

A review of kōwhai (*Sophora* spp.) and its potential for commercial forestry

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Abstract

Background: Demand for imported sawn timbers in New Zealand has increased over the last decade, reflecting the lack of New Zealand-grown, naturally durable timber in the domestic market. Therefore, a market opportunity exists for sustainably grown, naturally durable timbers in New Zealand for specialty applications. Kōwhai (*Sophora* spp.) are New Zealand native tree species, known for their bright, yellow flowers and reported to produce coloured, naturally durable heartwood.

Methods: Information on kōwhai was collated from literature, focusing on their potential for commercial forestry. The taxonomic relationships, species descriptions, establishment, and growth rates of kōwhai were examined, along with timber properties and historical uses, as well as medicinal applications. The review identified potential market opportunities for kōwhai and key areas for further research.

Results: Kōwhai refers to eight different *Sophora* species that are endemic to New Zealand. Kōwhai is easily established and the different species hybridise readily. While growth and form of kōwhai varies with species, site, and management, examples of straight single-stemmed trees and annual diameter increments exceeding 20 mm have been found. Kōwhai timber properties might be comparable to those of teak (*Tectona grandis* L.f.). Kōwhai contains alkaloids, a class of compounds used in pharmaceutical applications. The species have been used for timber and traditional medicine by Māori in the past, while European settlers used kōwhai for their durable and flexible timber.

Conclusions: Kōwhai could be established as a sustainable, domestic source of high-quality timber and substitute imported specialty timbers in New Zealand on account of their natural durability, strength, stiffness, colour, and density properties. The residues could support a secondary industry, as a source of alkaloids for pharmaceutical applications or natural dyes. Key areas that require further study include growth rates and silviculture, mechanical timber properties, machining/processing characteristics, natural durability and cytosine levels in kōwhai, as well as the cultural, economic, and ecological framework required for a commercial kōwhai forestry industry. Lack of literature on, and expertise in the use of native timbers in general are barriers to promoting native species for commercial forestry in New Zealand.

Keywords: heartwood, indigenous forestry, natural durability, native forestry, specialty timbers, timber properties

Introduction

Kōwhai (*Sophora* spp.) trees are well-known throughout New Zealand for their attractive foliage and beautiful, bright yellow flowers, and are considered the country's unofficial national flower (Salmon 1980; Wardle 2011). Though commonly planted in parks and gardens as ornamental species in current times, kōwhai were used in the past by Māori and European settlers for timber

and other applications. The timber was hailed for its durability, strength, and flexibility (Blair 1879; Kirk 1889), but the use of kōwhai timber decreased with the decline of native forest cover and availability of suitable trees (Howard 1951). The Forest Amendment Act 1993 ensured that the unsustainable logging of native forests was halted, and timber from exotic plantations, particularly *Pinus radiata* D. Don, has long supplanted

native timber. However, the current domestic plantation resource does not satisfy the demand for coloured or naturally durable timbers.

New Zealand's wood product imports have increased by about 70% over the last decade (Jones 2020). The volume of high value hardwood sawn timber imports has increased from 22,000 m³ to 26,000 m³ from 2013 to 2018 (Ministry for Primary Industries 2021b), valued at more than \$50 million NZD annually. There are ongoing concerns about the legality and sustainability of the sources of timber being imported into New Zealand (Jones 2020). Currently, New Zealand has no legislation to prevent the import, export, or trans-shipment of illegally harvested wood, unlike some key forestry trading partners such as Australia, the United States, or the countries in the European Union (EU). However, in New Zealand, there is a government wood procurement policy that requires government departments to procure timber and wood products only from legal and sustainable sources (Ministry for Primary Industries 2020b). New Zealand has also begun to develop a policy to address illegal logging (Ministry for Primary Industries 2020a) and the forestry industry has been working on establishing a definition of legality for New Zealand-grown wood products.

Interest in planting native tree species for a wide range of purposes, typically focusing on habitat restoration, is increasing in New Zealand. The focus of Te Uru Rākau/Forestry New Zealand, includes indigenous forestry (Ministry for Primary Industries 2021a), reflecting in part the aspirations of Māori, who are becoming the largest owners of privately-owned forest land in New Zealand. Native forest species are compatible with commercial aspects of forestry, as evidenced by New Zealand's established silver beech (*Lophozonia menziesii* (Hook.f.) Heenan et Smissen) industry (Olson 2004) and the emerging Tōtara Industry Pilot project (Tōtara Industry Pilot 2020). Other native species, such as kōwhai have the potential to become commercial forestry species in New Zealand to meet the demand for specialty timbers. Kōwhai may be promising species for commercial forestry in New Zealand because they produce coloured heartwood, which is anecdotally naturally durable. Kōwhai are assumed to have Class 2 in-ground durability, lasting at least 20 years in service, though this has not formally been tested (T. Singh, personal communication, June 22, 2020).

This review summarises the available literature on kōwhai including taxonomic relationships, species descriptions, information on the establishment and threats of kōwhai, along with the available data on the growth and form of the species. The known timber properties of kōwhai as well as the historical uses of kōwhai by Māori and European settlers are covered before potential markets are explored. From this, key areas where research is lacking are identified.

Literature review

Taxonomic relationships

The name 'kōwhai' collectively refers to eight species in the genus *Sophora* that are endemic to New Zealand

(Thomas & Spurway 2001). The genus *Sophora*, which is part of the nitrogen-fixing Fabaceae family, is comprised of about 45 species of small shrubs and trees that are native to Asia, Australasia, the Pacific Islands, South America, and the United States (iNaturalist Network 2020). *Sophora* species are known for their emetic and intoxicating properties and some species are used for medicinal applications (Tipa 2018). *Sophora* species are also planted as ornamentals around the world. For example, *Sophora cassioides* (Phil.) Sparre is an ornamental species in Chile (Hoffman 1982), while *S. secundiflora* (Ortega) DC., which produces violet flowers, is a common landscape plant in Texas, United States (Forrester et al. 2020).

The species that are endemic to New Zealand are among the 19 species in the *Edwardsia* section which are distributed around the South Pacific. Of these, eight species are endemic to New Zealand, two are native to Chile, two are found on Juan Fernández Islands, and the seven other species are on islands in the Pacific and Indian Oceans (Mitchell & Heenan 2002). *Sophora toromiro* Skotts., a species from this section endemic to Rapa Nui (Easter Island), was reintroduced after extinction in the wild with plants raised from seed that was collected in the 1960s, by Thor Heyerdahl (Shepherd et al. 2020). The seeds of the *Sophora* species in the *Edwardsia* section are buoyant and can retain their viability in seawater, which has facilitated their dispersal around the South Pacific (Mitchell & Heenan 2002; Sykes & Godley 1968).

Historically, only three kōwhai species were recognised in New Zealand but after taxonomic revision by Heenan et al. (2001), five more species were recognised, namely *Sophora chathamica* Cockayne, *Sophora fulvida* (Allan) Heenan et de Lange, *Sophora godleyi* Heenan et de Lange, *Sophora longicarinata* G.Simpson et J.S.Thomson, and *Sophora molloyi* Heenan et de Lange. Consequently, historical information on kōwhai and their properties should be examined critically, as past records tend to only refer to three species (*S. microphylla* Aiton, *S. tetraptera* J.Mill, and *S. prostrata* Buchanan) and considered the other five species as variants of *S. microphylla*, with the variation in morphology being attributed to geographic variation.

Sophora microphylla and/or *S. tetraptera* were also thought to occur in Chile and Gough Island in the past. For example, Hoffman (1982) refers to *S. microphylla* being used in small quantities in Chile. Since the taxonomic revision by Heenan et al. (2001) it is now known that occurrences of what was thought to be *S. microphylla* or *S. tetraptera* in Chile were actually *S. cassioides* (pelú), a species native to Chile.

Species descriptions

Sophora chathamica (Chatham Island kōwhai or coastal kōwhai) occurs naturally on the west coast of the North Island. It can also be found around Wellington Harbour and on the Chatham Islands, though these occurrences were probably the result of deliberate plantings by Māori in the 18th and 19th centuries for ornamental and medicinal purposes (Heenan et al. 2001; Molloy 2002). The species occurs in coastal or lowland areas, and is

one of the larger kōwhai species, growing up to 20 m in height. The conservation status of this species is 'Not Threatened' (New Zealand Plant Conservation Network 2020).

Sophora fulvida (West Coast kōwhai or Waitakere kōwhai) occurs naturally in coastal areas around the Auckland, Northland, and Waikato regions (Wardle 2011). *Sophora fulvida* can be found on open or disturbed sites, basaltic and rocky outcrops, or as part of coastal shrubland. The species grows between 4 to 10 m tall and has been classified as 'Chronically Threatened' due to its restricted range (New Zealand Plant Conservation Network 2020).

Sophora godleyi (Godley's kōwhai or Rangitikei kōwhai) occurs naturally in the west of the North Island from the Taranaki region to the Manawatu-Wanganui region (Heenan et al. 2001) on limestone, siltstone, sandstone, and calcareous mudstone. It is one of New Zealand's larger kōwhai species, growing up to 25 m in height. This species is considered to be 'Not Threatened' in New Zealand (New Zealand Plant Conservation Network 2020).

Sophora longicarinata (limestone kōwhai) occurs naturally in the upper South Island in the east of the Nelson region and the southwest of the Marlborough region in lowland or montane forests, on marble or limestone outcrops (Wardle 2011). It has a shrub or tree form growing to a height of 6 m, and reaches a diameter of 20 cm. *Sophora longicarinata* has been identified as an 'At Risk' species in New Zealand, due to its limited range (New Zealand Plant Conservation Network 2020).

Sophora microphylla (common kōwhai, small-leaved kōwhai, weeping kōwhai or South Island kōwhai) is the most widely distributed kōwhai species in New Zealand, occurring naturally all around the country (Clifton 1990; Wardle 2011). This species occurs in lowland and montane forests from sea level up to an altitude of 800 m on the margins of rivers and lakes, coastal sites, open sites, and along forest margins on relatively fertile soil (Tāne's Tree Trust 2020). *Sophora microphylla* can grow to a height of 10 to 12 m and reach a diameter of up to 60 cm (Tipa 2018; Wardle 2011). This species is 'Not Threatened' due to its wide occurrence (New Zealand Plant Conservation Network 2020).

Sophora molloyi (Cook Strait kōwhai) occurs around the Cook Strait as well as on Kapiti Island on dry, windy, and exposed bluffs. *Sophora molloyi* has a bushy habit and is generally wider than tall, growing up to 3 m in height. The species is classified as 'At Risk' because of its limited natural range (New Zealand Plant Conservation Network 2020).

Sophora prostrata (prostrate kōwhai or dwarf kōwhai) is endemic to the eastern South Island from Marlborough to south Canterbury, and is common on Banks Peninsula (Tipa 2004). *Sophora prostrata* has a shrub form and retains dense, divaricating branches throughout its life. It can grow up to 2 m tall. This species is considered 'Not Threatened' (New Zealand Plant Conservation Network 2020).

Sophora tetraptera (large-leaved kōwhai, North Island kōwhai, or eastern kōwhai) occurs naturally on

the eastern side of the North Island from East Cape to Wairarapa but can be found planted all over New Zealand due to its popularity as an ornamental (Manatū Taonga Ministry for Culture and Heritage 2021; Wardle 2011). *Sophora tetraptera* occurs in coastal and lowland forests from sea level up to 450 m in altitude on streamsides and forest margins. It does not grow well on open sites or waterlogged soils, and generally requires moister sites than *S. microphylla* (Wardle 2011). The species grows up to a height of 12 m and can reach a diameter of 60 cm. Although there have been past reports of *S. tetraptera* reaching up to 90 cm in diameter in the Southland region (Blair 1879), these reports may have been referencing another kōwhai species as the natural distribution of *S. tetraptera* is in the North Island. Due to its popularity as an ornamental, the conservation status of *S. tetraptera* is 'Not Threatened' (New Zealand Plant Conservation Network 2020).

Establishment and threats

Kōwhai are easy to establish and can grow on most soils so long as they are not waterlogged. They can be propagated directly from seed or from cuttings, and are easily transplanted (Thomas & Spurway 2001; Wardle 2011), which is a key requirement for commercial forestry. High survival rates for plantings have been reported (Meason et al. 2020). These species are light demanding, though they can tolerate partial shade (Wardle 2011). Kōwhai fixes nitrogen (N) in root nodules, enabling them to be grown on low fertility sites (Thomas & Spurway 2001). Kōwhai is said to be able to tolerate a wide range of conditions, such as frost, wind and drought (Wardle 2011), though this statement may only apply to some of the kōwhai species, as it is known that *S. fulvida*, *S. godleyi* and *S. longicarinata* are restricted in distribution and prefer base-rich soils derived from limestone or volcanic rock (Thomas & Spurway 2001; Wardle 2011). Two species, *S. microphylla* and *S. tetraptera* are known to be frost-hardy and drought-tolerant, though *S. microphylla* is hardier than *S. tetraptera* (Tipa 2018; Wardle 2011). Kōwhai hybridise readily. Hybridisation and introgression occurred naturally before human disturbance, with bird pollinators such as tūī (*Prosthemadera novaeseelandiae*) or bellbirds (*Anthornis melanura*) facilitating hybridisation between sympatric species (Heenan et al. 2018). However, with the widespread planting of non-regional kōwhai and the disturbance of native habitats and landscapes, hybrids have been able to colonise new ranges and outcompete non-hybrid kōwhai populations in these novel habitats (Heenan et al. 2018). Hybridised kōwhai plants are a threat to natural (non-hybrid) kōwhai populations, especially to species with a limited natural range (i.e. *S. fulvida*, *S. godleyi* and *S. longicarinata*). This may be an issue not only to the biodiversity value, but also the cultural value of kōwhai species as taonga (treasure). In addition, kōwhai populations have low genetic diversity and high selfing rates (Etten et al. 2015; Robertson et al. 2011). The high inbreeding depression can be problematic when balancing the need to maintain genetic diversity in natural populations. However, significant improvements in kōwhai planting

stock suited for commercial timber production should be achievable by outcrossing in a breeding programme.

Biotic threats to kōwhai could impact the growth and productivity of the species in a plantation setting. Kōwhai moth (*Uresiphita māorialis*) larvae can cause defoliation of *Sophora* trees (Kay 1980), with *S. tetraptera* reported to be more susceptible to attack than *S. microphylla* (Wardle 2011). Kererū (*Hemiphaga novaeseelandiae*) feed on the foliage and flowers (McDougal et al. 2018). However, kōwhai seem to be tolerant of defoliation. The New Zealand drywood termite (*Kaloterms brouni*) is known to infest kōwhai wood (Barton 2006). According to Milligan (1984), there have been records of termites infesting the heartwood of living kōwhai trees. The success of termites establishing inside a living tree depends on the presence of dry, dead branch stubs that allow termites access to the inside of the tree. The vulnerability of kōwhai to termite infestation could be a limitation in their use in outdoor applications.

The nectar of *S. microphylla* is toxic to honeybees, causing a narcotic effect which can be fatal and have significant hive impacts (Clinch et al. 1972). Therefore, kōwhai plantations could affect New Zealand’s beekeeping industry. Nevertheless, kōwhai is often planted in restoration projects to attract native nectar-feeding birds such as tūi and bellbirds which do not experience the toxic effects of the nectar. The benefits of planting kōwhai to attract native nectar-feeding birds may outweigh the negative impact that kōwhai nectar has on honeybee populations. It may be possible to produce bee-friendly kōwhai species or breeds through selection, as nectar toxicity varies from tree to tree and between kōwhai populations (Clinch et al. 1972).

Growth and form

As ornamental species, kōwhai has a spreading crown (Heenan et al. 2001). However, according to Blair (1879), *S. tetraptera* can grow a single, straight stem that is clear for up to 7.5 m. An example of *S. microphylla* growing with a clear, straight stem can be seen in Figure 1. Pardy et al. (1992) found that stem form and height of native trees was greatly influenced by spacing, with trees at close spacings (2 m or less) having tall, straight stems with minimal forking and branching. This implies that kōwhai could be grown with clear, straight stems in a plantation setting for timber by planting at an appropriate spacing. However, no research has been conducted on kōwhai silviculture. Breeding planting stock with improved form is a common approach in commercial forestry, which could further improve timber yields.

Very little data is available on the growth rates of kōwhai. Pardy et al. (1992) found that of the planted small



FIGURE 1: *Sophora microphylla* growing in the Marlborough region.

native hardwood trees and shrubs surveyed, kōwhai was one of the most vigorous growers in its initial years, comparable to tarata (*Pittosporum eugenioides* A.Cunn.), lancewood (*Pseudopanax crassifolius* (Sol. ex A.Cunn.) C.Koch), lacebark (*Hoheria populnea* A.Cunn.) and kōhūhū (*Pittosporum tenuifolium* Sol. ex Gaertn.). The survey included measurements of height and diameter at breast height (dbh) over different age classes (Table 1).

The predicted mean annual increment (MAI) for kōwhai, as well as the historically significant timber species: tōtara (*Podocarpus totara* G.Benn. ex D.Don), kauri (*Agathis australis* (D.Don) Lindl.) and rimu (*Dacrydium cupressinum* Lamb.), are summarised in Table 2. The predicted height MAI for kōwhai was comparable to that of tōtara, kauri and rimu up to age 20 years, but height growth ultimately reduced compared to the other species (Table 2). The dbh increment for kōwhai was lower than that of tōtara, kauri and rimu. Overall, this reflects differences in mature sizes among the species. For comparison, the national average site

TABLE 1: Mean height and dbh of planted kōwhai in 10-year age classes. Adapted from Pardy et al. (1992).

Age class (years)	1 – 10	11 – 20	21 – 30	31 – 40	41 – 50	51 – 60	>71
Height (m)	...	6.7	9.5	...	11.9	11.0	...
DBH (cm)	...	12	13	16	23	25	...

TABLE 2: Predicted mean annual height and dbh increments for kōwhai and significant native tree species (standard error in brackets). Adapted from Pardy et al. (1992).

Species	Height (cm/year)			DBH (mm/year)
	Age 20 years	Age 40 years	Age 80 years	All ages
Kōwhai	42 (2)	28 (1)	15 (1)	5.5 (0.6)
Tōtara	38 (3)	32 (1)	24 (1)	7.8 (0.4)
Kauri	44 (3)	36 (3)	26 (2)	6.9 (0.4)
Rimu	37 (2)	32 (1)	25 (1)	6.8 (0.4)

index for *P. radiata* is 30.4 m (Palmer et al. 2010), which is equivalent to a MAI of 152 cm for height, up to an age of 20 years. This information applies to an intensively managed plantation of improved planting stock, and should not be directly compared to the growth rates of kōwhai and other native species.

The predicted height and dbh MAIs (Table 2) match measurements of 11 kōwhai trials planted around New Zealand (Barton 2006), with height increments of around 45 cm per annum, reducing to less than 20 cm per annum for 80-year-old trees, and diameter increments of 8 mm per annum for trees up to 20 years old, slowing to 4 to 5 mm per annum for trees over 35 years old. Neither study (Barton 2006; Pardy et al. 1992) specified which kōwhai species were measured but growth rates are expected to differ significantly between the kōwhai species, as evidenced by the differences in mature size.

Barton (2006) suggested that greater growth rates for kōwhai could be achieved in a plantation setting. Kōwhai can reach dbh values of over 20 cm after 40 years (Table 1) but with careful site selection and management, these dimensions could be reached at a younger age. Some combinations of kōwhai species and site can result in remarkable growth rates (Fig. 2). The disk from the kōwhai tree on the right in Figure 2 had a diameter of approximately 25 cm and showed 13 year rings, with a heartwood diameter of about 15 cm. This demonstrated that kōwhai can produce significant amounts of coloured heartwood at a younger age.



FIGURE 2: Two *Sophora* spp. discs from two trees grown in the Christchurch area, one growing naturally in the open in Islington (left) and one growing in a garden in Riccarton (right).

Timber properties

Kōwhai sapwood is pale brown in colour while the heartwood is yellowish brown, with dark streaks running through it (Clifton 1990). The wood has a moderately straight grain and fine texture, and is said to resemble oak in appearance (Blair 1879). Machined samples of *S. microphylla* and *S. tetraptera* timber can be seen in Figure 3. Blair (1879) reported that the region of sapwood in kōwhai is clearly defined and small, stating that in a sample of 200 logs ranging from 15 to 56 cm (6 to 22 inches) in diameter, the measured sapwood thickness never exceeded 3.8 cm (1.5 inches). This is favourable as kōwhai produces a significant amount of durable and coloured heartwood.

Meylan & Butterfield (1978) examined the anatomy of *S. microphylla* and *S. tetraptera* wood. *Sophora microphylla* and *S. tetraptera* have similar anatomy, featuring vessel members, fibres, axial parenchyma, uniseriate and multiseriate rays. The growth rings in *S. microphylla* and *S. tetraptera* are indistinct to slightly distinct and vessels are distributed evenly throughout the growth ring in irregular clusters of 2 to 15 or more, separated into bands by fibres (Meylan & Butterfield 1978). The vessels are of medium length and are interconnected by simple perforation plates in their end



FIGURE 3: Quarter-sawn timber showing sapwood and heartwood labelled *S. microphylla* (left) and sapwood timber labelled *S. tetraptera* (right), from the New Zealand School of Forestry’s historic wood collection.

walls. The walls of the vessels have prominent helical thickenings. The intervessel pits are circular to ovate in outline and arranged alternately. The fibres have thick to very thick walls. The rays in the wood are mostly multiseriate and are 5 to 10 cells wide, while the ray pits are small, circular and simple in shape (Meylan & Butterfield 1978). These features can be seen in Figures 4 to 6.

Sophora cassioides, formerly known as *S. tetraptera*, was described as having distinct growth rings (Wiedenbrug 1949). The vessel elements in *S. cassioides* have a mean diameter of 50 µm, with a maximum diameter of up to 70 µm, and are 70 to 190 µm in length. The vessels in *S. cassioides* also exhibit helical thickenings and have simple intervessel pits. The fibres have a mean diameter of 12 µm and are 500 to 1000 µm in length, with very thick walls. The rays are generally multiseriate and can reach up to 10 cells wide (Wiedenbrug 1949).

There is limited data on the properties of kōwhai timber. Kōwhai timber was appreciated for its high density, hardness and elasticity by Māori and European settlers (Blair 1879; Wallace 1989), and is one of New Zealand’s strongest hardwoods (Barton 2006).

Bier (1999) reported wood properties of *S. microphylla* timber (Table 3). It must be noted that only two samples from old-growth trees were tested, and it is uncertain whether these were from the species now recognised as *S. microphylla*. Furthermore, many timber properties from young, plantation-grown trees are typically lower than those for wood cut from old-growth trees (Lachenbruch et al. 2011; Zobel & Sprague 1998). More testing is required to establish the wood properties of kōwhai, and the variation within and among species and hybrids.

Sophora microphylla seems to be stiffer, harder, and denser than the internationally highly regarded, naturally durable teak (*Tectona grandis* L.f.) (Table 3). With kōwhai’s comparably coloured heartwood, it could be a substitute for *T. grandis* imports for specialty applications. The natural durability of kōwhai heartwood has not been formally tested. From anecdotal reports, it is estimated to have an in-ground durability of Class 2. Kirk (1875) reported fence posts, house blocks and house piles made from kōwhai timber being sound after nearly 20 years in service.

Kōwhai are toxic to humans and some animals. Cytisine, the main compound, causes nausea, vomiting and other symptoms if ingested. All parts of the kōwhai tree contain alkaloid compounds (Brooker et al. 1987) but the alkaloids are concentrated in the seeds and therefore kōwhai is not a great risk to human health unless the seeds are deliberately ingested, and the hard seed coat is cracked (Landcare Research 2002; McDougal et al. 2018). This is unlikely to occur in a plantation and is probably more of a risk in private gardens, where young children may ingest the seeds. However, there have been accounts of both Māori and European settlers feeling sick after eating from bowls or utensils made from kōwhai wood. Consequently, the timber should not be considered for use for food utensils, food containers and similar items (Tipa 2018; Wardle 2011).

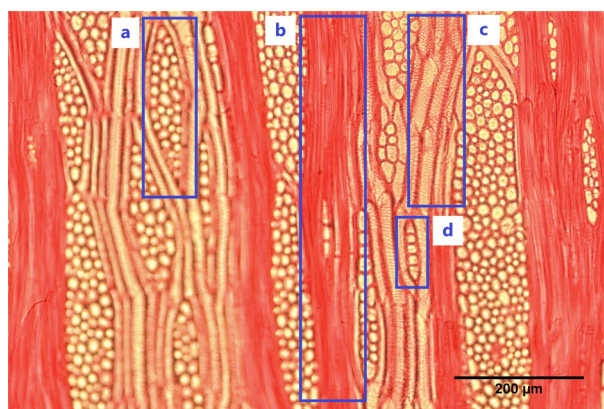


FIGURE 4: Light-microscopy image of a tangential-longitudinal wood section of *S. microphylla* stained with safranin; (a) multiseriate ray, (b) fibres, (c) vessels, and (d) uniseriate ray.

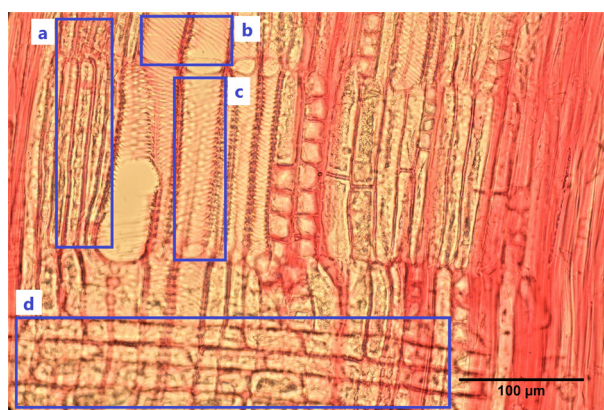


FIGURE 5: Light-microscopy image of a radial-longitudinal wood section of *S. microphylla* stained with safranin; (a) axial parenchyma, (b) helical thickenings on vessel walls, (c) intervessel pits, and (d) ray.

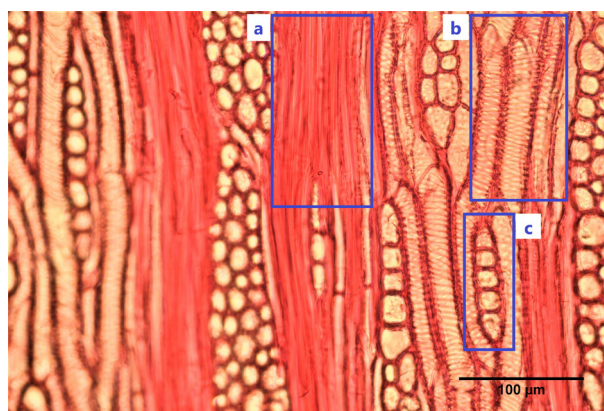


FIGURE 6: Light-microscopy image of a tangential-longitudinal wood section of *S. microphylla* stained with safranin; (a) fibres, (b) vessels with helical thickenings on walls, and (c) uniseriate ray.

TABLE 3: Mean wood property values for kōwhai, radiata pine and teak (sources are noted in the table, abbreviations are explained in the list of abbreviations).

Species	Moisture content	Density (kg/m ³)	MoR (MPa)	MoE (MPa)	Comp. parallel (MPa)	Shear parallel (MPa)	Hardness (N)	Source
<i>Sophora microphylla</i>	Green	719	81.44	10137	39.85	13.24	8584	Bier (1999)
	12%	787	134.68	13603	61.21	14.16	9597	
<i>Pinus radiata</i> , (nominal density 450 to 500 kg/m ³ , New Zealand)	Green	437	41.32	5827	16.27	5.40	2625	Bier (1999)
	12%	472	93.69	9510	38.70	12.08	4200	
<i>Tectona grandis</i> (old growth, India)	Green	...	76.00	10000	...	...	4800	Bootle (2005)
	Dry	630	88.00	11000	...	...	4600	
<i>Tectona grandis</i> (old growth, East Timor)	Green	...	...	...	...	...	...	Miranda et al. (2011)
	11.5%	...	141.00	10684	50.00	...	...

Historical uses of timber

Māori used kōwhai for a wide variety of purposes that utilised the timber’s high hardness, strength, and density. This included weaponry, agricultural tools, and waka (canoe) paddles. Weapons that were made from kōwhai timber included mauls, patu and taiaha. For these, the density and strength of the wood was paramount (Wallace 1989). Agricultural implements such as kō (digging sticks), fernroot beaters, wood-splitting wedges and heavy axe handles made use of the hardness and strength of the wood (Clifton 1990; Cooper & Cambie 1991). Kōwhai were occasionally used for waka paddles due to its strength and elasticity (Cooper & Cambie 1991; Wallace 1989). Other uses exploiting the timber’s elasticity included bird snares (made from kōwhai branches) and eel spears (Manatū Taonga Ministry for Culture and Heritage 2021; Wardle 2011). Māori also recognised the durability of kōwhai timber and utilised the timber for whare (house) construction and fencing (Tipa 2018).

European settlers prized kōwhai for its natural durability, especially as a fencing timber. Other applications in which kōwhai was used for its durability included sleepers, house blocks, house piles and bracing for wharf construction (Blair 1879; Clifton 1990; Kirk 1889). European settlers also used kōwhai timber for purposes which required its elasticity. For example, it was used for the teeth and bows of hay rakes (Blair 1879; Clifton 1990; Kirk 1889). It was also used for the rims of carriage wheels and the tops of circular windows. Kōwhai were used for making tool handles, which made use of the timber’s strength, hardness, and density (Blair 1879). Despite its colour, strength, toughness and elasticity, a limitation for their wider use was the limited availability of large dimension logs, with logs often being of narrow widths (15 cm) and short lengths (Howard 1951; Kirk 1889).

Kōwhai timber was also used for furniture making, cabinetry and ornamental turnery (Blair 1879; Kirk 1875, 1889). The wood’s good machining properties meant that it is suitable for turning and carving work (Wardle 2011). Clifton (1990) stated that it is a good

wood for turning with an excellent finish and lovely colour, but underused. The timber was also well regarded for furniture making, expressing little warp, but having a propensity to cracking while drying (Blair 1879; Tāne’s Tree Trust 2020).

In other countries, species of *Sophora*, though mainly known for being ornamental plants, have been used for timber in limited quantities. For example, the Hawaiian *Sophora chrysophylla* (Salisb.) Seem. (māmāne) was used for adze handles, farming spades, rafters, thatching posts, and purlins in house construction. The species was also used for posts and fences because of its durability. *Sophora chrysophylla* timber was also used to make sled runners up to 5.5 m (18 feet) long used in a sport called hōlua (Native Plants Hawaii 2009). In Chile, *S. cassioides*, formerly classed *S. microphylla*, was used in small quantities for axles and other parts in wagon wheels, as well as tool handles (Shepherd & Heenan 2017).

Medicinal uses and other applications

Kōwhai contains alkaloids that are mostly concentrated in the seeds, followed by the foliage, twigs, bark, wood and roots (McDougal et al. 2018). The main alkaloid present is cytisine. Other alkaloids found in kōwhai include methyl cytisine, matrine, sophochrysin, anagyrine, diosmin and hesperidin (Brooker et al. 1987). Cytisine and matrine are the main compounds in *S. microphylla* and *S. tetraptera* (Thompson-Evans et al. 2011).

Medicinal applications for some *Sophora* species are recorded in different parts of the world. For example, the seeds of *S. secundiflora* were used by the Native Americans in the southwest United States and Mexico for ceremonial, divinatory and medicinal purposes (Forrester et al. 2020). The roots of *Sophora flavescens* Aiton have a long history of being used in Chinese traditional and modern medicine. The root extracts are used to treat fever, dysentery, jaundice, inflammatory reactions and, more recently, also cancer and infectious diseases (He et al. 2015).

Kōwhai are used in rongoā Māori (traditional Māori medicine), and some traditional medicinal practices persist today. Māori mainly utilised kōwhai bark for

medicinal purposes, though other parts of the tree such as the flowers, leaves and roots were also used to treat a variety of ailments. Bark was always taken from the sunny side of the tree, to avoid killing the tree after harvesting the bark (Brooker et al. 1987). Infusions of kōwhai bark were used as an emetic and a purgative, as well as to relieve sore throats and colds. These infusions were also drunk to relieve internal pain or applied topically to relieve external pain (Salmon 1980). Kōwhai bark infusions, mixed with kōwhai or manuka (*Leptospermum scoparium* J.R.Forst. et G.Forst.) wood ash, were rubbed onto the skin to treat scabies and ringworm (Brooker et al. 1987; Cooper & Cambie 1991). Poultices were also made from the bark and applied to cuts, wounds, and sprains to accelerate healing (Brooker et al. 1987; Tipa 2004). The ashes of kōwhai and mānuka wood was rubbed onto the scalp as a treatment for dandruff (Tipa 2018; Vennell 2019). Sap extracted from the root of the kōwhai tree was also said to be ingested to cure gonorrhoea (Brooker et al. 1987). Kōwhai seeds were not recorded as being used in rongoā Māori and this may be because the seeds have a higher concentration of alkaloids (McDougal et al. 2018).

Cytisine, one of the main alkaloids in kōwhai, has been used successfully as a smoking cessation product in eastern Europe and central Asia since the 1960s (Thompson-Evans et al. 2011). In Europe, the cytisine used in smoking cessation products is extracted from laburnum (*Laburnum anagyroides* Medik.). Māori have the highest smoking rates in New Zealand (Cancer Society NZ 2021). A study by Thompson-Evans et al. (2011) stated that smoking cessation products currently available on the market were ineffective with Māori. The study also found that Māori participants were overwhelmingly interested in using cytisine as a smoking cessation product were it available. It was perceived as rongoā as the compound can be extracted from *S. microphylla* and *S. tetraptera* (Brooker et al. 1987). Clinical trials of cytisine against a placebo showed that efficacy and abstinence rates were similar or equal to another cessation product, Varenicline (Walker et al. 2018).

Kōwhai were also used in the past by Māori to make natural dye. Flowers were used to make yellow dye, the seed pods yielded pale yellow dye while the twigs and bark were made into brown dye (Tipa 2004). Tannin compounds can be extracted from all parts of *S. tetraptera* (Tipa 2018).

Potential markets

Potential markets for kōwhai timber should exploit its characteristics including its colour and texture, natural durability, good mechanical properties (elasticity, hardness, and toughness), and their status as taonga species. Their use is likely to be limited to applications where large log dimensions are not important, or where the timber can be laminated.

Kōwhai could be grown to produce naturally ground-durable posts for agricultural industries. This 300,000 m³ per annum domestic market is currently dominated by copper-chromium-arsenic (CCA) treated *P. radiata*

posts with an average retail price of 750 NZD per m³ (van Bruchem 2020). However, CCA-treated timber is toxic and needs disposal in secure landfills (Read 2003; Rhodes 2013), and cannot be used in the organic agricultural industry (Millen et al. 2018; Organics Aotearoa New Zealand 2010). The organic sector demand for agricultural posts alone is estimated to be about 15,000 m³ per annum (van Bruchem 2020). It is conceivable that kōwhai can supplement the existing efforts by the New Zealand Dryland Forests Initiative (NZDFI) (New Zealand Dryland Forests Initiative 2021) to establish a domestic ground-durable hardwood resource (Millen et al. 2020), by expanding the *Eucalyptus*-based programme to colder regions. Partnering with a programme like the NZDFI would provide kōwhai easier entry into this market, by utilising the established infrastructure.

The colour, texture and good finishing properties of kōwhai timber lend it to use in joinery, furniture, and crafts like turning. Examples of pieces turned from kōwhai timber can be seen in Figure 7. Its mechanical properties could lead to the development of niche products such as tool handles (toughness), in wood bending (elasticity) or music instruments (hardness) (Venn & Whittaker 2003). Ash (*Fraxinus* spp.) and hickory (*Carya* spp.) have prominent status in the European and North American tool handle market respectively, due to their toughness (Mania et al. 2020), and a New Zealand equivalent is conceivable. Alternative regional timbers are demanded to replace unsustainably harvested tropical timber for use in musical instruments (Gibson & Warren 2018; Shirmohammadi et al. 2021).

In any potential market, the cultural value of kōwhai as native species and as taonga can add value to the product, though exactly how this can be achieved needs to be explored. Actions which capitalise on kōwhai's status as native and/or taonga species need to be carried out in collaboration with Māori and iwi, to reflect Māori culture and interests. The Te Pai Tawhiti – WAI 262 work programme, resulting from the settlement of the WAI262 claim in 2011, is part of this complex theme (Te Puni Kōkiri - Ministry of Māori Development 2021).

Kōwhai could be promoted in a similar way to koa (*Acacia koa* A.Gray), a small-dimension, culturally relevant hardwood grown for specialty markets such as furniture, crafts and musical instruments in Hawaii (Pejchar & Press 2006). The species was assessed for important market attributes such as colour, heartwood and density, and koa wood processing was demonstrated by woodworkers to craft showcase pieces from young koa wood (Hawaii Forest Institute 2016). In the New Zealand context, lessons can be learned from the Tōtara Industry Pilot, which is establishing a timber market for regenerating tōtara (Tōtara Industry Pilot 2020).

Despite the New Zealand population preferring domestically-grown timber (Biggsby & Ozanne 2007; Biggsby & Ozanne 2001), New Zealand's imports of high-value timber species to satisfy the market demand for specialty timber has been increasing over the last decade. These imports are not necessarily sustainably or legally harvested, and the New Zealand government is currently preparing legislation to ensure that these



FIGURE 7: Decorative bowl turned from *Sophora* spp. heartwood and sapwood (left) and pen turned from *Sophora* spp. heartwood by Dave Page (Scion).

imports are derived from legal sources (Jones 2020). Such legislation exists in countries like Australia and the United States, and those of the EU. Kōwhai could be established in New Zealand as a sustainable domestic source for high-quality timber to replace imported timbers in the domestic market.

Additionally, non-timber products have the potential to be developed from kōwhai, supplementing the economic viability of the species. This could include cytisine and other alkaloids for pharmaceutical applications, natural dyes, or tannin.

Conclusions

In the past, kōwhai were used by Māori as a source of strong, hard timber and medicine, and by European settlers in New Zealand as a durable, coloured, flexible timber. Kōwhai has potential to be grown as a commercial forestry species. The timber has properties that are comparable to those of *Tectona grandis*, a highly regarded tropical hardwood species. *Sophora microphylla* and *S. tetraptera* has attractive, yellow-brown heartwood which is reputed to have Class 2 durability. These properties mean that kōwhai could be grown to substitute imported specialty timbers, thereby reducing the risk of importing illegally or unsustainably sourced timbers. The natural durability of kōwhai timber also means that it can serve the domestic market by replacing CCA-treated timber in outdoor applications such as posts for the organic agricultural industry. The colour, texture, and machinability of the kōwhai timber can be utilised in the furniture, crafts, and musical instrument markets. In these markets, kōwhai's status as a native species and taonga can add value, utilising the cultural significance to Māori and the New Zealand people to create a positive reception to kōwhai products.

Sophora microphylla and *S. tetraptera* can be established easily and are widespread throughout the country, due to their popularity as ornamental species and use in ecosystem restoration, but some kōwhai species, namely *S. fulvida*, *S. godleyi* and *S. longicarinata* have limited ranges. Growth and form of kōwhai can be improved by breeding and silviculture. Kōwhai's propensity to hybridise can be advantageous for breeding

kōwhai for improved planting stock, though the threat of hybrids to the biodiversity and cultural value of natural kōwhai populations is yet to be explored. Kōwhai could be grown as a multi-use forestry species as residues are a source of alkaloids for pharmaceutical applications.

Literature on kōwhai is limited and recent literature on kōwhai timber properties typically refers to information from a few historical reports. Further research is essential to overcome the lack of expertise on New Zealand's native timbers, which is a barrier to promoting native forestry in general. Areas which require further study include:

- Kōwhai growth rates and silviculture to improve growth and form, including the variations between the eight endemic *Sophora* species and their hybrids across regions in New Zealand.
- The mechanical wood properties, machining and processing characteristics, natural durability, and cytisine levels in each of the kōwhai species and hybrids.
- The cultural, economic, and ecological framework of a commercial kōwhai forestry industry.

List of abbreviations

EU: European Union
 CCA: copper-chromium-arsenic (treatment)
 Comp. parallel: Compression strength parallel to grain
 dbh: diameter at breast height
 MAI: Mean Annual Increment
 N: nitrogen
 NZDFI: New Zealand Dryland Forests Initiative
 MoE: Modulus of Elasticity
 MoR: Modulus of Rupture
 Shear parallel: Shear strength parallel to the grain

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

All authors discussed the topic, contributed to the literature search, and revised the manuscript. LN drafted the manuscript. CA initiated the research.

References

- Barton, I. (2006, May). Timber trees of the future. *Tāne's Tree Trust Newsletter*, (9).
- Bier, H. (1999). *Strength properties of small clear specimens of New Zealand-grown timbers*. Retrieved from <https://scion.contentdm.oclc.org/digital/collection/p20044coll6/id/659/>. Accessed 11 March 2021.
- Bigsby, H., & Ozanne, L.K. (2007). The effect of forest context on consumer preferences for environmentally certified forest products in New Zealand and Australia. *Journal of Forest Products Business Research*, 4, 14.
- Bigsby, H.R., & Ozanne, L.K. (2001). Consumer preference for environmentally certified forest products in New Zealand. *New Zealand Journal of Forestry*, 46, 36-41.
- Blair, W.N. (1879). *The building materials of Otago and south New Zealand generally*. Dunedin, New Zealand: J. Wilkie & Co.
- Bootle, K.R. (2005). *Wood in Australia: types, properties and uses* (2nd ed.). Sydney, Australia: McGraw-Hill.
- Brooker, S.G., Cambie, R.C., & Cooper, R.C. (1987). *New Zealand medicinal plants*. Auckland, New Zealand: Heinemann Publishers.
- Cancer Society NZ. (2021). *Māori and smoking*. Retrieved from <https://cancernz.org.nz/reducing-cancer-risk/what-you-can-do/smoking-and-cancer/smoking-and-cancer/maori-and-smoking/>. Accessed 11 March 2021.
- Clifton, N.C. (1990). *New Zealand timbers: exotic and indigenous*. Wellington, New Zealand: Government Printing Office.
- Clinch, P.G., Palmer-Jones, T., & Forster, I.W. (1972). Effect on honeybees of nectar from the yellow kōwhai (*Sophora microphylla* Ait.). *New Zealand Journal of Agricultural Research*, 15(1), 194-201. <https://doi.org/10.1080/00288233.1972.10421295>
- Cooper, R.C., & Cambie, R.C. (1991). *New Zealand's economic native plants*. Auckland, New Zealand: Oxford University Press.
- Etten, M.L.V., Tate, J.A., Anderson, S.H., Kelly, D., Ladley, J.J., Merrett, M.F., Peterson, P.G., & Robertson, A.W. (2015). The compounding effects of high pollen limitation, selfing rates and inbreeding depression leave a New Zealand tree with few viable offspring. *Annals of Botany*, 166, 833-843. <https://doi.org/10.1093/aob/mcv118>
- Forrester, M.B., Layton, G.M., & Varney, S.M. (2020). Abuse and misuse of *Sophora secundiflora* in Texas. *Clinical Toxicology*, 58(4), 302-303. <https://doi.org/10.1080/15563650.2019.1648819>
- Gibson, C., & Warren, A. (2018). Unintentional path dependence: Australian guitar manufacturing, bunya pine and legacies of forestry decisions and resource stewardship. *Australian Geographer*, 49, 61-80. <https://doi.org/10.1080/00049182.2017.1336967>
- Hawaii Forest Institute. (2016). *Young-growth koa wood quality assessment and demonstration project*. Retrieved from <https://hawaiiforestinstitute.org/our-projects/young-growth-koa-wood-quality-assessment-demonstration-project/>. Accessed 11 March 2021.
- He, X., Fang, J., Huang, L., Wang, J., & Huang, X. (2015). *Sophora flavescens* Ait.: traditional usage, phytochemistry and pharmacology of an important traditional Chinese medicine. *Journal of Ethnopharmacology*, 172, 10-29. <https://doi.org/10.1016/j.jep.2015.06.010>
- Heenan, P., Mitchell, C., & Houlston, G. (2018). Genetic variation and hybridisation among eight species of kōwhai (*Sophora*: Fabaceae) from New Zealand revealed by microsatellite markers. *Genes*, 9(2), 111. <https://doi.org/10.3390/genes9020111>
- Heenan, P.B., de Lange, P.J., & Wilton, A.D. (2001). *Sophora* (Fabaceae) in New Zealand: taxonomy, distribution and biogeography. *New Zealand Journal of Botany*, 39(1), 17-53. <https://doi.org/10.1080/0028825X.2001.9512715>
- Hoffman, A.E. (1982). *Flora silvestre de Chile zona Araucana* (5th ed.). Santiago, Chile: Ediciones Fundacion Claudio Gay.
- Howard, A.L. (1951). *A manual of the timbers of the world* (3rd ed.). London, England: Macmillan & Co.
- iNaturalist Network. (2020). *iNaturalist*. Retrieved from <https://www.inaturalist.org/>. Accessed 11 March 2021.

- Jones, S. (2020). *Proposed legislation to implement a national wood legality assurance system*. Wellington, New Zealand: Ministry for Primary Industries.
- Kay, M.K. (1980). *Uresiphita polygonalis māorialis* (Felder) kōwhai moth. *Forest and timber insects in New Zealand*, No. 42. Rotorua, New Zealand: Forest Research Institute.
- Kirk, T. (1875). Report on the durability of New Zealand timbers in constructive works. In G. Didsbury (Ed.), *Report on the durability of New Zealand timbers in constructive works etc., etc.* Wellington, New Zealand: Government Printer.
- Kirk, T. (1889). *The forest flora of New Zealand*. Wellington, New Zealand: Government Printer.
- Lachenbruch, B., Moore, J.R., & Evans, R. (2011). Radial variation in wood structure and function in woody plants, and hypotheses for its occurrence. In T. D. F. C. Meinzer, & B. Lachenbruch (Ed.), *Size- and age-related changes in tree structure and function* (Vol. 4, pp. 121-164). Dordrecht, Netherlands: Springer Netherlands. https://doi.org/10.1007/978-94-007-1242-3_5
- Landcare Research. (2002). *Plants in New Zealand poisonous to children*. Retrieved from <https://www.landcareresearch.co.nz/uploads/public/Publications/plants-in-new-zealand-poisonous-to-children.pdf>. Accessed 11 March 2021.
- Manatū Taonga Ministry for Culture and Heritage. (2021). *Te Ara - the encyclopedia of New Zealand*. Retrieved from <https://teara.govt.nz/en>. Accessed 11 March 2021.
- Mania, P., Siuda, F., & Roszyk, E. (2020). Effect of slope grain on mechanical properties of different wood species. *Materials*, 13(7), 1503. <https://doi.org/10.3390/ma13071503>
- McDougal, O.M., Heenan, P.B., Perry, N.B., & van Klink, J.W. (2018). Chemotaxonomy of kōwhai: leaf and seed flavonoids of New Zealand *Sophora* species. *New Zealand Journal of Botany*, 56(3), 227-236. <https://doi.org/10.1080/0028825X.2018.1472107>
- Meason, D., Dreenen, A., & Palmer, H. (2020). Performance of indigenous and exotic species at Rewanui Forest Park: ten years on. *New Zealand Tree Grower*, 41, 8-13.
- Meylan, B.A., & Butterfield, B.G. (1978). *The structure of New Zealand woods*. Wellington, New Zealand: New Zealand Department of Scientific and Industrial Research Bulletin.
- Millen, P., Altaner, C., & Palmer, H. (2018). Naturally durable timber posts performing well. *New Zealand Tree Grower*, 39, 24-26.
- Millen, P., Altaner, C., & Palmer, H. (2020). Durable hardwood peeler pole plantations: a new growing regime for eucalypts. *New Zealand Tree Grower*, 41, 8-13.
- Milligan, R.H. (1984). *Kaloterme brouni* Froggatt (Isoptera: Kalotermitidae): New Zealand drywood termite. *Forest and timber insects in New Zealand*, No. 59. Rotorua, New Zealand: Forest Research Institute.
- Ministry for Primary Industries. (2020a). *New Zealand policy to address illegal logging and associated trade*. Wellington, New Zealand: Ministry for Primary Industries Retrieved from <https://www.mpi.govt.nz/dmsdocument/13837-New-Zealand-policy-to-address-illegal-logging-and-associated-trade>. Accessed 13 April 2021.
- Ministry for Primary Industries. (2020b). *New Zealand timber and wood products procurement policy (TWPP)*. Wellington, New Zealand: Ministry for Primary Industries Retrieved from <https://www.mpi.govt.nz/dmsdocument/13843-New-Zealand-government-policy-on-purchasing-timber-products>. Accessed 13 April 2021.
- Ministry for Primary Industries. (2021a). *Forestry*. Retrieved from <https://www.mpi.govt.nz/forestry/>. Accessed 11 March 2021.
- Ministry for Primary Industries. (2021b). *Wood product markets*. Retrieved from <https://www.mpi.govt.nz/forestry/new-zealand-forests-forest-industry/forestry/wood-product-markets/>. Accessed 19 June 2021.
- Miranda, I., Sousa, V., & Pereira, H. (2011). Wood properties of teak (*Tectona grandis*) from an unmanaged stand in East Timor. *Journal of Wood Science*, 57(3), 171-178.
- Mitchell, A.D., & Heenan, P.B. (2002). *Sophora* sect. *Edwardsia* (Fabaceae): further evidence from rDNA sequence data of a recent and rapid radiation around the southern oceans. *Botanical Journal of the Linnean Society*, 140, 435-441. <https://doi.org/10.1046/j.1095-8339.2002.00101.x>
- Molloy, B.P.J. (2002). Origin of *Sophora chathamica* (Fabaceae) on Chatham Island. *Canterbury Botanical Society Journal*, 36, 37-46.
- Native Plants Hawaii. (2009). *Sophora chrysophylla*. Retrieved from http://nativeplants.hawaii.edu/plant/view/Sophora_chrysophylla. Accessed 11 March 2021.
- New Zealand Dryland Forests Initiative. (2021). *New Zealand Dryland Forests Initiative: breeding tomorrow's trees today*. Retrieved from <https://nzdfi.org.nz/>. Accessed 12 March 2021.
- New Zealand Plant Conservation Network. (2020). *New Zealand Plant Conservation Network*. Retrieved from <https://www.nzpcn.org.nz/>. Accessed 11 March 2021.
- Olson, S. (2004). The silver beech industry in transition. *New Zealand Journal of Forestry*, 48(4), 26-28.

- Organics Aotearoa New Zealand. (2010). *Over the fencepost: alternatives to CCA (copper chromium arsenate) treated wood*. Retrieved from <https://www.readkong.com/page/over-the-fencepost-alternatives-to-cca-copper-chromium-5704779>. Accessed 13 April 2021.
- Palmer, D., Watt, M., Kimberley, M., Höck, B., Payn, T., & Low, D. (2010). *Mapping the productivity of radiata pine*. Retrieved from <https://www.nzffa.org.nz/farm-forestry-model/resource-centre/tree-grower-articles/may-2010/mapping-the-productivity-of-radiata-pine/>. Accessed 20 April 2021.
- Pardy, G.F., Bergin, D.O., & Kimberley, M.O. (1992). Survey of native tree plantations. *FRI Bulletin No. 175*. Rotorua, New Zealand: Scion.
- Pejchar, L., & Press, D.M. (2006). Achieving conservation objectives through production forestry: the case of *Acacia koa* on Hawaii island. *Environmental Science & Policy*, 9, 439-447. <https://doi.org/10.1016/j.envsci.2006.03.007>
- Read, D. (2003). *Report on copper chromium and arsenic (CCA) treated timber*. Retrieved from <https://www.ecotect.co.nz/downloads/cca-report.pdf>. Accessed 11 March 2021.
- Rhodes, S. (2013). *Recovery and disposal options for treated timber*. Retrieved from <https://www.wasteminz.org.nz/wp-content/uploads/Scott-Rhodes.pdf>. Accessed 11 March 2021.
- Robertson, A.W., Kelly, D., & Ladley, J.J. (2011). Futile selfing in the trees *Fuschia excorticata* (Onagraceae) and *Sophora microphylla* (Fabaceae): inbreeding depression over 11 years. *International Journal of Plant Sciences*, 172(2), 191-198. <https://doi.org/10.1086/657678>
- Salmon, J.T. (1980). *The native trees of New Zealand*. Auckland, New Zealand: Reed Publishing New Zealand.
- Shepherd, L.D., & Heenan, P.B. (2017). Evidence for both long-distance dispersal and isolation in the southern oceans: molecular phylogeny of *Sophora* sect. *Edwardsia* (Fabaceae). *New Zealand Journal of Botany*, 55(3), 334-346.
- Shepherd, L.D., Thiedmann, M., & Lehnebach, C. (2020). Genetic identification of historic *Sophora* (Fabaceae) specimens suggests *toromiro* (*S. toromiro*) from Rapa Nui/Easter Island may have been in cultivation in Europe in the 1700s. *Journal of Botany*, 58(3), 255-267. <https://doi.org/10.1080/0028825X.2020.1725069>
- Shirmohammadi, M., Faircloth, A., & Redman, A. (2021). Assessment of sound quality: Australian native hardwood species for guitar fretboard production. *European Journal of Wood and Wood Products*, 79, 487-497. <https://doi.org/10.1007/s00107-020-01631-9>
- Sykes, W.R., & Godley, E.J. (1968). Transoceanic dispersal in *Sophora* and other genera. *Nature*, 218(5140), 495-496. <https://doi.org/10.1038/218495a0>
- Tāne's Tree Trust. (2020). *Kōwhai*. Retrieved from <https://www.tanestrees.org.nz/species-profiles/kowhai/>. Accessed 11 March 2021.
- Te Puni Kōkiri - Ministry of Māori Development. (2021). *Te Pae Tawhiti: Wai 262*. Retrieved from <https://www.tpk.govt.nz/en/a-matou-kaupapa/te-ao-maori/wai-262-te-pae-tawhiti>. Accessed 25 May 2021.
- Thomas, M.B., & Spurway, M.I. (2001). Kōwhai (*Sophora* species) and other nitrogen-fixing plants of New Zealand. *Combined Proceedings International Plant Propagator's Society*, 51, 94-97.
- Thompson-Evans, T.P., Glover, M.P., & Walker, N. (2011). Cytisine's potential to be used as a traditional healing method to help indigenous people stop smoking: a qualitative study. *Nicotine & Tobacco Research*, 13(5), 353-360. <https://doi.org/10.1093/ntr/ntr002>
- Tipa, R. (2004). Kōwhai: our national flower. *Te Karaka*, (25), 16-17.
- Tipa, R. (2018). *Treasures of Tāne - plants of Ngāi Tahu*. Wellington, New Zealand: Huia Publishers.
- Tōtara Industry Pilot. (2020). *Tōtara Industry Pilot*. Retrieved from <https://www.totaraindustry.co.nz/>. Accessed 11 March 2021.
- van Bruchem, B. (2020). *Analysis of the treated wood market for agricultural and horticultural uses in New Zealand*. Christchurch, New Zealand: University of Canterbury. <https://ir.canterbury.ac.nz/bitstream/handle/10092/101893/Boris%20van%20Bruchem%20Dissertation.pdf?sequence=1&isAllowed=y>
- Venn, T.J., & Whittaker, K. (2003). Potential specialty timber markets for hardwoods of western Queensland, Australia. *Small-scale Forest Economics, Management and Policy*, 2, 377-395. <https://doi.org/10.1007/s11842-003-0026-2>
- Vennell, R. (2019). *The meaning of trees*. Auckland, New Zealand: Harper Collins Publishers.
- Walker, N., Smith, B., Barnes, J., Verbiest, M., Kurdziel, T., Parag, V., Pokhrel, S., & Bullen, C. (2018). Cytisine versus varenicline for smoking cessation for Māori (the indigenous of New Zealand) and their extended family: protocol for a randomized non-inferiority trial. *Addiction*, 114(2), 344-352. <https://doi.org/10.1111/add.14449>
- Wallace, R. (1989). A preliminary study of wood types used in pre-European Māori wooden artefacts. In D.G. Sutton (Ed.), *Saying so doesn't make it so: papers in honour of B. Foss Leach* (pp. 222-232). Dunedin, New Zealand: New Zealand Archaeological Association.

Wardle, J. (2011). *Wardle's native trees of New Zealand and their story*. Wellington, New Zealand: New Zealand Farm Forestry Association.

Wiedenbrug, G.W. (1949). Maderas chilenas contribucion a su anatomia e identificacion *Actas del segundo Congreso Sudamericano de Botánica: Tucumán, octubre 10-17 de 1948* (pp. 236-375). Tucumán, Argentina: Republica Argentina.

Zobel, B.J., & Sprague, J.R. (1998). *Juvenile wood in forest trees*. Berlin, Germany: Springer Verlag. <https://doi.org/10.1007/978-3-642-72126-7>