpedigreed, mixed or single provenance								
E. fastigata	2		9	9	Unpedigreed, mixed or single provenance								
E. globoidea	76		2	16		Yes	Yes	1	CSO, SSO	Yes	Yes	Yes	Yes
E. longifolia	37		6	9	Unpedigreed, mixed or single provenance								
E. macrorhyncha	49		6	15					SSS	Yes	Yes	Yes	Yes
E. maculata	1		9	9	Unpedigreed, mixed or single provenance								
E. microcorys	2		9	9	Unpedigreed, mixed or single provenance								
E. muelleriana	3		9	9	Unpedigreed, mixed or single provenance								
E. notablis	16		9	9	Unpedigreed, mixed or single provenance								
E. pilularis	2		9	9	Unpedigreed, mixed or single provenance								
E. quadrangulata	61		2	13		Yes	Yes	1			Yes	Yes	Yes
E. saligna	3		9	9	Unpedigreed, mixed or single provenance								
E. sphaeracarpa	2		9	9	Unpedigreed, mixed or single provenance								
E. tricarpa	53		6	9		Yes	Yes	1			Yes	Yes	Yes
P. radiata	5		9	9	GF19								
Eucalypt Mix	2		9	17									

Current status of NZDFI breeding populations at March 2020

PlantYr	Landowner	Species	Trial	Surround (No. Planted)	Mass selection	Grand Total
2009	Martin	E.bosistoana	1336			1336
	Lawson-A	E.bosistoana	2852			2852
	Lawson-B	E.bosistoana	264			264
	MDC Cravens	E.bosistoana	223			223
2010	Avery	E.bosistoana	1103	400		1503
		E.argophloia	270	150		420
	Martin	E.bosistoana	1115	300		1415
	MDC Cravens	E.bosistoana	207	350		557
2011	Atkinson	E.globoidea	3444	1300		4744
	Avery	E.cladocalyx		50		50
		E.globoidea	5300	650		5950
		E.tricarpa	600	750		1350
	Martin	E.quadrangulata	920	400		1320
	Cuddon	E.argophloia	899	250		1149
		E.quadrangulata	795	200		995
	Dillon	E.argophloia	912	160		1072
		E.tricarpa	480	300		780
	McNeil	E.quadrangulata	921	300		1221
	JNL Ngaumu	E.argophloia	950	300		1250
		E.globoidea	1917	1800		3717
	Trimble	E.tricarpa	720	200		920
		E.quadrangulata	900	448		1348
2012	Dillon	E.bosistoana	2890	1312		4202
	McNeil	E.bosistoana	4075	820		4895
		E.cladocalyx			1800	1800
	JNL Ngaumu	E.bosistoana	4548	400		4948
		E.cladocalyx			4200	4200
2016	NZRC Paparoa	E.quadrangulata	3096	700		3796
	Webb	E.quadrangulata	0	0		0
	Bradshaw	E.quadrangulata	3600	1316		4916
2017	Dillon	E.tricarpa	870			870
	Lissaman	E.bosistoana		250		250
		E.tricarpa	870			870
2018	Dillon	E.bosistoana	620	240		860
	MDC Northbank	E.bosistoana	1568	410		1978
Grand Total			**48265**	**13756**	**6000**	**68021**

Appendix 2: Summary of the likely best indigenous trees for planting.

Tanes Tree Trust list the indigenous tree species that they believe are the timber trees of the future (https://www.tanestrees.org.nz/species-profiles/ [TTT]). These are summarised below (from the website) as well as drawing from summaries from the key species on the NZ wood website (http://www.nzwood.co.nz/forestry-2/lc-timber-species-indigenous-species/ [NZW]).

(Adapted from TTT and NZW).

Name		Author
Red beech (*Nothofagus fusca*)	Red beech is sourced from sustainably managed forests. It is stable and suitable for interior joinery, decking, cladding and flooring. The fine, even texture of the timber makes it most suitable for turning into dowels and brushware. Being hard wearing, it is also suitable as stair treads and flooring. As a flooring timber, it has an attractive, figurative appeal and lustre, and is significantly harder and more resistant to impact than alternative softwood species, such as rimu and matai.	NZW
Silver beech (*Nothofagus menziesii*)	Silver Beech Silver beech is sourced from sustainably managed forests and is becoming the favoured wood to replace rimu as the prime native species. It is excellent for turnery and cabinetry, and particularly good in brushes and dowels. It also is renowned for its steam-bending properties and was once used widely for motor body building.	NZW
Black beech (*Nothofagus solandri)*	Black beech was used in house construction for framing, flooring, subflooring, and panelling, and in framing and constructional use in fence posts, gates, rails, bridges, and piles. The limited quantities now available are used where the timber's stability, machining properties and appearance are paramount, such as for tool handles, furniture, exposed floors, panelling, and bench tops.	NZW
Black maire (*Nestegis cunninghamii*)	Has potential for many high-value uses, particularly in veneer and turnery but also cabinet making for which it seems to have been little used in recent years. Just why huge quantities were used as firewood when it had higher value for other uses is unknown. One can only hope that only low-grade wood was burnt.	TTT
Hinau *(Elaeocarpus dentatus)*	The wood is light brown in colour, tough, strong but non-durable, although the black heart will last up to 25 years in the ground. Being of similar colour, the sap and heartwood cannot easily be distinguished from each other although the heart is slightly more durable than the sap, lasting up to 10 years in the ground. Sap and heart are moderately resistant to pressure treatment but can be treated. The wood has a fine even texture which dries, machines, and finishes well.	TTT
Kahikatea *(Dacrycarpus dacrydioides)*	Easy to establish and grow and its relatively fast growth and potential for many uses when treated, suggests that kahikatea should be given greater prominence than it is. Because of its prolific fruiting habit, it is also important for biodiversity.	TTT
Kaikawaka *(Libocedrus bidwillii)*	May have uses where lightness and moderate durability are desirable e.g., roof shingles.	TTT
Kanuka *(Kunzea ericoides)*	Can be a nurse for and podocarps, for firewood or for carbon and/or timber production. The spp can be grown to produce honey and essential oils	TTT
Kauri *(Agathis australis)*	A versatile timber. Post WW2, the timber was reserved for boat building, due to diminishing supplies. Recovered kauri	NZW

	from swamps makes a most interesting turnery timber, and recycled kauri from old buildings is excellent for carving and can hold a fine edge. Second-growth and plantation timbers are suitable for all interior purposes where a moderately dense softwood species is suitable and makes an excellent furniture timber. Easily peeled or sliced for veneering purposes.	
Manoao *(Halocarpus kirkii)*	The species is worthy of study because of its durable attributes but nothing done in a forestry context. Chemical extracts are used in the perfume industry.	TTT
Matai *(Prumnopitys taxifolia)*	Excellent durable timber properties but very slow growing.	TTT
Pink pine *(Halocarpus biformis)*	Has high durability and chemical extracts are used in the perfume industry.	TTT
Pohutukawa *(Metrosideros excelsa)*	Good timber and growth potential although lacking in form.	TTT
Pukatea *(Laurelia novae-zelandiae)*	A potentially fast growth rate and lack of damaging agencies, together with the straight and tall natural form of the tree, indicates it could be one of the more useful of our hardwood species. It is an easily worked, stable and light timber and, although not naturally durable, is relatively tough and resistant to marine borer.	TTT
Puriri *(Vitex lucens)*	Durable, dense, and strong; potential for furniture and decorative purposes. Although frost tender as a seedling, it is one of the faster growing indigenous hardwoods. The drawback is that it is attacked by the puriri moth.	TTT
Rewarewa *(Knightia excelsa)*	Potential to be a fast-growing timber tree which, on the right site, could produce good-quality timber for specialist uses including veneer. Multi-leaders can occur in planted stands.	TTT
Rimu *(Dacrydium cupressinum)*	Rimu is one of the most popular of our native timbers. Because it was used extensively in older character homes as both a structural and finishing timber, it is probably New Zealand’s best-known native species. Rimu has been proven as a remarkably versatile and exceptionally beautiful timber. Good supplies of recycled rimu are available from a range of suppliers and demolition timber yards. Rimu timber can also be sourced from sustainably managed forests.	NZW
Tanekaha *(Phyllocladus trichomanoides)*	High quality timber, regenerates especially under kauri. Expected that faster growth and better wood quality will result under optimum conditions, but these are still to be well defined for planting	TTT
Tawa Beilschmiedia tawa	Tawa is an excellent furniture timber, its strength properties make it suitable for handles and rods, and it is particularly good for turnery across the grain such as in doorknobs. Tawa is an interior finishing timber, and not suitable for exterior uses. Both the heartwood and sapwood are classed as Perishable and will last less than five years in the ground.	NZW
Totara (*Podocarpus totara)*	Totara has been the most widely planted native conifer in New Zealand with small plantations established from the early 1900s. Seedlings are easily raised in large numbers in nurseries and transplant well to a range of planting sites. There is a wide variation in growth rates due to differences in site type, management history and stocking rate. Growth modelling of a limited number of stands indicates that while growth is initially slow, it does accelerate during the pole phase with significantly higher volume growth compared to unmanaged dense naturally regenerated stands.	TTT

Appendix 3: Terms of Reference.

The Forest Grower's science and innovation strategy review has identified that as a result of climate change, increased trade and international tourism that there is likely to be an increased biosecurity risk to our mainstream commercial forestry species. If this is confirmed a consequence may need to be an increased focus and investment on alternative species and contingency species for our current radiata pine and Douglas-fir commercial forestry estate.

As a first step the FRC wish to commission a strategic review of the biosecurity risks facing the radiata pine and Douglas-fir forest estate to determine if the overall risks and exposure have increased relative to earlier assessments.

Phase One – risk assessments for the current radiata pine estate.

Current conclusions from Phase one:
Implications of results for the client
Switching from monocultures to mixed forests or stands has many benefits, which will need to be explored before any formal decision is made. Fortunately, with our current biosecurity measures, the changes in trade trends and the exploration and implementation of improved technologies for biosecurity, there is time to investigate whether forest diversification makes sense. Forest diversification may involve replacement of radiata pine or Douglas-fir with alternative species, deployment of mixed species (with or without the current two main species) in stands or forests, and a broadening of the gene pool within one species. One form of diversification may be more feasible or attractive to growers than another. If current biosecurity measures, including pathway management are being continually updated, we could limit the risk associated with the ever-increasing list of pest and pathogen threats. While we are able to limit the invasion of many of these pests and pathogens already, some may slip through and forest diversification may be an additional strategy that could further safeguard our estates.

Further work
If mixed forests or stands are considered from a forest management perspective, we would need to look at a number of factors:

1. Which tree species could we use as an alternative species? This would depend on the industry's needs (wood properties, growth, form, etc.), their suitability to various sites, and their susceptibility to pests and pathogens already in New Zealand.
2. Where can germplasm for breeding and massive propagation be sourced?
3. Where and how to deploy these species – alternate species in monoculture or in mixed stands?
4. Will all our stands be mixed, or can we look at mixed stands as buffers to pathways?

An adoption of this strategy will require planning and a number of pilot studies to answer some of these questions. Models are also useful to help test certain scenarios and make predictions to save time, money and effort. We should explore the use of alternate species to supplement or replace radiata pine while improvements are made to our current biosecurity frameworks.

Diversification is only one approach to mitigate biosecurity risk. Technologies to reduce pest establishment and reduce impact is another. Both will be briefly described and evaluated in the phase 2 report.

Terms of Reference for Phase 2:

1. The FRC envisaged that a Stage Two report would focus on the species diversification component of risk mitigation rather than the broader risk mitigation measures.

2. **Identify potential contingency specie(s)** in the event of a significant and serious biosecurity event impacting our commercial radiata and Douglas-fir forests **that takes account of known performance in NZ, siting limitations, silvicultural considerations, disease and pest limitations and ability to deal with changing climatic conditions.** The selections should be **further prioritised by consideration of wood properties, market uses and ability to fit into existing industrial scale market supply chains, potential for genetic improvement and lead times.**

3. For the potential contingency species, **undertake a stock take of genetic resources** here in NZ, the security of the genetic resources, **seed sources** and a status summary of **growing from nursery through to establishment including weed control** and **what would be needed to scale up to commercial scale plantings and likely time frames**. **Hybrids in pines and other species should be included.**

4. Other species have the potential to meet alternative market opportunities that cannot be satisfied with radiata or Douglas-fir – active research is currently limited to redwoods, cypress species and hybrids, *Eucalyptus nitens, Eucalyptus fastigata, Eucalyptus regnans* and the selection of naturally durable *Eucalyptus* species in the Drylands Forests Initiative program. There is also research into native species establishment and totara management in Northland and a poplar breeding program run through Plant and Food Research that the industry has limited engagement with. Based on known performance in New Zealand **are there other species that should be added and are there any in the current research program that should be dropped. A similar stocktake of the security of seed sources, genetic improvement status, wood quality and end use/market demand/acceptance issues should be included.**

5. The project will need to include input from other parties who have trials and knowledge of other species in New Zealand including **Farm Forestry Association, NZDFI, NZ Redwood Company, Plant and Food and Tane's Tree Trust.**

6. The budget allocation for the project is $25,000 plus GST with completion of a draft report by the 30th October and final report by the 30th November.

7. It is envisaged that the Stage One and Stage Two reports along with existing knowledge and reports of the Farm Forestry Association and others would form the basis for a wider symposium involving government and industry to develop a comprehensive strategy for other species.