FRI BULLETIN NO. 124

INTRODUCED FOREST TREES IN NEW ZEALAND

Recognition, Role, and Seed Source

17. THE POPLARS

Populus spp.

A.G.WILKINSON

This FRI bulletin series was compiled for people with an interest in the introduced trees of New Zealand, such as foresters, farm foresters, nurserymen, and students. Copies can be obtained from: Publications, Forest Research, Private Bag 3020, Rotorua (Ph: 07 343 5899; e-mail: publications@forestresearch.co.nz).

1. *Pinus nigra* Arn. – European black pine
2. *Pinus contorta* Loudon – contorta pine
3. The larches – *Larix decidua* Miller, *Larix kaempferi* (Lambert) Carr., *Larix* ×*eurolepis* A. Henry
4. *Pinus mugo* Turra – dwarf mountain pine; *Pinus uncinata* Mirbel – mountain pine
5. *Pinus attenuata* Lemmon – knobcone pine
6. The spruces – *Picea sitchensis* (Bong.) Carrière, *Picea abies* (L.) Karsten, ornamental spruces
7. The silver firs – *Abies* spp.
8. *Pinus pinaster* Aiton – maritime pine
9. The cypresses – *Cupressus* spp.; *Chamaecyparis* spp.
10. Ponderosa and Jeffrey Pines – *Pinus ponderosa* P. Lawson et Lawson, *Pinus jeffreyi* Grev. et Balf.
11. *Eucalyptus nitens* (Deane et Maiden) Maiden
12. Radiata pine – *Pinus radiata* D. Don.
13. The redwoods – *Sequoia sempervirens* (D. Don) Endl. – coast redwood, *Sequoiadendron giganteum* (Lindley). J. Buchholz – giant sequoia, and the related ornamental genera *Taxodium* and *Metasequoia*
14. Douglas-fir – *Pseudotsuga menziesii* (Mirbel) Franco
15. The willows – *Salix* spp.
16. *Cryptomeria, Thuja* and *Tsuga*

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Allan Wilkinson was responsible for breeding poplars for erosion control, windbreaks and agroforestry in New Zealand from 1973 to 1997.

COVER PHOTOGRAPH: *Populus nigra* 'Italica' and *P. yunnanensis* on Waikato farmland.

Poplars planted for erosion control, drought fodder, amenity, and timber on Ewan McGregor's farm, Waipawa, Hawke's Bay. Spring brings a variety of colours of new foliage on poplars. Autumn used to bring golden foliage colours but the Italian hybrid poplars predominant in the lower scene have been defoliated by poplar rust. New rust-resistant plantings are returning autumn colours to this farm.

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Rotorua
2000

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Dedicated to C.W.S. van Kraayenoord for his major contribution to poplar cultivation and development in New Zealand.

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CONTENTS

EXPLANATION OF TERMS

Subspecies – a subdivision of a species having distinct morphological characteristics and geographical distributions. A species may be divided into two or more subspecies. A subspecies can be indicated by the abbreviations subsp. or ssp., e.g., *P. deltoides* subsp. *monilifera.*

Variety – a subdivision of a species. It is usually a geographic variant of the typical species having one or more heritable morphological characteristics that differ from the typical species and are retained even when grown under the same environmental conditions as the typical species. A variety is indicated by var., e.g., *P. nigra* var. *thevestina.* The same plant may be designated a subspecies by one botanist and a variety by another. Both subspecies and varieties breed true from seed.

Cultivar – a selected and named form reproduced in cultivation, e.g., for agriculture, horticulture or forestry. When reproduced sexually or asexually it retains its distinguishing features. The cultivar name is indicated by single quotation marks, e.g., *P. nigra* 'Italica' or by cv. (for cultivated variety), e.g., *P. nigra* cv. Italica. A cultivar may sometimes be incorrectly referred to as a variety, e.g., Lombardy poplar is sometimes referred to as *P. nigra* var. *italica.* Most poplar cultivars are vegetatively reproduced clones.

Clone – plants produced through vegetative multiplication of a single individual and therefore genetically identical. Unlike a cultivar, a clone can be reproduced only by vegetative means.

Hybrid – a plant resulting from a cross between parents which differ sufficiently to be given separate taxonomic status. Hybrids may be **interspecific**, i.e., between two species, or **intraspecific**, i.e., within a species involving subspecies or varieties. A hybrid is indicated by '×', e.g., *P. deltoides* × *P. nigra* (which is an interspecific hybrid). Sometimes a hybrid is given a hybrid name, e.g., *P.* ×*canadensis* (or *P.* ×*euramericana*) for *P. deltoides* × *P. nigra*.

Provenance – the original geographic source of plants, seed or other reproductive material.

SUMMARY

This booklet, the seventeenth in the Bulletin No. 124 series, provides a general account of poplars in New Zealand, principally *Populus alba*, *P. nigra*, *P. deltoides*, *P. trichocarpa*, *P. yunnanensis*, and their hybrids and cultivars. It covers their introduction and history in New Zealand and gives a brief account of the natural distribution and ecology of the important species. Their genetic improvement in New Zealand and elsewhere is discussed, and an overview given of the pests and diseases to which they are prone.

A table summarising the characteristics and uses of the main poplar clones and a guide to the recognition of the common poplars in New Zealand are provided. Guidelines are given on poplar establishment, including nursery practice, propagation techniques and site requirements, and their role in soil conservation, agroforestry and shelter is discussed. Currently available data and information on growth and yield, wood properties, processing and uses, and the present extent of the resource is summarised. The bulletin concludes with a brief look at the future role of poplars in New Zealand, a list of references and appendices covering the classification and natural distribution of *Populus* species, and the common names and parentage of poplars in New Zealand.

KEYWORDS: Poplars, *Populus alba*, *P. nigra*, *P. deltoides*, *P. trichocarpa*, *P. yunnanensis*, poplar hybrids, taxonomy, propagation, New Zealand.

INTRODUCTION AND HISTORY

The poplars belong to the genus *Populus* L. and are generally fast-growing, medium to tall, deciduous or occasionally semi-evergreen, broadleaf tree species, native to a wide range of Northern Hemisphere habitats. Poplars are closely related to willows and are grouped with them in the family Salicaceae. Characters shared by poplars and willows include mainly dioecious flowering (male and female flowers on different plants), very small flowers arranged in catkins, and the ability of trees of different species to hybridise readily. Both genera are, with a few exceptions, very easily propagated vegetatively. Vegetative propagation from a single tree (a genotype) can produce an infinite number of genetically identical trees (a clone).

The number of poplar species has been the subject of international disagreement among taxonomists, particularly in China and Russia. At least 80 species have been described and named. However, the more conservative view generally adopted currently recognises 30 to 40 species as well as numerous subspecies, varieties, hybrids, and cultivars.

Populus is an immensely variable group of trees with fastigiate to globe-shaped or ovate crowns, leaves varying from the size of a small willow leaf to that of a large deltoid or ovate dinner plate, and stem colours and waxiness ranging from white-barked aspen to the thick, deeply furrowed, grey bark of eastern cottonwood, *P. deltoides.* Temperature tolerances range from over +50°C in summer to under -50°C in winter. One species, *P. euphratica*, has the ability to excrete salt. There is a varying ability to produce propolis, used by bees, and to produce phenolic derivatives that affect the plant's palatability to vertebrates. Wood basic density is in the same range as radiata pine and *Eucalyptus nitens* (280–550 kg/m^3). Rooting systems are variously capable of producing clonal sucker thickets up to tens of hectares in extent or of penetrating desert sands to depths exceeding 13 metres.

A natural ability to hybridise within and between species in the genus, together with obligatory out-breeding by wind pollination ensured by separate male and female plants, results in enormous potential variability in poplars. This has been threatened over the last century by the widespread planting of a limited number of selected cultivars and by the rapid and continuing clearance of riparian forests to establish croplands. This problem is common to both Western and Eurasian nations. It has reached critical proportions in 'developing' countries where the prime roles of poplar are for fuelwood, fodder and local building construction, and where there is severe human population pressure on all resources.

Poplars are classified into about seven morphologically and ecologically distinct groups known as sections. The commonly cultivated poplars in New Zealand fall into the three main sections: black poplars, balsam poplars and white or silver and aspen poplars (Table 1). Most poplar cultivars used in New Zealand are interspecific hybrids, both within and between the black and balsam poplars.

Table 1 - Main species of current and potential importance in poplar breeding and cultivation in New Zealand

Section	Species	Common names	Origin
AIGEIROS Black poplars	*P. deltoides*	Eastern cottonwood, American black poplar, Necklace poplar	Eastern North America
	P. nigra	European black poplar	Europe to central Asia, North Africa
TACAMAHACA Balsam poplars	*P. trichocarpa*	Western balsam poplar, Black cottonwood	Western North America
	P. balsamifera	Balsam poplar	North-east North America
	P. yunnanensis	Yunnan poplar	South-west China
	P. maximowiczii		North-east China, Japan, Korea
POPULUS Aspens and white poplars	*P. tremula*	Aspen	Europe, Asia
	P. tremuloides	Trembling aspen	North America
	P. alba	White or silver poplar	Western Europe, Asia

In New Zealand the most frequently seen member of the white poplar group is a single female clone of *P. alba*, commonly known as silver poplar. It forms thickets and is easily recognised by the lobed leaves conspicuously felted with white on the underside. The black poplars, of which the American cottonwood clone, *P. deltoides* subsp. *monilifera* 'Frimley', locally known as necklace poplar, and the Lombardy poplar, *P. nigra* 'Italica', are familiar local representatives, have toothed leaves with well-defined translucent margins. A commonly encountered balsam poplar in New Zealand is *P. yunnanensis*. Balsam poplars are characterised by scented sticky buds and ovoid leaves without translucent margins.

The most important poplars in New Zealand are the black and balsam poplars and their hybrids. These have been used effectively for soil conservation, windbreaks, and a few small woodlots, and have been utilised in small quantities as lightweight, pale coloured, general purpose timbers.

Natural Distribution and Ecology

Poplars occur naturally throughout most parts of the temperate and cold regions of the Northern Hemisphere (see Fig. 1) from the Arctic Circle to Central Mexico, North Africa and southern China. One species, *P. ilicifolia*, occurs in an isolated population south of the Equator in Africa. Vast areas in North America and Asia are dominated ecologically by poplar species.

Most poplar species are confined naturally to moist but free-draining alluvial land along river valleys, with major differences in adaptive characteristics between species which inhabit riverbanks on the hot plains and those found in mountain valleys. The exceptions are the aspens which form extensive clonal stands (0.5–200 ha in extent) over moist hill and mountain terrain, *P. euphratica* which is uniquely adapted to saline riparian soils and temperature extremes in desert areas, and *P. heterophylla* which occurs in the frequently flooded swamplands of south-eastern North America. A few of the balsam poplars such as *P. balsamifera* and *P. trichocarpa* in North America and *P. ciliata* in India also extend into hillside areas. In general the balsam poplars and aspens are more tolerant of acid soils and *P. euphratica*, *P. alba* and *P. nigra* are more tolerant of saline soils. Most black poplars grow satisfactorily over a pH range of 5.5 to 7.5.

Historically, poplars have been widely used by rural communities for house construction, firewood, stock fodder, windbreaks, and shade. They are still used for these purposes, particularly in Eastern Europe, the Middle East, Africa, India and China, and because of a long history of domestication by humans, species and cultivars have been distributed outside their natural ranges. This makes the precise boundaries of their natural distribution very hard to determine and leads to considerable taxonomic confusion.

Throughout the Northern Hemisphere the **aspens** cover an immense area from the Arctic Circle to the mountains of Mexico. *Populus tremula* has an extremely wide natural range across temperate Europe, western Asia and North Africa. It usually grows in mixtures with other hardwoods on heavy, rather wet soils, although it tolerates a wide range of soil types and site conditions. *Populus tremuloides* is one of the most widely distributed trees in North America, occurring almost from coast to coast in northern USA and Canada, growing on a wide range of soils from moist loamy soils to shallow rocky soils and clay, and displaying considerable natural variation over its range.

White poplars occur naturally in Europe, Asia and North Africa, and some related species have been identified recently from Mexico. *Populus alba*, common in New Zealand, is widely distributed in central and southern Europe, ranging eastwards into western Siberia and central Asia, and south into North Africa. Because of the long period of cultivation, however, the boundaries of its natural distribution are obscure. It is usually associated with the presence of water and is found on river valley bottoms and near streams.

The **black poplars** consist of a Eurasian species, *P. nigra*, and a North American group of species including *P. deltoides* and *P. fremontii*. *Populus nigra*, a parent of many clones cultivated in New Zealand, occurs naturally over much of southern and central Europe and in North Africa and central

Asia, extending from the United Kingdom to north-west China and south to Algeria and Morocco. Because of the length of time over which it has been cultivated, the exact boundaries of its original distribution are difficult to determine. It is essentially a tree of moist alluvial lowlands and, in natural stands, it grows in association with other poplar species, willows and alders. There are several fastigiate forms in cultivation. *Populus nigra* 'Italica' has been cultivated widely round the world and is reputed to have arisen in northern Italy at the end of the 17th or in the early 18th century as a mutant from the broad-crowned form of the western European black poplar, *P. nigra*. *Populus nigra* var. *thevestina* from the Middle East and Afghanistan is also fastigiate in habit, has distinctive white bark and grows well in Mediterranean climates. There is a new, as yet unproven, hypothesis that Lombardy poplar may have originated from a natural hybrid between the normal broad-crowned form of *P. nigra* and the fastigiate *P. nigra* var. *thevestina*.

Populus deltoides, also involved in the parentage of many clones cultivated in New Zealand, occurs naturally in North America east of the Rocky Mountains (Fig. 2). In New Zealand it is represented by two distinct subspecies or varieties. *Populus deltoides* subsp. *deltoides* occurs from southern Quebec westward into North Dakota and south-western Manitoba, south to central Texas, and east to north-western Florida and Georgia. It is not common in the north-east and Appalachian regions but covers a wide area from the Rocky Mountains to the southern Atlantic coast. Primarily a species of alluvial lowlands, its best growth is on moist, well-drained, fine sandy or silt loams close to streams. It does not grow naturally on dry soils or develop into a well formed tree more than about 5–6 m above the average level of streams. Over the area of its natural distribution, average annual rainfall ranges from less than 380 mm to over 1400 mm. On moist alluvial sites it often forms pure stands but it also grows in mixed stands associated with a number of other species, including *Fraxinus nigra* (black ash), *Ulmus americana* (American elm), *Acer rubrum* (red maple), *A. saccharinum* (sugar maple), *Quercus phellos* (willow oak), *Platanus occidentalis* (American plane), and *Salix* spp. (willows). *Populus deltoides* is very shade intolerant. In its natural habitat it is a short-lived species, usually deteriorating rapidly when aged over about 70 years.

Populus deltoides subsp. *monilifera*, also known as *P. deltoides* var. *occidentalis*, the eastern or plains cottonwood, occurs naturally from southern Canada through the Great Plains as far south as north-eastern New Mexico. The area of its distribution has a dry humid to semi-arid continental climate with average annual precipitation of about 250–760 mm, and is prone to rapid temperature changes, drought and strong winds. Growth is best on deep, rich, well-drained loams along river flood plains and stream-bottom lands, but it also grows in deep, sandy soils on level sub-irrigated uplands. It occurs at higher altitudes and under more adverse conditions than subsp. *deltoides*, between elevations of about 300 m near its eastern limit to about 1830 m in the foothills of the Rocky Mountains. It is seldom found above about 2130 m. The two subspecies intergrade where they meet.

The North American black poplars intergrade with some similar Mexican species which have been classified into a new section, *Abaso* (see Appendix 1).

The **balsam poplars** are native to east Asia and North America but not Europe. Some of the Asian species from the Himalayas are still poorly described in Western literature. They cover a wide range of forms from the small-leafed, more drought-tolerant *P. simonii* in Mongolia, to the large-leafed *P. szechuanica* in the valleys of the high hill country of Szechuan Province, China.

Populus yunnanensis is distributed through mountain valleys at elevations of 1300–2700 m, between latitudes 25–30°N in the sub-tropical climate zone of Yunnan, Guizhou and Szechuan provinces of

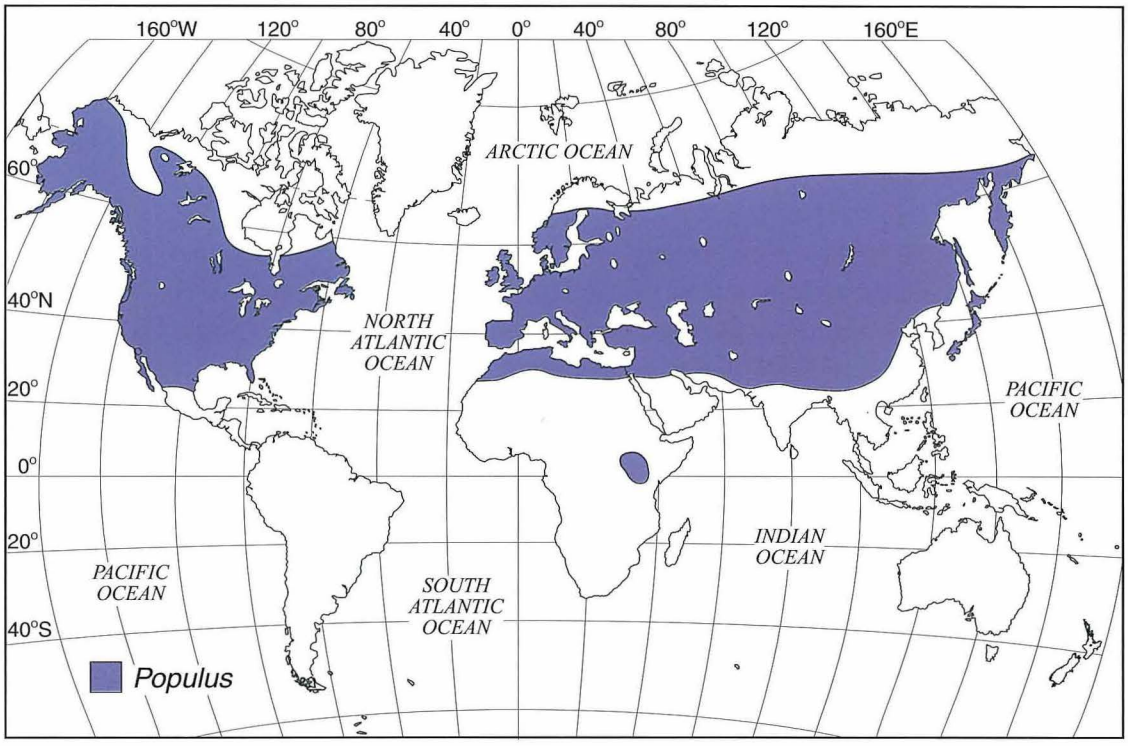

Fig. 1 - Approximate natural distribution of *Populus* (based on FAO Forestry Series No. 10, 1979).

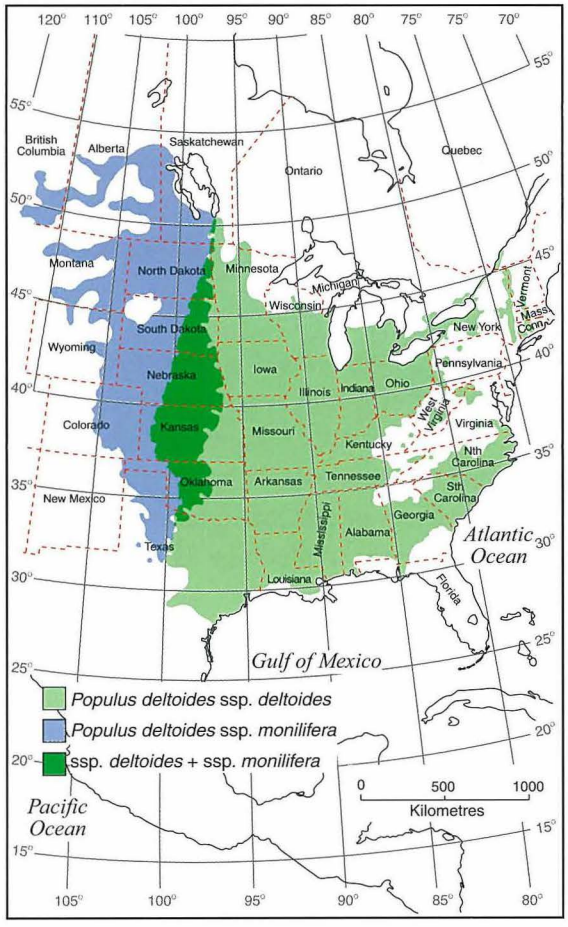

Fig. 2 - Approximate natural distribution of *Populus deltoides* (based on Burns and Honkala, 1990).

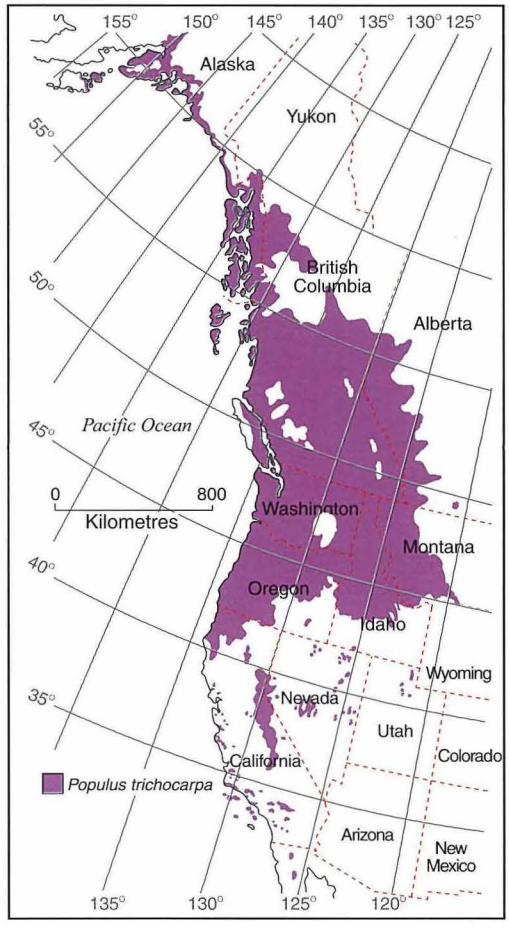

Fig. 3 - Approximate natural distribution of *Populus trichocarpa* (based on Burns and Honkala, 1990).

China. Stands extend along the riverbanks, mixing with *Pinus densata*, *P. armandii*, *Larix* sp., *Populus davidiana* and *Quercus* spp. In the distribution area, average annual rainfall is about 940 mm of which 80% falls in June-September, and temperatures range from -7°C to 32°C. The New Zealand clone of Yunnan poplar is atypical in that it was selected specifically as a drought-tolerant street tree and has tougher, thicker leaves than the typical species.

Populus maximowiczii is distributed through hill country along the Pacific coast of eastern Asia, occurring in Kamchatka, Sakhalin Island, Hokkaido and Honshu in Japan, and north-eastern China and Korea. In Japan it ranges from cool-temperate areas to the sub-frigid zone at elevations of 800–2000 m a.s.l. in Honshu and 0–1000 m in Hokkaido. It appears as a pioneer plant on the colluvium at the base of mountain screes and hill country slips, or on alluvial soils and gravels along riverbanks. It usually associates with other broad-leaved trees and rarely occurs in large pure stands.

There are three balsam poplar species in North America – the smaller-statured, narrow-leaved cottonwood, *P. angustifolia*, which extends in riverbank thickets through the Rocky Mountain chain from Mexico to Canada, *P. trichocarpa*, and *P. balsamifera* (syn. *P. tacamahaca*). *Populus trichocarpa* is the tallest hardwood species in North America, with an extensive north-south distribution (Fig. 3) in the west stretching from southern Alaska to southern California and from the Pacific coast to the Rocky Mountains in Montana and Idaho. Generally it prefers a moist climate away from the ocean but the Californian *P. trichocarpa* is more coastal and has a greater tolerance of dry soils and wind. It occurs most frequently on moist sandy, gravelly or deep alluvial soils, and the best growth occurs in the humid coastal forests of the Pacific Northwest on moist, fertile, near-neutral soils. Trees may be dwarfed on poor, dry, infertile sites. Limited pure stands and groves develop, especially on newly formed river bars. Tree willows are its main associates on alluvial soils at low coastal elevations. In interior forests *P. trichocarpa* grows with such species as *Pseudotsuga menziesii* (Douglas-fir), *Pinus monticola* (western white pine), *Picea glauca* (white spruce), *Thuja plicata* (western red cedar), *Tsuga heterophylla* (western hemlock), *Abies concolor* (white fir), *A. lasiocarpa* (subalpine fir), and *Larix occidentalis* (western larch). *Populus trichocarpa* ranges in altitude from sea level to 1500 m in the Cascade Range in Washington and 2100 m in the Selkirk Range in British Columbia. Over its range the annual precipitation varies from 250 mm to over 3050 mm.

Populus balsamifera is usually a slightly smaller tree than *P. trichocarpa* and is more resistant to cold and the extreme conditions of wind and drought encountered in inland areas such as the Great Plains. Its distribution overlaps with *P. trichocarpa* in Alaska and the Rocky Mountains, and extends to the east over the whole of Canada from the northern tree line to latitude 45°N in the USA. Where *P. balsamifera* overlaps with *P. trichocarpa*, hybrids with characters intermediate between the two parents occur. Because of this intermixing, *P. trichocarpa* is sometimes treated as a subspecies of *P. balsamifera-P. balsamifera* subsp. *trichocarpa.*

Wherever balsam poplars encounter black poplars or each other, hybrid swarms occur naturally.

Introduction into New Zealand

Poplars were probably introduced into New Zealand as early as 1830 (Weston, 1957). Two black poplars, Lombardy poplar, *P. nigra* 'Italica' (a single fastigiate male clone of *P. nigra*), and *P. deltoides* subsp. *monilifera* 'Frimley' (syn. 'Virginiana'), a female clone of the American eastern cottonwood,

were introduced into New Zealand before 1850 and were planted extensively for farm shelter and homestead amenity. 'Frimley', the New Zealand clone of *P. deltoides*, is named after a specimen tree in Frimley Park, Hastings, planted in 1875, which is now over 47 m high and has a basal diameter of about 3 m, making it one of the largest poplars in the world. This clone was planted as a shade, windbreak and fuelwood tree around early gold diggings and farm homesteads. The other early black poplar introduction, *P. nigra* 'Italica', Lombardy poplar, is well known for its wide adaptation to temperate climates and soils, and its narrow, fastigiate crown form. It has fulfilled a similar role to *P. deltoides* 'Frimley' and was also the mainstay of horticultural windbreaks, planted widely as a single specimen, and in rows for its avenue effect.

Other introductions before 1900 included a single female clone of *P. alba* (white or silver poplar), the fastigiate male clone *P. alba* 'Pyramidalis' (syn. 'Bolleana'), and *P.* ×*gileadensis* 'Candicans' ('Balm-of-Gilead'), which is thought to be a hybrid between *P. balsamifera* and *P. deltoides*. White poplar, *P. alba*, one of the most visible poplars in New Zealand, was widely planted for riverbank and hill country erosion control but is now declining in health because of repeated early defoliation by the leaf anthracnose disease *Marssonina castagnei.*

Another notable poplar in the New Zealand landscape, reported to have been planted in Blenheim in 1908 (Burstall and Sale, 1984), is a single male clone of the Chinese or Yunnan poplar, *P. yunnanensis*. This poplar has been widely planted for amenity, erosion control and windbreaks in the North Island because its foliage is resistant to both disease and browsing by possums. It loses its leaves in June and, in colder climates, its golden autumn colouring is an asset in early to mid-winter, as are its bright, glossy green leaves in summer. This clone has become increasingly popular around Auckland and Waikato in recent years, particularly for use on smaller 'lifestyle' farm blocks. The good tolerance of established trees to summer droughts on clay soils in the region has contributed to its popularity. These clones, none of which are particularly suitable for commercial timber planting, were the only poplars available in New Zealand until the late 1920s.

Largely as a result of the ease of mass vegetative propagation, poplar breeding overseas concentrated on the selection and testing of clones and cultivars derived mainly from inter-specific hybrids amongst *P. deltoides*, *P. nigra*, *P. maximowiczii*, and *P. trichocarpa*. From the 1920s onwards, introductions to New Zealand were largely of such clones which did not provide an adequate genetic basis for evaluating the potential of any pure species.

In 1930 a consignment of 12 hybrid cultivars was introduced from the Royal Botanic Gardens, Kew, London, by the New Zealand Forest Service and formed the stock for planting about 120 ha in State forests between 1932 and 1950. The consignment included 'Robusta', 'Marilandica', 'Regenerata', 'Eugenei', and 'Serotina' – clones of the black poplar hybrid *P. deltoides* × *P. nigra* (= *P.* ×*euramericana** , *P.* ×*canadensis*) – as well as 'Generosa', a hybrid clone of the *P. deltoides* and *P. trichocarpa* cross.

Between 1945 and 1950, a further 35 clones were introduced by the Botany Division of the DSIR (Department of Scientific and Industrial Research), the New Zealand Forest Service and several commercial nurseries. These introductions included ten Stout and Schreiner hybrids – 'Frye', 'Rumford'

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*Populus ×euramericana *is accepted by the International Poplar Commission as a name for* P. deltoides × P. nigra *but it is of doubtful validity according to the rules of botanical nomenclature.* P. ×canadensis *is a generally accepted botanical name for this hybrid.*

and 'Strathglass' (*P. nigra* × *P. laurifolia)*, 'Roxbury' and 'Andover' (*P. nigra* × *P. trichocarpa)*, 'Geneva' and 'Oxford' (*P. maximowiczii* × *P.* ×*berolinensis*), 'Rochester' (*P. maximowiczii* × *P. nigra*), 'Androscoggin' (*P. maximowiczii* × *P. trichocarpa*) and 'Maine' (*P.* 'Balm of Gilead' × *P.* ×*berolinensis*), as well as four hybrid black poplar clones (*P. deltoides* × *P. nigra* 'I 30', 'I 78', 'I 214' and 'I 455').

Greater awareness of the results of uncontrolled soil erosion, and the establishment of Catchment Authorities in the late 1940s, meant that the demand for poplars for soil conservation increased rapidly, as did interest in their timber potential. In 1956 a poplar improvement and selection programme was initiated by the National Plant Materials Centre in Palmerston North and a large number of clones were introduced from Belgium, England, Italy, and the Netherlands for testing.

In 1964 an initial selection of eight overseas clones suitable for erosion control and timber production was released by the centre for general use. These were the *P. deltoides* × *P. nigra* clones 'Eugenei PU', 'Laevigata', 'I 30', 'I 78', 'I 214', 'I 455', 'Robusta', and 'Robusta PH'. Because this genetic base was considered too narrow to support long-term poplar culture, further clones were introduced and clonal trials established with species and hybrids of the black poplar, *P. deltoides*, and the balsam poplars *P. maximowiczii*, *P. trichocarpa* and *P. yunnanensis*. A breeding programme began in New Zealand in 1968 based on inter-specific hybridisation, followed by clonal propagation of the best individuals.

By 1972 one million poplars were being planted annually for erosion control, river protection, windbreaks, and timber production. However, this received a serious setback in 1973 with the arrival in New Zealand of two *Melampsora* leaf rusts (*M. larici-populina* and *M. medusae*) that were thought to have been borne by wind currents from Australia. The leaf rusts were followed by the leaf anthracnose fungus (*Marssonina brunnea*) imported on seed of *P. deltoides* from the Netherlands in 1975. The severity of rust attacks on black and balsam poplar hybrid clones and the lack of disease-resistant breeding materials necessitated the importation of seed of a wide range of provenances of pure species, and cuttings of both pure species and hybrid clones. These provided a more diverse genetic base from which to select improved disease-resistant clones.

The narrow-crowned, fastigiate Lombardy poplar clone, which had made up a significant proportion of farm and horticultural windbreaks, proved highly susceptible to *M. larici-populina.* So too was *P. nigra* 'Sempervirens', the semi-evergreen Lombardy poplar which originated in Chile and was introduced in 1948, becoming an important shelter clone during the 1960s. Because of their susceptibility to rust, these two poplars were replaced in new shelter plantings by a single female clone of the Chinese tree willow, *Salix matsudana*, and New Zealand-bred hybrids between this matsudana willow and two Italian clones of the European white willow, *Salix alba.*

For new erosion control and farm forestry plantings, the Italian hybrid black poplars were replaced in the 1970s and 1980s with nine new, more disease-resistant poplar clones introduced from Belgium, Italy, Netherlands, and South Korea. The first tested New Zealand-bred hybrid poplar, 'Kawa', a hybrid between the black poplar, *P. deltoides*, and *P. yunnanensis*, a balsam poplar, was released for general use in 1986. This was followed in 1993 by 'Manawatu Gold' and 'Crow's Nest' (black poplar hybrid cultivars, *P. deltoides* × *P. nigra*). In 1996 the black × balsam hybrid cultivars, 'Toa' ([*P. deltoides* × *P. nigra*] × *P. yunnanensis*), 'Pakai' (*P. deltoides* × *P. trichocarpa*) and the black poplar hybrid, 'Argyle' (*P. deltoides* × *P. nigra* 'Italica') were released.

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* *P.* ×*berolinensis* = *P. laurifolia* × *P. nigra* 'Italica'

In addition to this wide range of seed and cuttings introduced for the New Zealand Government-funded poplar improvement programme, two ornamental cultivars, a weeping hybrid aspen – 'Hiltingbury Weeping' (*P. tremula* × *P. tremuloides*), and the colourful, variegated hybrid balsam poplar, 'Candicans Aurora', have been introduced from England by private nurseries.

Since their introduction, poplars have been abundantly planted throughout settled areas of New Zealand, with a strong focus on hill country erosion control in the North Island and on windbreaks and shade in the South Island.

Although hundreds of 'elite' poplar cultivars have been introduced into New Zealand, many poplar species with wide natural ranges and variation are represented only by single clones or single seed-lots (e.g., *P. ciliata*, *P. tremuloides*, *P. yunnanensis*). Even though some of the introduced cultivars have grown very well, the narrow genetic and species base of these introductions has resulted in an inadequate long-term foundation for poplar improvement and cultivation in New Zealand. This problem is being addressed in an ongoing collaborative poplar breeding programme by HortResearch and Forest Research.

Hybridisation

Poplar species exhibit a high degree of crossability between species within sections, e.g., *P. deltoides* × *P. nigra*, and also, in some cases, between species in different sections, e.g., *P. deltoides* (a black poplar) × *P. yunnanensis* (a balsam poplar). Natural hybridism is very common both in natural populations, where species overlap, and among cultivated poplars when compatible species are in close proximity.

White poplar (*P. alba*) hybridises freely with the Eurasian aspen (*P. tremula*) to produce the grey poplar of Europe (*P.* ×*canescens*) and similar hybrids in Asia (*P.* ×*tomentosa* in China and *P. alba* × *P. glandulosa* in Korea). Aspens and white poplars do not normally hybridise with poplars of other sections but incompatibility barriers can sometimes be overcome by special breeding techniques.

Black poplars usually hybridise freely within their own section (*Aigeiros*) and with balsam poplars (section *Tacamahaca*), but pollen compatibility and seed development problems occur when *P. nigra* or any of the balsam poplars are used as the female parent in crosses with *P. deltoides* as the male parent.

Artificial hybridisation, particularly interspecific crossing, has been one of the foundations of poplar breeding work, and comprehensive crossing programmes have revealed a wide extent of potential crossability. Inter-specific crosses using poplars from the sections *Abaso*, *Leucoides*, and *Turanga* (see Appendix 1) have been made only rarely but sufficient information is available to indicate that most inter-sectional and inter-specific barriers to hybridisation can be overcome. This means that, unlike most other tree genera, much of the genus can be considered to be a huge genetic resource for artificial hybridisation and vegetative propagation of elite seedlings at any stage in the breeding process. However, interspecific hybrid clones mostly show a combination of the particular adaptabilities and other characteristics of each parent genotype – they still need to be carefully tested and chosen for the particular environments in which hybrids will be cultivated.

Genetic Improvement

Most early overseas poplar breeding programmes evolved around the black poplars, *P. deltoides* and *P. nigra* and their hybrids. Breeding concentrated largely on interspecific hybridisation and selecting and testing clones rather than strategically planned development of breeding populations. The clone, rather than the species or provenance, was the main unit of evaluation. Exceptions to these clonally-based breeding strategies have included range-wide provenance seed collections and field trials in USA and Europe involving the black poplars, *P. deltoides* and *P. nigra*, and the balsam poplar, *P. trichocarpa*. In the Pacific North-western USA, studies of provenance differences and genetic variability of *P. trichocarpa* have formed the basis for developing interspecific hybrids of this species with *P. deltoides* for production of short-rotation pulpwood in intensely managed and irrigated plantations.

Over 40 poplar-growing countries are actively seeking to improve poplar cultivation by undertaking some or all of the following activities:

- Protection of indigenous poplar stands.
- Introduction of new species.
- Provenance selection within introduced and indigenous species.
- Controlled pollination to produce both intra- and inter-specific hybrids.

In the Southern Hemisphere, Argentina, Australia and South Africa, as well as New Zealand, have been actively involved in provenance and clonal testing. In South Africa and South America, match companies are now testing new poplar clones.

Most poplar growing countries now belong to the FAO International Poplar Commission (IPC) and many also contribute to poplar research working parties through the International Union of Forest Research Organisations (IUFRO). The IPC has a poplar breeding sub-committee which arranges international seed collections, often in conjunction with IUFRO, and holds regular meetings to inform member countries of work in progress and of the results of member countries' breeding programmes.

The New Zealand poplar breeding programme, the breeding objectives of which have been largely soil conservation-oriented, has followed a similar approach to many of the overseas programmes in its concentration on selecting and testing clones and cultivars. Initially, vegetative material of selected clones was collected overseas, imported into New Zealand, raised in quarantine, multiplied, and clonally tested. Seedling material, such as open-pollinated family seedlots, was imported and raised primarily to make early-selections in the nursery of a small number of candidate clones for disease resistance. These were then given longer-term evaluation in field trials.

A hybrid breeding programme, originally under Ministry of Works administration and now under HortResearch, was initiated in 1968 to generate poplar clones, primarily for erosion control. There has recently been more emphasis on including wood quality as part of the selection process. The 11 clones that have been released from this programme were bred locally, but utilised imported clones as parents. All are interspecific hybrids, mostly of *P. deltoides* with *P. nigra*, *P. maximowiczii*, *P. yunnanensis*, and *P. trichocarpa*. In addition to the clones mentioned in Table 2, another 10 hybrid clones (*P. deltoides* × *P. nigra* and *P. deltoides* × *P. trichocarpa*) are available. However, a new disease or a new insect pest like the willow sawfly, or simply requirements for selection for additional traits like wood quality, could make many of these clones no longer acceptable. There are no major breeding populations of species such as *P. deltoides* or *P. maximowiczii* to provide new clones or

new parents for interspecific crosses (although there are a number of clones of *P. deltoides* and other species in clone banks).

Objectives of the New Zealand breeding programme

In overseas countries the primary objective of breeding programmes is to select clones or multi-clonal cultivars for plantation-based wood production, usually in conjunction with some cropping. In New Zealand the programme has been limited to selecting a range of clones suitable for soil conservation and windbreaks, i.e., to provide a major tree component on which to base the sustainable use of pastoral hill country. Since these soil conservation trees are planted singly, or at wide spacings in unstable pasture, they are more exposed than plantation-grown trees to damage from wind, stock grazing and trampling, and soil movement.

In practice, the programme has aimed to develop genetically diverse clones or cultivars conforming to three basic types:

1. WS–A tree for wide-spaced plantings in silvo-pastoral systems.
2. SR– A tree for single-row windbreak or stream bank plantings.
3. BP–A tree for block planting, either in conventional woodlots or in multiple-row riparian plantings.

Basic requirements shared by these three categories are:

- High resistance to current diseases and insect pests.
- High rooting ability from unrooted stem cuttings.
- Rapid growth.
- Straight stem.
- Low palatability to possums.
- Basic wood density of at least 360 kg/m^3.
- Low incidence of pathological black heart caused by bacteria.

In addition:

- WS trees require rough, thick bark by age 5–6 years, narrow to intermediate width crowns, high wind resistance, and low incidence of epicormic sprouting following pruning.
- SR trees require narrow to intermediate width crowns, low phototropic reaction (i.e., alternate trees should not lean sideways to utilise available light), and a low incidence of epicormic sprouting following pruning.

Release of disease-resistant clones

Between 1974 and 1996, 343 clones were introduced from overseas. Of these, only 11 clones were found to be acceptable for soil conservation planting. None proved entirely suitable to replace Lombardy poplar as a horticultural and farm windbreak tree. Some clones, which might have been acceptable for plantation-based forestry, were not tested for this use because of the lack of acceptance of poplar by the forest industry.

Of the introduced clones, the black poplars and their hybrids were mostly heavily attacked by possums and were suitable for use only where possum densities were low. Possum-resistant balsam poplars, notably *P. trichocarpa* and *P. maximowiczii*, were smooth-barked and thus prone to bark browsing by cattle. They were also sensitive to strong winds, and poorly adapted to most North Island environments because of their original selection from provenances from higher latitudes.

New Zealand selections which have been released since 1986 ('Kawa', 'Toa', 'Pakai', 'Argyle', 'Crow's Nest', and 'Manawatu Gold'), vary in their attractiveness to possums. The new hybrid black poplar clones such as 'Argyle' have medium palatability, compared to 'Flevo', 'Luisa Avanzo', 'Tasman', and 'Veronese' which are highly attractive to possums. The black × balsam poplar hybrid, 'Pakai,' has low palatability similar to 'Eridano' (released in 1980), and the Yunnan poplar × black poplar hybrids 'Kawa' and 'Toa' have low to medium palatability.

Both the introduced and New Zealand-bred cultivars were selected for high resistance to the rust *Melampsora larici-populina*. However, the resistance of some of the *P. deltoides* × *P. nigra* clones ('Luisa Avanzo' and 'Veronese') is already failing locally because of the continuing evolution of new races of rust on the alternate host plants, *Larix decidua* and *L. kaempferi.* Table 2 summarises the characteristics and uses of the main poplar clones.

Over the next 5-10 years HortResearch and Forest Research intend to develop a long-term improvement strategy for the American black cottonwood, *P. trichocarpa*, which is a promising species for poplar forestry and timber production in New Zealand. At the same time, HortResearch will continue to purpose-breed inter-specific hybrid cultivars for silvo-pastoral plantings in the presence of stock, for horticultural and farm windbreaks, and for amenity.

The potential of balsam poplars native to India, Pakistan, China, and the Himalayas is not well known. However, single male clones of *P. ciliata* from Kulu in India, and *P. yunnanensis* from Kunming, China, have given excellent results in terms of hybrid vigour and disease resistance, in crosses with a wide range of *P. deltoides* in New Zealand. There is potential for further benefit from the introduction of more seedlots from different provenances of these balsam poplar species.

Potential of poplars to become weeds

Where breeding populations with both male and female plants are formed, poplars have the potential to become serious weeds, particularly near natural wetlands and rivers. Very few poplar populations in New Zealand are considered to be naturalised, i.e., firmly established and self perpetuating. Widely distributed clones of *Populus* are currently either unisexual or are non-breeding hybrids so that spread is by asexual reproduction only, e.g., suckering of *P. alba* (Fig. 13) to form large stands. If fertilisation does occur, seeds can be produced in great quantities. They are very small and light, and have a fluffy tuft of hairs making them easily distributed by wind and able to float long distances in water. Growth is rapid once a seedling is established.

Diseases and Pests

Fungal diseases

The most significant poplar diseases in New Zealand are caused by the poplar leaf rust (*Melampsora larici-populina*) and the leaf spot or anthracnose fungus (*Marssonina brunnea*) (Fig. 4). Both of these leaf diseases thrive in our cool, moist environments and cause early defoliation, reduced root and stem growth, and dieback in susceptible cultivars.

Two other leaf disease fungi, *Marssonina castagnei*, (Fig. 5) which affects white poplars (especially the widespread female silver poplar cultivar), and *Melampsora medusae*, an American poplar rust that is well established in Australia, can cause minor problems. Incorporating resistance to all four diseases has been included as an objective in the HortResearch poplar breeding programme.

Table 2 - Guide to the characteristics and uses of the main poplar clones grown in New Zealand

Clone	Sex	Parentage	Year of release	Pest and disease resistance				Crown spread	Uses	Comments
				Poss.	*Mel. l*	*Mel. m*	*Marss.*			
'Flevo'	Male	*deltoides* × *nigra*	1974	*	***	***	***	III	S,F	Suitable for chips and pulp
'Eridano'	Male	*deltoides* × *maximowiczii*	1980	***	***	**	***	II	S,T	Potential for sawn timber
'Kawa'	Male	*deltoides* × *yunnanensis*	1986	**	***	**	***	II	S,T,F	Recommended for sawn timber, veneer
'Pakai'*	Male	*deltoides* × *trichocarpa*	1995	***	***	*	**	II	S,F,T?	Worth trialing in woodlots for timber
'Tasman'	Male	*deltoides* × *nigra*	1980	*	***	***	**	II	S,T,F,W,H	Good farm windbreak tree
'Trichocarpa 471'	Male	*trichocarpa*	1978	**	***	***	***	II	S,A	Better growth in cool, sheltered locations
'Yeogi 1'	Male	*alba* × *glandulosa*	1979	**	***	***	***	II	S,T	Worth trialing in woodlots for timber
'Yunnan'	Male	*yunnanensis*		***	**	***	***		A,S,W	The only shiny-leaved poplar
'Argyle' *	Female	*deltoides* × *nigra*	1996	*	***	***	**	II	S,T,F,W	Rough bark, best for pasture with cattle
'Crow's Nest' *	Female	(*deltoides* × *nigra*) × *nigra*	1994	*	**	**	**	I	A,S,H	Narrow crown, best for horticulture
'Luisa Avanzo'	Female	*deltoides* × *nigra*	1986	*	***	*	**	II	T,F	Good for plantations only
'Toa'*	Female	(*deltoides* × *nigra*) × *yunnanensis*	1996	**	***	***	***	II	S,T,W,H	Reliable multipurpose tree
'Veronese'	Female	*deltoides* × *nigra*	1986	*	**	*	**	II	S,T,F,W,H	Good woodlot and windbreak clone

*** New Zealand Plant Variety Rights: These can be awarded to the breeder of a newly named clone or cultivar that meets certain stipulations. The breeder then has exclusive rights over commercialisation for 23 years (woody plants).**

Pest and disease resistance
Poss. possum damage
Mel. l leaf rust *Melampsora larici-populina*
Mel. m leaf rust *Melampsora medusae*
Marss. leaf spot *Marssonina brunnea*, *M. castagnei*

* Low resistance
** Medium resistance
*** High resistance

Crown spread
I Narrow crown (like Lombardy poplar)
II Medium width crown, suits farm windbreaks
III Broad crown, suitable for shade, not windbreaks

Uses
A Amenity
F Stock fodder
H Horticultural and small rural holdings
S Soil conservation
T Timber (best timber is produced in regularly-spaced woodlots on river flats)
W Farm windbreaks

Maintaining a diverse genetic base for poplar, as well as a population-based, recurrent selection breeding strategy is important. This has been emphasised by the continual appearance of new races of *Melampsora* rust and the detection of spores of *Melampsora*, *Marssonina* and *Septoria*, as well as bacteria and insect eggs, on seed of poplars and willows imported from the USA.

Exclusion/interception of new pests and pathogens has been reasonably effective in New Zealand due to a high awareness level of the problem and strict quarantine procedures. Nevertheless, the white poplar anthracnose fungus, *Marssonina castagnei*, appeared only one year after its first detection in Australia. This fungus spread rapidly throughout the country, and severe defoliation and consequent loss in diameter and root growth occurred in the widespread silver poplar clone that played an important role in roadside stabilisation and gully erosion control.

Two other minor leaf diseases are caused by the fungi *Taphrina populina* (poplar leaf curl), which causes large orange-yellow blisters on the underside of leaves (Fig. 6), and *Sphaceloma populi*, which causes small to large leaf spots, primarily on leaves of Lombardy poplar.

Armillaria spp. can attack the lower trunk and root system of poplars resulting in slow decline and death. Such infections are associated with site conditions that affect plant vigour such as an intermittent high water table. *Armillaria* spp. are also effective agents of decay. *Chondrostereum purpureum* (silverleaf) may invade wounds or cut surfaces (Fig. 7), and has been recorded killing recently established poplar stools. In older plants *C. purpureum* causes white decay. Other white and brown rot fungi such as *Junghuhniana vincta*, *Rosellinia necatrix*, *Ganoderma applanatum*, and *Trametes* sp. have been recorded from poplars in New Zealand (Pennycook, 1989).

Bacterial diseases

In addition to diseases caused by fungi, individual plants within a monoclonal planting may suffer bacterial blast and stem cankering caused by the bacteria *Pseudomonas syringae* and *Xanthomonas campestris.* This is more common in balsam poplars and some hybrids with black poplars. Affected plants may suffer shoot blackening (Fig. 8) and partial or complete dieback to ground level. If affected tissues are cut away cleanly, however, resprouting from below the damaged zone usually occurs.

Crown gall caused by *Agrobacterium tumefaciens* can be a major nursery problem for the production of one-year-old rooted plants of aspen and white poplars. Large galls may form at ground level causing girdling of the main stem, poor growth, restricted shoot growth, and toppling. Large galls may occasionally form on the first 1-2 m of the trunk of older trees.

Insect pests

Insect damage to poplars is generally of minor importance in New Zealand. However, insect pests that have been recorded as locally damaging include the following:

Sapsuckers

- The leafhoppers, *Idiocerus distinguendus* (on white poplars and aspens) and *Idiocerus decimusquartus* (on black poplars), cause mottling (symptoms similar to virus attack) and malformation of expanding leaves on spring growth.
- The green vegetable bug (*Nezara viridula*) sucks sap from the veins, leaf stalks and stems, and can cause localised swelling of young stems and small, sunken lesions in the bark.

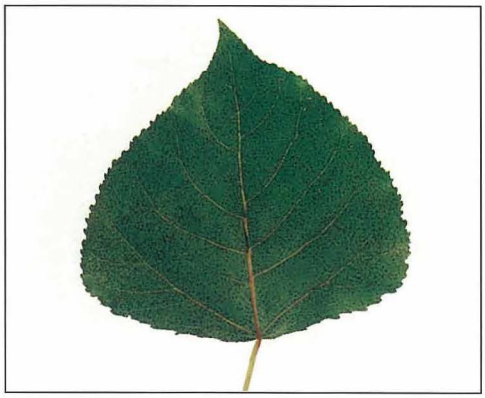


Fig. 4 - Poplar leaf rust fungus, *Melampsora larici-populina*, shown on *Populus* 'Generosa' (left), and anthracnose (or black spot) fungus, *Marssonina brunnea,* shown on a hybrid black poplar (above), significantly affect the growth and health of susceptible cultivars.

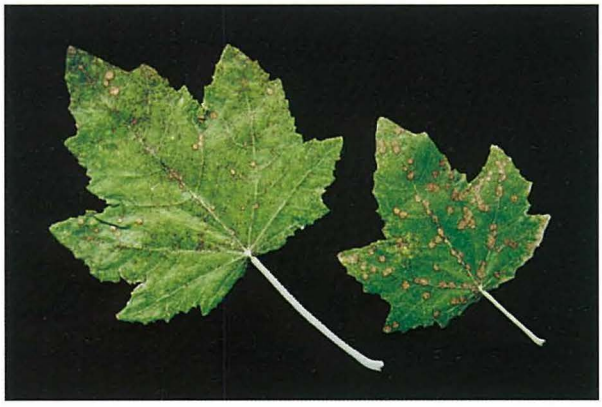


Fig. 5 - *Marssonina castagnei*, shown here on *P. alba*, causes early defoliation on white poplars.

Fig. 6 - These orange-yellow blisters on the underside of the leaves of a hybrid black poplar are caused by *Taphrina populina.*

Fig. 7 - *Chondrostereum purpureum* (silverleaf) on *P. trichocarpa* in a coppice stoolbed.

Fig. 8 - Stem blackening is a characteristic symptom of bacterial blast caused by *Pseudomonas syringae.* The disease is shown here on *Populus deltoides* × *P. ciliata.*

Foliage feeders

- The brown beetle or grass grub beetle (*Costelytra zealandica*) chews leaves from the edges in to the mid-rib, and its larvae may feed on the surface roots. Similar damage can be caused by the green beetle (*Stethaspis* spp.) and the green manuka beetle (*Pyronota* spp.). The smaller bronze beetle (*Eucolaspis brunnea*) may chew leaves to produce a 'shot-hole' effect.
- The brown-headed leaf-roller (*Ctenopseustis obliquana*) feeds singly on leaves, young stems (cambium) and buds of the host plant while sheltering beneath a web of silk and foliage. Apical buds may be hollowed out and stems chewed. Similar damage may be caused by the green-headed leaf-roller (*Planotortrix excessana*) or the light-brown apple moth (*Epiphyas postvittana*).
- Other minor foliage feeders include the bag moth (*Liothula omnivora*), the katydid (*Caedicia simplex*), and Fuller's rose weevil (*Asynonychus cervinus*).

Gall-formers

- The poplar gall aphid (*Pemphigus bursarius*) forms small purse-shaped galls on the leaf stalks of Lombardy poplar and some *P. deltoides*.

Wood and cambium feeders

- The lemon tree borer (*Oemona hirta*) is the main insect pest of poplars in New Zealand. Larvae bore in twigs and branches throughout the year, occasionally girdling young stems and causing breakage. It has caused losses in both poplar and tree willow pole production (coppice) nurseries, but usually tends to attack trees under water stress on drier or free-draining soils.
- Other native borers which have occasionally caused problems include puriri moth (*Aenetus virescens*) and the pinhole borer (*Platypus apicalis*).

Miscellaneous pests

- Large cicadas (*Amphisalta* spp.) make herring-bone patterns of cuts on young branches and stems during egg-laying. These cuts often result in breakage of smaller stems and branches, allowing entry of fungal pathogens and bacteria.
- Honey bees (*Apis mellifera*) collect balsam from the elongating shoots of young balsam poplars causing reduced internode extension and bunching of shoot growth.

Possums

The common Australian brush-tailed possum (*Trichosurus vulpecula*) is by far the most important pest of poplars and tree willows in New Zealand. It prefers to feed on foliage, buds and young fresh bark (adjacent to buds or branches) of the black poplars, *P. deltoides* and *P. nigra*. The balsam poplars, *P. angustifolia*, *P. maximowiczii*, *P. simonii*, *P. trichocarpa*, and *P. yunnanensis*, vary considerably in attractiveness with at least half the trees within any one family being unpalatable to possums. This has been used to advantage in developing possum-resistant black × balsam poplar hybrids such as 'Eridano', 'Toa' and 'Pakai'.

RECOGNITION

Identification of Poplars

Poplar identification is often difficult, even for an experienced observer, mainly because many of those commonly cultivated are cultivars and clones, often of interspecific hybrids. Many of these are derived from the same parents and differ only slightly in morphological characteristics.

Other features complicating the identification of poplars are that:

- Leaves are deciduous and thus not available in the winter.
- There is considerable variation in the size and shape of the leaves on any one plant, particularly between those on long shoots and those on short shoots* (Fig. 9). Those on coppice and sucker shoots are especially variable.
- Immature leaves differ from mature leaves in size and often in shape and hairiness.
- Catkins and mature foliage are often not available at the same time, preventing observation of both together.
- Features relating to the catkins can be critical for identification, but catkins are available only when the tree is at least five years old and then only for a short time in the spring.
- As male and female flowers are borne on separate trees, available flowers are usually of one sex only.

Features important in identification include:

- Shape of crown – whether broad and spreading or narrow and upright.
- Angle of branches.
- Bark characteristics – whether rough or smooth.
- Presence of suckers.
- Bud size, shape, and whether sticky with resin or not.
- Shape of leaves – triangular, diamond-shaped, heart-shaped, round, ovate (egg-shaped), or lobed (Fig. 10).
- Leaf margins – whether toothed, entire, wavy, translucent.
- Presence or absence of glands at the base of the leaf. Several leaves from the same plant need to be inspected when checking this feature.
- Leaf tip – twisted or not.
- Leaf-stalk (petiole) – rounded or flattened.
- Sex of the plant, colour, length and shape of the catkins, and number of stamens or stigmas.

As a result of wind pollination and seed dispersal by wind and water, natural poplar hybrids are often found well away from one or both of their parents and this has sometimes led to their description as new species, further complicating their nomenclature.

*** Short shoots and long shoots**
Winter buds in poplars contain a preformed set of leaves of adult shape. In short shoots the shoot extends only a short distance to release these leaves and then forms another terminal bud in mid-summer. In long shoots these preformed leaves develop first, but the shoot keeps extending and produces leaves of a juvenile shape before forming a terminal bud in autumn.

Fig. 9 - Terminal long shoot and short lateral (side) shoots on *Populus tremula*. Note the difference in size and shape between the long shoot and short shoot leaves.

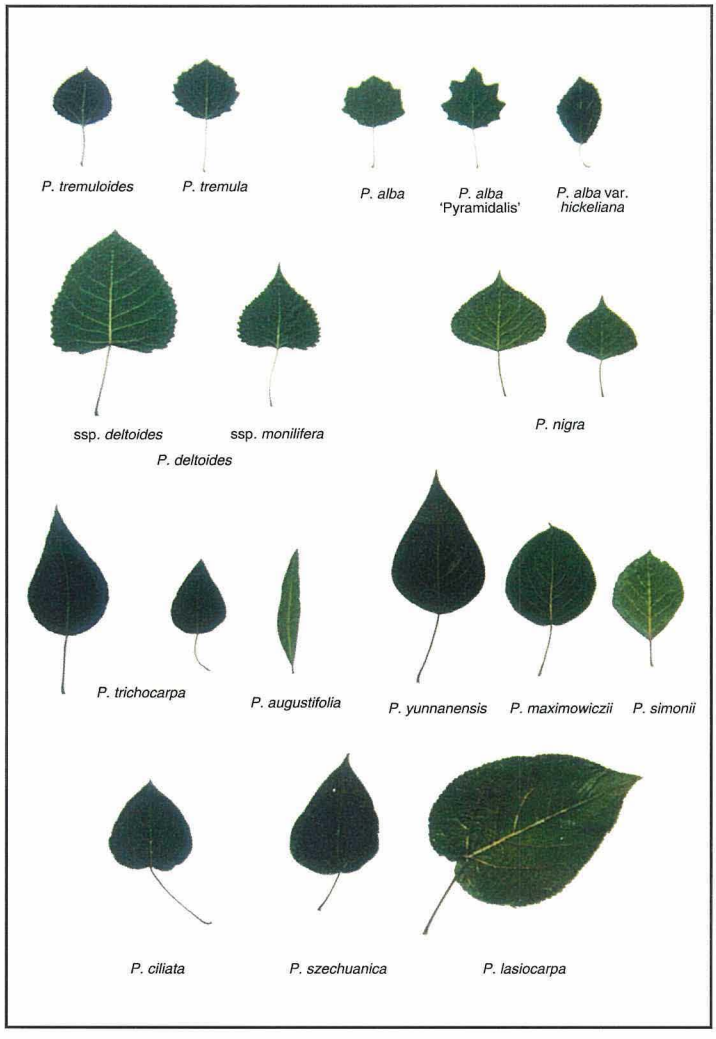


Fig. 10 - Short shoot leaves of *Populus* species showing variation in size and shape.

Fig. 11 - Receptive female catkins of 'Frimley' at fertilisation (left) and (right) male catkins of 'Robusta' releasing pollen.

Fig. 12 -Tiny greenish white poplar seeds, each with a fluffy tuft of hairs, are released in great quantities and can be carried long distances by wind or by floating on water.

General Description of *Populus*

***Habit*:** Medium to tall deciduous (or occasionally semi-evergreen) trees (15–50 m), usually single-stemmed, some species (*P. angustifolia*, *P. euphratica*, *P. alba*, and all aspens) sucker, sometimes forming dense clonal thickets. Two species, *P. alba* and *P. nigra*, have fastigiate (narrow, columnar-crowned) varieties or subspecies.

***Bark*:** Young trees of all species except *P. deltoides* have smooth bark. As the tree ages (10-20 years), the bark becomes shallowly or deeply fissured. *Populus deltoides* bark roughens more quickly, becoming thick and fissured over the first 3–5 years, depending on the origin. *Populus angustifolia* develops thick bark which, in older trees, resembles *P. deltoides*, unlike most other balsam poplars that have smooth or thin and flaky bark for long periods. Bark colour varies from white in some forms of aspen and fastigiate *P. nigra* and *P. alba*, through greyish green to grey-brown.

***Shoots*:** Shoots vary from circular to five-angled in cross section, with prominent ridges or wings in some species, and are hairless to densely pubescent (covered in short hairs). The five-angled pith of *Populus* easily distinguishes it from *Salix* in which the pith is round. The shoots are of two forms (Fig. 9); short side-shoots with typical adult foliage, and indeterminate or long terminal shoots which develop continuously during the growing season. The long shoots have large and variable foliage.

***Buds*:** All species have a distinct terminal bud. Winter buds have several overlapping (imbricate) scales. Winter buds and young shoots vary from viscid (sticky) and strongly balsam-scented in the balsam poplars to pubescent/tomentose or hairless and non-scented in the white poplars and aspens.

***Foliage*:** Foliage is deciduous or occasionally semi-evergreen, with leaves alternate, leaf stalk (petiole) usually long, and inconspicuous stipules (leaf-like or scale-like appendages at the base of the leaf stalk), which fall off at an early stage. Leaves are lanceolate to broad-ovate or deltoid (seedling and juvenile leaves may be lanceolate in some species such as *P. trichocarpa*), entire (without teeth), or toothed. Many species have conspicuous glands at the junction of the leaf stalk and the leaf blade. The leaf stalk is flattened vertically in the short shoot foliage of many species so that leaves, particularly those of aspens, are noted for the way they tremble in the wind.

***Flowers*:** Poplars do not flower until they are five years old and some take as long as 10–15 years. This is in contrast to willows which can flower as early as their second year. The flowers are densely arranged in pendulous catkins that usually appear with or before the leaves. Male and female flowers are usually on separate trees, but bisexual catkins have been occasionally recorded on trees of some species (e.g., *P. deltoides* and *P. lasiocarpa*). Each flower is in the axil of a very small, scale-like, toothed or occasionally entire bract. Unlike those of willows, the individual flowers do not bear nectaries as poplars rely on wind pollination.

Female catkins (Fig. 11) bear small yellow-green flowers, each consisting of a cup-shaped disc and a finely cut or fringed bract that usually falls away during or after pollination. The female flower contains 2-4 stigmas on a style that is short and sometimes stalkless.

After pollination the female catkins ripen and expand to form chains of 20–40 individual, globe-shaped, two- to four-valved, green capsules.

Male catkins (Fig. 11) typically have red flowers but bright yellow flowers have also been observed in *P. deltoides*. They have 20–50 stamens attached to the disc, in the axil of a toothed or fringed bract which soon falls away, and are prolific pollen producers. Male catkins wither and fall away within a fortnight of pollen release, while fertilised female catkins remain on the tree until seed fall is complete, between two months (aspens and white poplars) and four months after pollination.

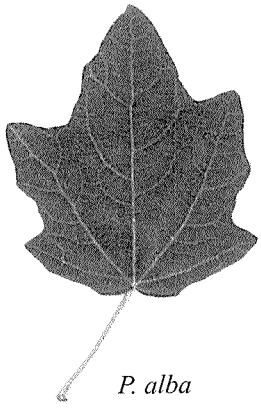
***Seeds*:** When the capsules are mature the 2–4 valves split open to release the tiny greenish white seeds (Fig. 12). The seed is released in such large quantities that the ground beneath the trees often has a white snow-like covering. The seed coat is very thin with a tuft of fine white hairs (pappus) attached to the radicle end. Each fertilised capsule contains 2–40 seeds, depending on species and the success of pollination.

Like those of the willows, poplar seeds are very small and light, and the fluffy tuft of hairs makes them easily distributed by wind and able to float long distances in water. The seed is short-lived and perishes quickly when not in contact with moist soil, silt or sand. Under suitable conditions germination occurs from within a few hours to two days.

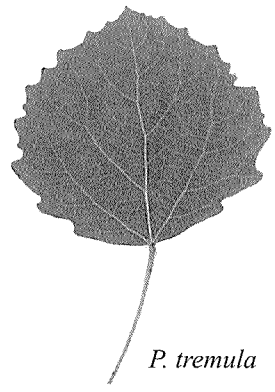
General Characteristics of the Main Poplar Sections Represented in New Zealand

SECTION POPULUS (LEUCE) – white or silver, grey and aspen poplars

Leaves coarsely toothed or lobed,
green above, white felted beneath or,
if not felted beneath, then leaves roundish.



P. alba

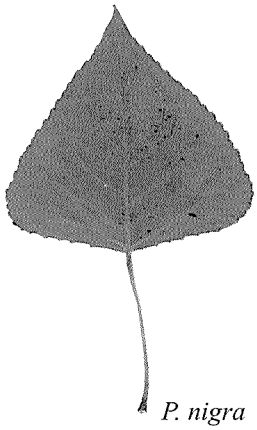


P. tremula

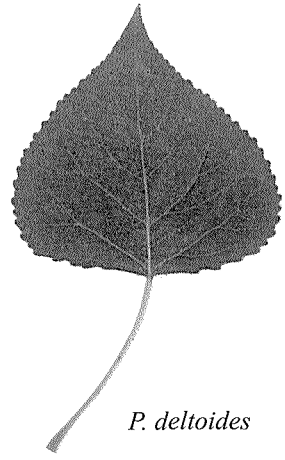
P. alba
P. alba var. *hickelliana*
P. alba 'Pyramidalis'
P. ×*canescens* (*P. alba* × *P. tremula*)
P. alba × *P. glandulosa* 'Yeogi 1'
P. alba × *P. glandulosa* 'Yeogi 2'
P. tremula
P. tremuloides

SECTION AIGEIROS – black poplars

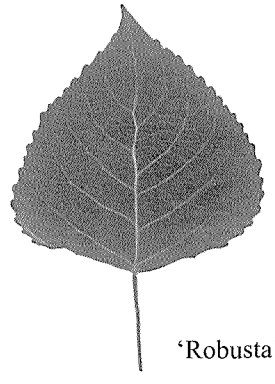
Leaves green on both sides, paler beneath,
triangular, diamond- or heart-shaped, toothed with
a clearly defined translucent margin; leaf stalk flat
towards leaf blade; buds sticky but not strongly scented.



P. nigra



P. deltoides



'Robusta'

American black poplars
P. deltoides subsp. *monilifera* 'Frimley'
(syn. *P. deltoides* 'Virginiana')

European black poplars
P. nigra
P. nigra 'Italica' (Lombardy poplar)
P. nigra 'Sempervirens'
P. nigra var. *thevestina*

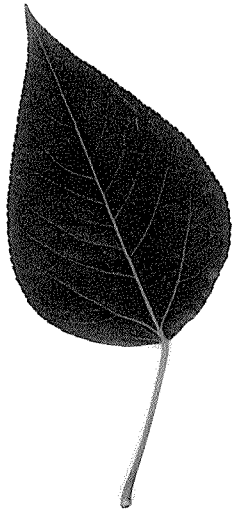
Hybrid black poplars *P. deltoides* × *P. nigra*
(syn. *P.* ×*euramericana*, *P.* ×*canadensis*)

Pre 1980
'Eugenei', 'Flevo', 'I 30', 'I 78', 'I 154','I 214',
'I 455', 'I 488', 'Laevigata', 'Marilandica',
'Regenerata', 'Robusta', 'Serotina', 'Tasman'

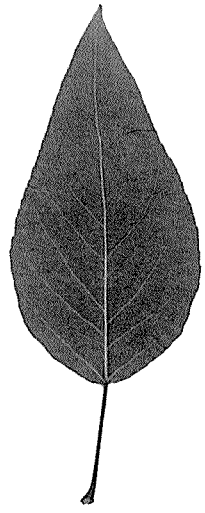
Post 1980
'Luisa Avanzo', 'Veronese', 'Argyle'
'Crow's Nest', 'Manawatu Gold'

SECTION TACAMAHACA – balsam poplars

Leaves green above, under-surface with a whitish, greyish, or greyish green metallic appearance, sometimes flushed with a rusty coloration, oval to egg-shaped without an obvious translucent margin, often only faintly or obscurely toothed; leaf stalk roundish in cross-section; buds sticky and usually strongly balsam scented.

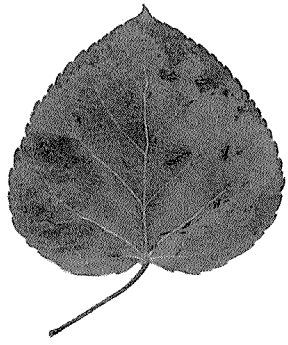


P. yunnanensis



P. trichocarpa

P. angustifolia
P. cathayana
P. ciliata
P. maximowiczii
P. simonii
P. szechuanica
P. trichocarpa
P. yunnanensis



'Candicans'

HYBRIDS INVOLVING BALSAM POPLARS

American Schreiner hybrids

P. maximowiczii × *P. trichocarpa* 'Androscoggin'
P. maximowiczii × *P.* x*berolinensis* 'Oxford'
P. maximowiczii × *P. nigra* 'Rochester'

Hybrids between black and balsam poplars

P. ×*gileadensis* 'Candicans'
(syn. *P.* ×*jackii* 'Gileadensis')
P. deltoides × *P. maximowiczii* 'Eridano'
P. deltoides × *P. trichocarpa* 'Generosa'
P. deltoides × *P. trichocarpa* 'Pakai'
P. deltoides × *P. yunnanensis* 'Kawa'
(*P. deltoides* × *P. nigra*) × *P. yunnanensis* 'Toa'

Description of the Vegetative Characteristics of the Main Species and Hybrids of Poplar found in New Zealand

Populus alba L. – white poplar, silver poplar

Habit: Tree, growing to 25 m, usually suckering profusely from the roots.

Bark: Grey to white, rather smooth, becoming shallowly fissured with age.

Shoots: Covered in white felted tomentum, rounded.

Buds: White, covered in hairs, not sticky.

Leaves: Variable in shape, maple-like with three to five coarsely toothed lobes on vigorous long shoots, shallowly lobed on short, less vigorous shoots, 6–12 cm long, covered in white hairs when young, becoming dark green above with a felty covering of white hairs below and on the round leaf stalk.

Represented in New Zealand by a single, widely naturalised female clone with a broad spreading crown (Fig. 13), and by a narrow-crowned male clone, *P. alba* 'Pyramidalis' (syn. 'Bolleana').

Another less common, suckering poplar that may be confused with white poplar is the grey poplar *P.* ×*canescens* (Ait.) Sm., a complex of hybrids between the Eurasian aspen, *P. tremula*, and various forms of *P. alba.* In New Zealand the grey poplars are represented by a few male and female clones of *P.* ×*canescens* introduced from Britain, and four clones of *P. alba* × *P. glandulosa* introduced from Korea of which the male clone, 'Yeogi 1', is currently recommended for woodlots and forestry. These grey poplars can be distinguished from *P. alba* by leaves that are grey rather than white on the underside except when young, and by the leaves at the base of the shoot becoming hairless by autumn. The leaf stalks are generally longer and less hairy or pubescent than *P. alba*. 'Yeogi 1' (Fig.14) is easily distinguished from the earlier introductions of white and grey poplars by its straight trunk and long internodes.

A rare, ornamental, female white poplar from Spain and Morocco, *P. alba* var. *subintegerrima* Lange (syn. *P. alba* var. *hickeliana*), is distinguished from the other white and grey poplars by its semi-evergreen habit, its much smaller, cupped leaves without lobes, and its yellow male catkins.

Populus tremula L. – aspen

Habit: Small tree, growing to 20 m (Fig. 15), usually suckering profusely from the roots.

Bark: Smooth, greyish green, becoming dark grey and furrowed with age.

Shoots: Thin, cylindrical and smooth.

Buds: Shiny, slightly sticky.

Leaves: On long shoots: large, heart-shaped, whitish downy at first, becoming hairless. On short shoots: hairless, suborbicular, coarsely and irregularly toothed with long, flattened leaf stalks. The flattened leaf stalks cause the leaves to flutter or tremble in the lightest breeze and are a characteristic of all aspen species.

This aspen is Eurasian in natural distribution and has many variable forms. Most of the *P. tremula* in New Zealand, some 20 clones in total, are male and occur as single trees or thickets on farms and in parks. A few small trials were established in exotic forests.

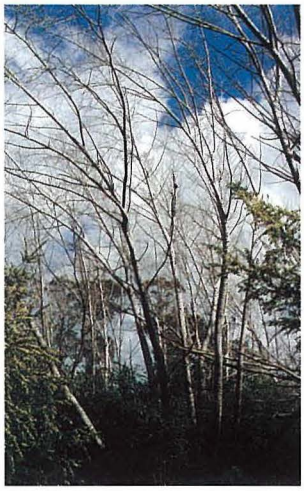


Fig. 13 - *Populus alba,* shown in winter (left) and in spring (right), spreads by suckers to form thickets.

Fig. 14 - *Populus* 'Yeogi 1' (*P. alba* × *P. glandulosa*) (right) showing its straight trunk and profusely suckering habit.

Fig. 15 - *Populus tremula* at Rotorua.

Fig. 16 - *Populus deltoides* 'Frimley', seen here near Tirau, Waikato, is a familiar sight on farmland throughout New Zealand.

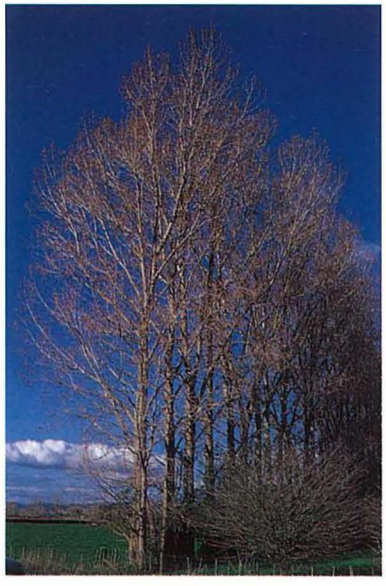


Fig. 17 - The hybrid 'Robusta' (*P. deltoides* × *P. nigra*) being grown as a farm windbreak.

Fig. 18 - The Italian hybrid 'I 78' (*P. deltoides* × *P. nigra*), aged 34 years, growing at Palmerston North.

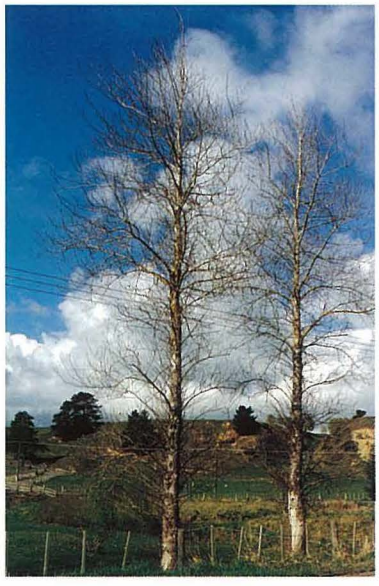


Fig. 19 - *Populus trichocarpa,* aged 20 years, growing at a site near Palmerston North.

Another less common aspen in New Zealand is the American aspen, *P. tremuloides*, which can be distinguished from *P. tremula* by the leaves on its short shoots having smaller, finer serrations or teeth around the leaf margin. None of the aspen clones in New Zealand are suitable for forestry or erosion control.

Populus deltoides Marshall – eastern cottonwood, American black poplar, necklace poplar

Habit: Tall tree, growing to 40 m, with a large trunk (up to a maximum diameter of 3 m), and a heavy-branched, spreading crown.
Bark: Smooth, greenish brown or reddish brown, rapidly becoming thick, dark grey and deeply furrowed with age.
Shoots: Long shoots hairless, clearly five-sided, angular to winged; short shoots more cylindrical.
Buds: Shiny brown, resinous, long egg-shaped, sharply pointed.
Leaves: Long shoot leaves: large, triangular to broadly egg-shaped with a heart-shaped to straight leaf base, two or more large glands at the junction of the leaf stalk and leaf blade, leaf blade green above, slightly paler below and hairless. The leaf margin is translucent and ciliate (with small fine hairs). Leaf stalks are flattened but not as much as in the aspens. Short shoot leaves: smaller, with larger teeth and a longer, flattened leaf stalk. Basal glands may be absent in Western subspecies. The leaf base has a similar but less accentuated heart-shape or straight shape. Western subspecies also tend to have leaves as broad as they are long, and older trees may have some foliage that is more rhomboid in shape resembling *P. nigra*.

The commonest cottonwood in New Zealand is *P. deltoides* subsp. *monilifera* 'Frimley' (syn. 'Virginiana') (Fig. 16). This female clone, one of the first poplars introduced to New Zealand, has smaller leaves than later introductions of *P. deltoides* subsp. *deltoides* from central and southern Mississippi River States. It is common on farmland throughout both islands and, being a female, is noticed in early summer principally because of its massive shedding of snowy white, cotton bearing, wind-borne seeds. Prior to seed release the seeds are borne in long necklace-like chains of capsules, hence the name necklace poplar. It has also often been erroneously called aspen. *Populus deltoides* subsp. *angulata* 'Carolinensis' is a male clone with large leaves and angular branches. Occasionally found in Waikato and northern Hawke's Bay, it is difficult to propagate from hardwood cuttings. Later introductions of *P. deltoides* are confined to trial plantings on a limited number of farms and in arboreta such as Eastwoodhill near Gisborne.

Populus nigra L.– black poplar

Habit: Tall tree, growing to 40 m. It has two forms – the normal heavy-branched, broad-crowned form and the fastigiate/columnar form so common in New Zealand. The trunk may form large burrs. There is profuse production of epicormic shoots on trees at wide spacings.
Bark: Yellowish brown, becoming dark grey-brown and deeply fissured with age.
Shoots: Brown, becoming grey-brown later, cylindrical and fairly slender. Very vigorous shoots may be five-angled but are not usually winged or ribbed as in *P. deltoides*.
Buds: Small, reddish brown, pointed and sticky.
Leaves: Long shoot leaves are dark green above and below, rhomboid (diamond-shaped) to deltoid in form but mostly with a straight to wedge-shaped base. Margins are translucent, non-ciliate, regularly and shallowly round-toothed. Short shoot leaves are diamond-shaped, typically hairless,

with translucent margins regularly and shallowly round-toothed. *Populus nigra* can be distinguished from *P. deltoides* by the absence of marginal hairs on the leaves and absence of glands at the leaf base.

Populus nigra is represented in New Zealand almost exclusively by a single male clone, *P. nigra* 'Italica', the well known Lombardy poplar with fastigiate columnar growth habit (cover photograph). Rare specimens exist of some broad-crowned cultivars such as 'Manchester' and 'Betulifolia' from Britain. Other narrow-crowned forms of *P. nigra* var. *thevestina* from Turkey, exist only in a few trial plantings.

Populus* ×*canadensis Moench. = ***Populus deltoides* × *P. nigra*** [***P.* ×*euramericana*** (Dode) Guinier] – hybrid black poplar

Habit: Tall tree, growing to 40 m, crown shape varying between cultivars from broad ('Flevo', 'I 214') through intermediate ('I 78', 'Argyle') to narrow ('Tasman', 'Veronese'). All become broader-crowned with age. Only 'Crow's Nest', a back-cross hybrid to Lombardy poplar, has a columnar growth habit.

Bark : The age at which rough bark forms varies. Some cultivars (e.g., 'Argyle') develop a deeply furrowed bark by age five, while others (e.g., 'I 214') do not form rough bark until at least ten years old. Bark colour varies from reddish brown to greenish brown on young stems, becoming pale grey to dark grey with age.

Shoots: Generally more angular than in *P. nigra*, hairless, colour varying from red-brown to greenish brown, becoming grey-brown with age.

Buds: Intermediate between *P. nigra* and *P. deltoides.*

Leaves: Very variable. To compare clones it is necessary to take leaves from exactly the same orientation and position on the long or short shoot. This is usually done in late summer on leaves from the centre portion of the stem of one-year-old plants grown from cuttings. The leaf colour (yellow-green, coppery brown to dark reddish brown) of new spring growth of long shoots is also a useful distinguishing character but differs between cutting-grown trees and coppice shoots. The leaf size and shape is generally intermediate between *P. deltoides* and *P. nigra* in the first hybrid generation but then segregates towards one or other parent with subsequent crosses.

In New Zealand, hybrid black poplars, especially the male clones 'Robusta' (Fig. 17), and 'Flevo' and the female 'Italian' hybrids ('I 78' (Fig. 18) and 'I 214'), are the most common poplars after *P. deltoides* 'Frimley' and Lombardy poplar. More recently these have been superseded by 'Tasman', 'Veronese' and 'Argyle'.

Populus trichocarpa Hook. – black cottonwood

Habit: Tree, growing to 40 m, straight trunk, sometimes with large numbers of epicormic branches on the basal 5 m (Fig. 19). It has finer branching in the crown than *P. deltoides*. It is the tallest hardwood in North America and, in the USA and Canada, trees up to 60 m tall have been recorded in riverine forests.

Bark: Smooth, initially with greenish grey-brown flakes shed annually, becoming dark grey, rougher and more furrowed in trees over 15 years old.

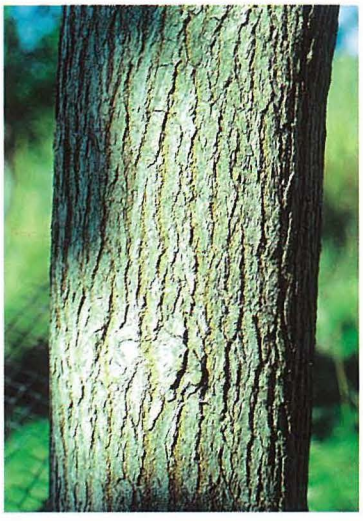
Shoots: Young shoots slightly angular, olive-brown, may be downy initially, soon becoming hairless

Buds: Brown, slender, often coated with yellow-brown, fragrant balsamic gum.

***Populus alba* has whitish smooth bark often marked with dark-coloured lenticels.**

'Argyle' (*Populus deltoides* × *P. nigra* 'Italica') has rough bark. Picture taken five years after planting.

***Populus trichocarpa* nine years after establishment from poles.**



'Kawa' (a *P. deltoides* × *P. yunnanensis* cultivar).

Mature tree of *P. deltoides* 'Frimley' showing the deeply furrowed bark that develops with age.

***Populus tremula.* The bark is smooth on the upper trunk and rough at the base.**

Fig. 20 - Bark of poplars.

P. alba

P. tremula

P. nigra

P. deltoides

P. trichocarpa

P. yunnanensis

Fig. 21 - Poplar shoots.

Leaves: Leaves egg-shaped, slightly heart-shaped to broadly wedge-shaped at the base, tapering to a slender point, large and vigorous on long shoots, dark green above, conspicuously white below. The leaf stalk is short on long shoots and longer on short shoots. Californian forms have smaller, tougher leaves and are greyer underneath.

The most common *P. trichocarpa* in New Zealand is the male clone 'PN 471', a Belgian selection released for erosion control and windbreaks in 1978. This clone retains a narrow compact habit even at wide spacings. A few older clones exist as specimen trees on farms or in old forestry arboreta.

Populus yunnanensis Dode – Yunnan or Chinese poplar

Habit: Tree, growing to 30 m, with a short straight trunk and a heavy-branched, wide-spreading crown. The form improves in woodlots.

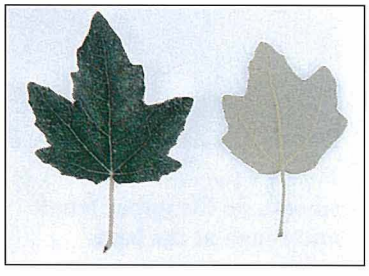
Bark: Initially smooth, shedding brown flakes annually, becoming rougher, darker grey-brown in trees over 15 years old. Young flaky bark is always browner than that of *P. trichocarpa*.

Shoots: Long shoots, strongly angled similar to *P. deltoides*, pale green becoming brown, hairless.

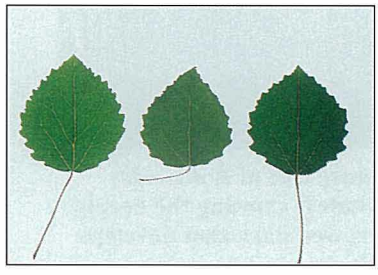
Buds: Shiny brown, hairless, sticky.

Leaves: Egg-shaped similar to *P. trichocarpa*, tapering to the apex, wedge-shaped at the base. Glossy green on the upper leaf surface, greyish on the lower surface, hairless, midrib and leaf stalk pink-red. Leaf stalk short on long shoots, longer on short shoots as for *P. trichocarpa*.

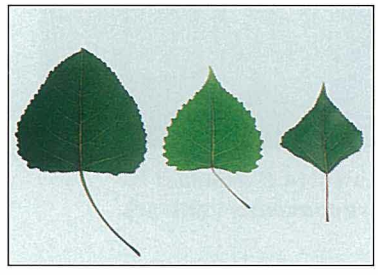
A single male clone of this species, 'Yunnan', has been widely planted on farmland throughout New Zealand, principally because of its possum resistance combined with highly attractive, glossy leaves. Later importations have a dull or matt green leaf and are present only in experimental plantings.



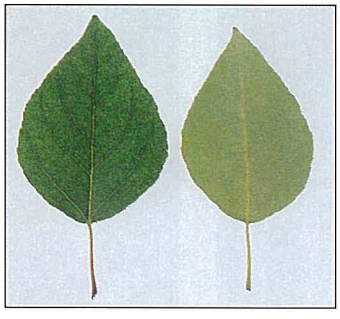
Populus alba **– upper and lower surfaces.**



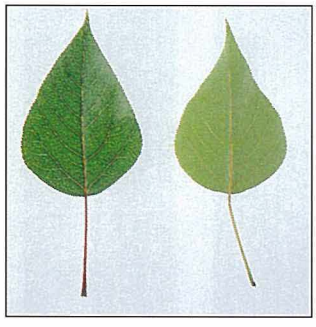
Populus tremula.



Populus deltoides **subsp.** ***deltoides*** **(left),** ***P. deltoides*** **subsp.** ***monilifera*** **(centre),** ***P. nigra*** **(right).**



Populus trichocarpa **– upper and lower surfaces.**



Populus yunnanensis **– upper and lower surfaces.**

Fig. 22 - Leaves of poplar species.

Hybrid balsam poplars

***Populus* ×*gileadensis* 'Candicans'**
Balm of Gilead poplar, a female clone thought to be a hybrid between *P. balsamifera* and *P. deltoides*, is easily distinguished by its heart-shaped leaves, large sticky buds, strong balsam scent, and vigorous suckering habit. It is present as a roadside and stream bank tree in the central North Island, Hawke's Bay and in Otago, and it has been planted as a farm specimen tree.

***Populus maximowiczii* hybrids**
'Androscoggin', 'Oxford' and 'Rochester' were planted in forestry woodlot trials and have attained good size and form in South Canterbury, Otago and Southland. A more recent, leaf rust-resistant *P. maximowiczii* hybrid is 'Eridano'. All these clones tend to have a smooth, pale grey bark for their first 15 to 20 years and large oval leaves, ***often with a twisted leaf tip*** typical of *P. maximowiczii.* Leaves are green to dark green above and pale and silvery beneath. All have large sticky buds with a balsam scent. *Populus maximowiczii* is uncommon in New Zealand as a pure species but it has contributed useful genes to many hybrid clones.

***Populus trichocarpa* hybrids**
Older erosion control and roadside plantings may contain both male and female clones of the *P. deltoides* × *P. trichocarpa* cultivar 'Generosa'. These clones have large, egg-shaped, tapering leaves intermediate between the two parent species and, within 5 to 10 years, smooth bark becoming rough, similar to *P. deltoides*. They are very susceptible to rust.

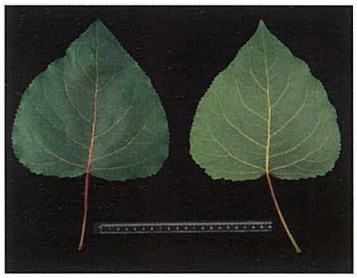
Natural hybrids

In New Zealand, although poplars have rarely become naturalised as abundantly as some willows, notably grey willow (*Salix cinerea)* and crack willow (*S. fragilis*), natural hybrids have occurred between some of the more common black poplars, *P. deltoides* × *P. nigra* (*P.* ×*euramericana*) and balsam poplars (*P. yunnanensis* and Schreiner hybrids). Resulting hybrid seedlings are occasionally found on riverbanks or bare roadside banks.

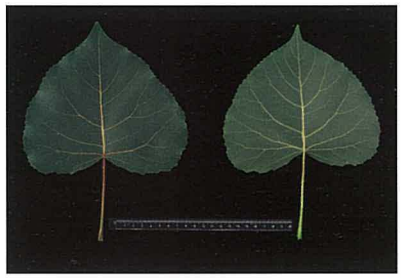
Recognition of Clones

Poplar clones, especially those derived from crosses between the black poplars, *P. deltoides* and *P. nigra*, can be very hard to tell apart, even by a trained observer. Features that can be helpful include the relative time of new leaf emergence, colour of new leaves, sex of the plant (discernible only from the catkins in late winter to early spring and then only when the tree is old enough to produce catkins), and leaf shape and petiole length. These last two features can, however, be very variable even on the same tree. Other features that can be helpful in identifying a clone include susceptibility to rust diseases, palatability to possums, and whether the tree suckers. The most reliable method, however, is an accurate record of the ancestry. Leaves of poplar cultivars recommended for planting in New Zealand, as at 2000, are shown in Figures 23 and 24.

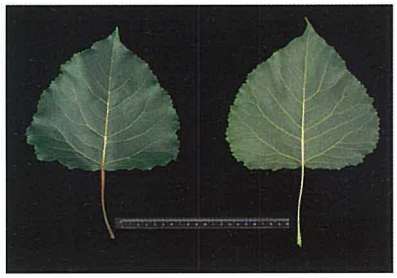
In New Zealand, accurate clone identification has been carried out by growing the clone of interest from hardwood cuttings in a nursery and comparing these plants directly with known cultivars. HortResearch, Palmerston North, provides this service nationally. In future, new DNA analysis techniques may be used.



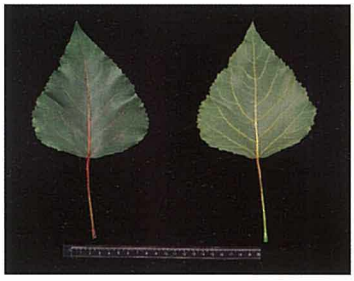
'I 214'
Flushes dark brownish bronze in the third week of September. Leaves have a straight to shallowly heart-shaped base. Trunks are leaning or wavy compared with other hybrid black poplars (except 'Flevo').



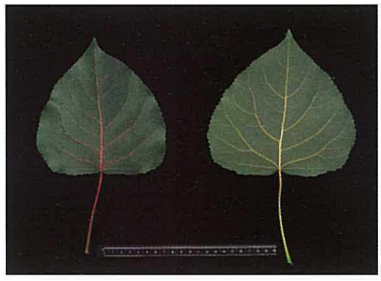
'Flevo'
Flushes dark bronze in the second week of September. Leaves are heart-shaped and as broad as long. Can be distinguished from 'I 214' by male flowers and the absence of leaf rust.



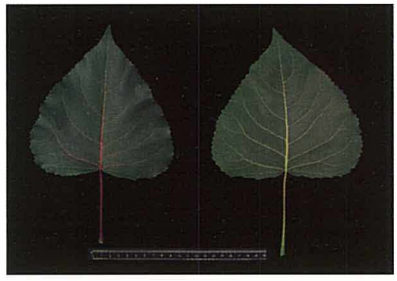
'Tasman'
Flushes yellowish bronze in the second week of September. Leaves have a straight to slightly heart-shaped base and yellow-green midrib. Can be distinguished from 'Toa' and 'Veronese' by male flowers.



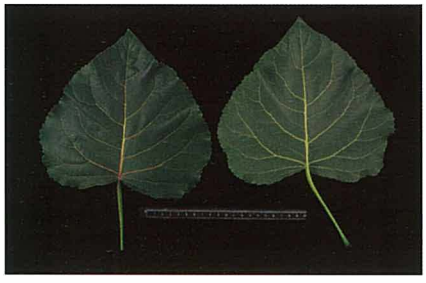
'Crow's Nest'
Flushes dark reddish bronze in mid to late September. Leaves have a wedge-shaped base. Distinguished from Lombardy poplar by female flowers, dark red-bronze colour of new leaves (green in Lombardy), and pinkish red midrib and veins.



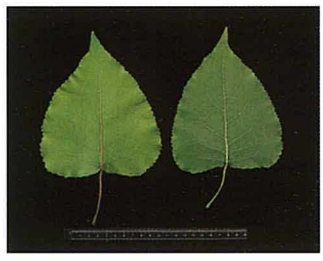
'Luisa Avanzo'
Flushes bronze in the third week of September. Very similar to 'Veronese' but 'Veronese' leaves have a more triangular shape with a shallowly heart-shaped base. Midrib and leaf stalk are not as red as those of 'Veronese'.



'Veronese'
Flushes dark reddish bronze in the third week of September. The angle of leaf stalk and branch insertion into the main stem are more acute (steeper) than for 'Luisa Avanzo'.

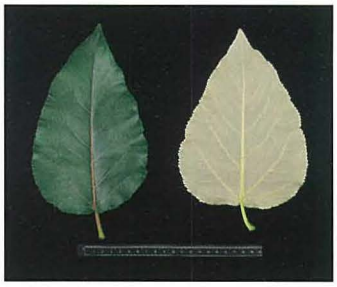


'Argyle'
Flushes bronze in late September. Similar to 'Luisa Avanzo' and 'Veronese' but leaves are more heart-shaped with a more undulate leaf margin. Easily distinguished from other hybrid black poplars by the early development (from age three years) of thick, furrowed bark.



'Manawatu Gold'
Flushes pinkish red in early October. Leaves become pale gold to lime green and then a deeper gold in late summer. Distinguished from other gold-foliaged cultivars by large deltoid leaves, longer than wide, and the typical open-crowned habit of *P. deltoides*.

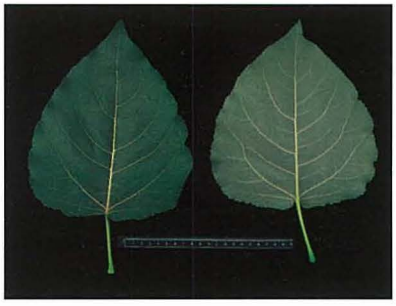
Fig. 23 - Leaves of black poplar hybrids (*P. deltoides* × *P. nigra*) recommended for planting (as at 2000).



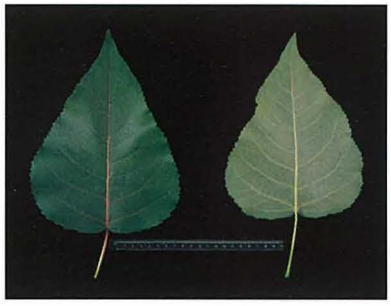
'Androscoggin'
Flushes green in mid September. Leaves are more oval and darker green on the upper surface than for 'Eridano'. Leaf stalks are short, similar to *P. maximowiczii*.

***P. trichocarpa* 'PN 471'**
Flushes green in late September to early October. Leaves are thin with a white waxy undersurface.

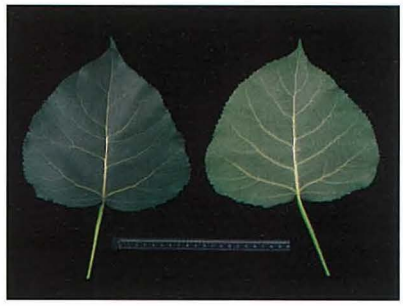
'Yunnan'
Flushes bronze to greenish brown in late September to early October. Leaves are glossy, dark green with a red midrib and leaf stalk on the upper surface, grey-green with rusty balsam streaks on the lower leaf surface.



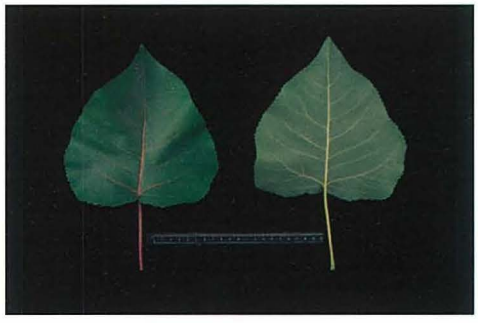
'Eridano'
Flushes pale green in the first week of September. Leaves are larger, broader and more deltoid than 'Androscoggin'. The leaf midrib is green, tinged red at the leaf base.



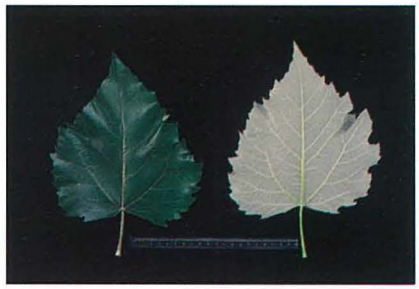
'Pakai'
Flushes green in the third week of September, about five days prior to 'Toa', 'Kawa' and 'Yunnan'. Leaves have a rounded leaf base.



'Toa'
Flushes light bronze in late September to early October. Leaves are similar in shape to 'Tasman' with straight to shallowly heart-shaped leaf bases. 'Toa' is a darker green on the upper leaf surface and grey-green below. The midrib on the upper leaf surface is tinged pink for up to half its length whereas in 'Tasman' it is yellow-green.



'Kawa'
Flushes pinkish green in late September-early October. Leaves become green above, pale grey-green below. The midrib and petiole are tinged pinkish red on the upper surface.



'Yeogi 1'
Flushes greyish white in the second week of September. Leaves are green on the upper surface and silver and hairy beneath with large teeth and a shallowly heart-shaped base.

Fig. 24 - Leaves of balsam poplar cultivars and hybrids between balsam and black poplars recommended for planting (as at 2000).

ROLE OF THE SPECIES

Site Requirements

In New Zealand, selected poplar cultivars can survive a wide range of environments from coastal situations to the bush line in both the North and South Islands. They grow best on moist valley bottoms and lower hill slopes and, like most deciduous trees, become deformed and stunted on exposed upper slopes and ridges and windy coastal sites. With few exceptions, poplars are not drought-resistant and require at least moderate soil moisture, maintained by a regular rainfall or irrigation of at least 20 mm per week throughout the growing season (September to early April). Poplars will grow in low rainfall areas provided they are confined to soils with a high water table, or are irrigated. 'Yeogi 1', other grey poplars and some *P. trichocarpa* cultivars possess the greatest tolerance of seasonal dry periods but, if planted on hillsides in summer-dry areas, they should be confined to channels, tunnel gullies and seepage areas.

Unlike tree willows, poplars will not grow well in poorly drained swampland. Where poplars are planted in wet areas, planting should commence on better-drained soils on the periphery and drains should be installed to lower the water table to provide a minimum 30–50 cm of aerated soil. Poplars are tolerant of a wide range of soil types, from pH 5–8, but will grow most rapidly on deep loamy soils. They respond well to weed control, irrigation, and nitrogenous fertilisers.

All poplars in their deciduous state can tolerate more than -30°C ground frost. *Populus yunnanensis* and its hybrids 'Kawa' and 'Toa', and also 'Pakai', a *P. deltoides* × Californian *P. trichocarpa* hybrid, may suffer growing shoot/tip damage caused by late spring and summer frosts. They are therefore less suitable for frosty flats at higher altitudes (above 500 m a.s.l.) in the North Island and inland sites in the South Island. Other clones, such as 'Veronese', 'Eridano' and 'Yeogi 1', suffer little, if any, frost damage in New Zealand.

The full extent of site adaptability of poplars in New Zealand remains a matter of conjecture in the absence of broadly-based population introductions involving provenance material from throughout the natural geographic range of the various species.

Establishment

Nursery Practice and Propagation Techniques

In New Zealand, poplars planted for soil conservation and shelter are usually established from unrooted material and only occasionally from one-year-old rooted cuttings. Vegetative material (wands, stakes and poles depending on size)* is produced in specialised stool nurseries, usually belonging to regional or district councils, whereas rooted material is produced by private nurseries. Rooted cuttings are used mainly for windbreak establishment but may play a greater role in future in farm forestry woodlots. For information on the production of vegetative and rooted material see pages 53–54 (Nursery Practice and Propagation Techniques).

* Wands 1–1.2 m long and 1.5–2.5 cm in diameter; stakes: 1–1.2 m long and 2.5–4 cm wide; light or sheep poles: 2–2.5 m x 4–6 cm; heavy or cattle poles: 3 m x 6–10 cm.

Establishment in association with pasture

Poplar trees can be established from 3 m poles, one-year-old saplings (1.5–2 m grade), or unrooted stakes (70–100 cm long, 15–25 mm small-end diameter) using specialised pole-drivers, motorised augers or spades. Unrooted poles are normally planted to 75–80 cm in depth, stakes or cuttings to half their length, and rooted trees with at least 20–30 cm of the stem buried. On wet clay soils, rooted trees should be planted to the same depth as in the nursery. This is more important for balsam and grey poplars and *P. deltoides*, as lack of oxygen in the rooting medium in spring can cause the bark to decay and result in planting failures. Suitable protection of poles (e.g., with Dynex© plastic tubes or Treegard© plastic netting sleeves) allows continuous livestock grazing of the planted area.

The other types of planting stock (one-year-old saplings and stakes) are cheaper but require more elaborate protection if the planting area is not retired from grazing. The cost of establishing a stake in a grazed area is close to that of a pole because of higher protection and tending costs. If stake plantings are unprotected, the area must be retired from grazing for 2–3 years to allow proper establishment.

If poplars are to be planted as plantation forests, the necessary technologies for raising planting stock, site preparation and weed control need developing specifically for this purpose. Regular releasing from grass and weed competition by cultivation, mulching or herbicide application is beneficial throughout the first two growing seasons and is essential for unrooted stake material and one-year-old trees or stumps.

Post-planting directed sprays of most knockdown herbicides can be used with confidence in calm conditions, especially before new foliage appears in spring. Care should be taken with the use of residual herbicides, particularly with unrooted stakes which tend to form new roots near the soil surface. On sites that have a near-surface water table during winter, or have a free-draining soil combined with high spring rainfall, the use of residual herbicides is best avoided for unrooted stakes. The following herbicides are suggested, per 10 litres of water, for knapsack application.

TYPE	HERBICIDE	USE
Knockdown	Gallant (10% a.i.)	Good pasture sites – ryegrass/clover
	Versatil (30% a.i.)	Good pasture sites – ryegrass/clover
	Glyphosate (36% a.i.)	Weedy sites – rhizomatous grasses, perennial broad-leaved weeds, brushweeds
Residual	Simazol (50% a.i.)	Sites where rapid-seeding grasses are likely to reclaim planting spots

If young trees are unprotected, the resumption of grazing depends on animal stock type and on the rate of formation of rough bark. In the case of the clone 'Argyle', rough bark formation usually starts in the second year after pole planting but will take an extra season for one-year-old saplings or stake planting material. 'Kawa' bark appears rough but is thin and still susceptible to stock browsing and damage by horned cattle. The clone 'Eridano' retains a smooth, thin bark for some years, however, and is best suited to only moderate sheep and light cattle grazing pressure, even when mature.

Establishment in association with crops

The best establishment and growth of poplars occurs when cuttings 25–40 cm long, or one-year-old rooted trees or stumps are planted in cleanly cultivated cropland in conjunction with cash crops of vegetables, cereals, maize, or melons. On fertile cropland, especially with regular irrigation, sawlogs and veneer logs can be produced on a 12–15 year rotation, as is routinely accomplished in Argentina, China, Italy, Turkey, and many other countries. The normal sequence is to grow vegetables, melons or maize for the first 2–3 years, then switch to oats and barley, and finally to *Lotus* spp. as canopy closure occurs. Weed control is maintained by herbicides or cultivation as for the crops.

Spacing

With a clone well matched to site, 100% survival is possible and trees can be planted at their intended final spacing. A number of spacing trials are under way to determine optimum spacings for growth rate and yield for different poplar varieties. This information will take some time to acquire. Meanwhile the general recommendation is 100 stems/ha (10 × 10 m or 20 × 5 m) for agroforestry where considerations of pasture versus timber production are fairly evenly balanced, and up to around 200 stems/ha (10 × 5 m or 7 × 7 m) where timber production is given predominance during the latter stages of the rotation. For variable or marginal sites, allowance should be made for lower establishment rates and later losses or damage to trees. Initial planting density could be increased by 15–20% over final crop spacing, and excess trees culled at the end of the third season or later depending on establishment and growth rates (but only if thinnings are marketable or can be used on-farm). For cropping situations, within-row spacings should be at least 4 m.

Pruning

Pruning is essential to produce clean, knot-free timber. Unrooted stakes, or trees which have been cut back to stumps, can be pruned during late summer to early autumn of the first season with removal of all growth except the most vigorous, straightest shoot. Branches should be pruned flush with the stem to avoid 'coathangers'. With all planting stock types, pruning at the end of the second season is aimed at maintaining the form of a straight, upright central leader. Regular pruning of side branches is carried out from around the third or fourth year depending on growth rate. From then on, the aim is to maintain central leader dominance and restrict the knotty core to 150 mm diameter over pruned branch stubs (as for radiata pine). It is recommended when pruning that at least 50% of the height of the tree be retained as green crown, in order to keep sufficient leaf area to maintain growth rates.

Pruning is best carried out late in the growing season (February–March) to reduce regrowth of epicormic shoots and to avoid the main flight season of wood-boring beetles (e.g., lemon tree borer). Pruning should preferably be confined to dry weather to avoid the possible infection of wounds by silverleaf fungus. Pruning in late summer also provides a livestock fodder bonus as leaves of all poplar varieties are nutritious and readily eaten by livestock.

Poplar clones vary in their response to pruning. *Populus nigra* and *P. deltoides* × *P. nigra* clones, and *P. trichocarpa* (coastal Oregon and California origins), resprout following heavy pruning of wide-spaced trees and may be better grown in woodlots. *Populus deltoides*, *P. maximowiczii*, *P. yunnanensis*, and their hybrids 'Eridano' and 'Kawa', appear to produce less epicormic shoots following pruning and may be easier to keep clean-pruned at wide spacings in pasture and in timberbelts.

Agroforestry

The sustainability of large areas of pastoral production in New Zealand depends on more tree planting being done on farms. Landcare Research studies have shown that 7.6 million ha of the New Zealand land resource require farm woodlots, wide-spaced tree plantings, and/or other soil conservation measures if physically sustainable pastoral use is to be maintained. The area requiring changes to current pastoral management practices covers 32% of the North Island and 25% of the South Island. Poplars could have an important role as multi-purpose trees compatible with pastoral and cropping systems. However, significant information gaps regarding species performance, site selection, growth, quality, value, and market demand currently restrict investor confidence.

Over the last 15 years, government financial subsidies for erosion control efforts by farmers have been progressively eliminated with the initial result that the numbers of poplars planted for erosion control were drastically reduced. This is changing with the realisation that silvopastoral systems including poplars and willows are necessary for sustainable pastoral farming on several million hectares of New Zealand hill country, and stream and riverbanks. There is thus a potential for creating a large, economic resource of pruned poplar sawlogs at spacings of 25–200 stems/ha in conjunction with improved grassland management and other erosion control measures. Farmers may be able to supplement farm income by producing sawlogs off wet river flats and stream banks in 12–15 years, compared to 25 years for a radiata pine woodlot.

Much of the existing poplar resource in New Zealand has not received any silvicultural tending and consists of a number of disease-susceptible poplar clones, generally referred to as the Italian hybrids. In future, New Zealand-bred, improved cultivars will be available. These vigorous, disease- and possum-resistant hybrid cultivars have been developed by HortResearch primarily for use in erosion-prone pastoral environments. They have been tested over the last 10 years in on-farm trials and regional council soil conservation nurseries.

Two clones already available are 'Kawa' (the first New Zealand-bred hybrid) and 'Veronese' (an Italian hybrid), which have some potential for timber production and have been evaluated by Forest Research for wood density, as well as sawing, seasoning and machining properties. In 1996 HortResearch released the possum-resistant, hybrid balsam poplars 'Toa' and 'Pakai', and the rough-barked black poplar clone 'Argyle' to commercial nurseries. Also, over the next three years, several more named poplar clones suitable for agroforestry, soil conservation and windbreak use will become available. These new clones are the result of 15 years' work, breeding and testing new hybrids from disease-resistant selections of pure species introduced to New Zealand during the 1970s.

Current forestry practice in New Zealand focuses largely on radiata pine. Poplars should not be regarded as a substitute in terms of planting site, growth response, management or marketability, but rather as a complementary farm forestry species to integrate with other pastoral activity.

Cultivar selection

Successful poplar agroforestry depends on matching a suitable variety to an appropriate site. Clones selected for frost-free North Island hillsides may grow well in inland areas of the South Island or parts of the central North Island, but young trees can be damaged by spring or summer frosts. Clones

resistant to wind damage (e.g., 'Tasman' and 'Veronese') are not generally resistant to possums. Varieties which are susceptible to leaf diseases in high rainfall North Island environments may be better suited to dry inland climates in the South Island.

The possum-resistant balsam hybrids (e.g., 'Eridano') perform best in relatively moist, sheltered situations. If subjected to strong winds, poor tree form usually results. The black poplar hybrids (e.g., 'Veronese') are better suited to more exposed situations and windbreak use. Of the released clones currently available through regional councils and/or commercial nurseries, those that possess agroforestry potential are 'Eridano', 'Kawa', 'Pakai', 'Tasman', 'Yeogi 1', 'Argyle', 'Toa', and 'Veronese'. See Table 2 for a summary of clonal characteristics.

Pastoral impact

In a recent study under a mature *P. deltoides* stand in the Pohangina valley, north-east of Palmerston North, summer pasture production losses were found to be 40% at a planting density of 37 stems/ha (Guevara-Escobar *et al.*, 1997). Pasture under the poplars was also of lower feed quality than that grown in the open. Preliminary estimates based on a poplar canopy closure model developed by Forest Research indicate summer pasture production losses of about 32% at age 10 years and 45% at age 15 years for stands planted at 100 stems/ha. During winter, however, the losses are expected to be only 6% at age 10 years and 8% at age 15 years. At 200 stems/ha, summer pasture production losses are predicted to be 47% at age 10 years and 62% at age 15 years, with winter losses at 9% at age 10 years and 11% at age 15 years.

Annual pasture production losses are likely to vary between clones and regions depending upon the dates of flushing and leaf fall, and the annual distribution of pasture growth. Regions that suffer from summer droughts but have high winter pasture growth rates may lose less pasture annually than regions where most pasture production occurs during summer. Assuming a five month leafless period from May to September, and using seasonal pasture growth data for the Gisborne plains (Radcliffe and Sinclair, 1975), annual understorey pasture losses at 200 stems/ha are estimated at 25% at age 10 and 30% at age 15.

Pasture production losses can be partly offset, however, by the forage value of the tree prunings. Recent studies of poplars by AgResearch in Hawke's Bay (Smith, 1992 unpublished) found the crude protein content of foliage and stem tips to be 13–15%, with crude digestibilities of 66–70%. In general, the nutritive value of fresh poplar leaves is close to that of lucerne hay and about 1.4 kg of fresh poplar leaves will maintain a ewe for a day.

Regular pruning at two-year intervals can yield an estimated 1–5 kg of edible dry matter per tree per year, the amount increasing as the tree increases in size. Poplar foliage can be fed to sheep and cattle in times of drought (Fig. 27), and the role of foliage as prunings from poplar stands grown for sawlogs or from the tops of pollarded tree willows is being investigated more fully to determine its role in sustainable, hill country silvopastoral systems. Some clones of balsam poplars such as *P. trichocarpa* and *P. maximowiczii* have high phenolic contents which may make them less palatable.

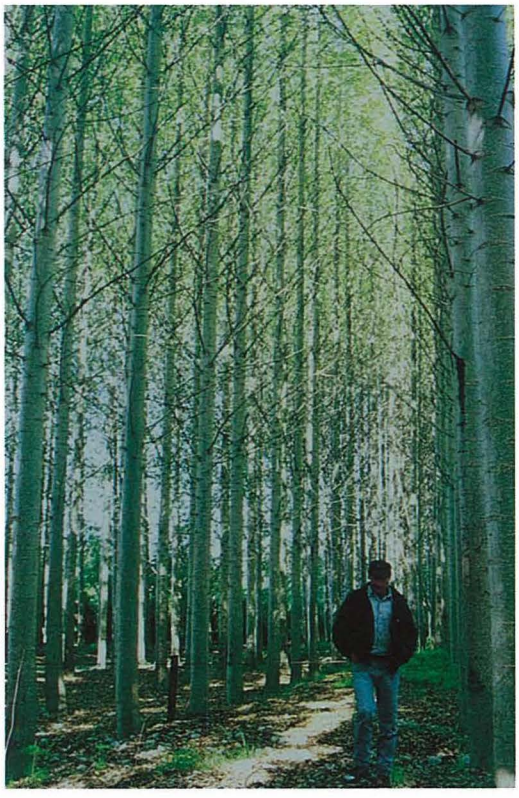


Fig. 25 - Stand of *P. maximowiczii* × *P. nigra* 'Rochester' aged 26 years, planted at 8 m × 3 m spacing at Temuka.

Fig. 26 - Stand of *P. deltoides* × *P. nigra* 'Robusta' aged at least 26 years, at Berwick Forest, Otago.

Fig. 27 - Poplar prunings providing late summer forage, Palmerston North.

Fig. 28 - Windbreak of 'Crow's Nest' (*P. deltoides* × *P. nigra*) × *P. nigra*, at Aokautere, Palmerston North.

Shelter

Poplar windbreaks for horticulture

Poplars should be planted only as perimeter or wide-spaced belts at 100 m apart in horticultural blocks. Alders such as *Alnus cordata* and *A. glutinosa* are better for internal windbreaks as their root systems are both nitrogen-fixing and less spreading than those of poplars and willows, and do not compete as vigorously with the crop for water and nutrients.

The most popular clones for shelter are the hybrid black poplars, 'Tasman', 'Veronese' and 'Crow's Nest' (Fig. 28), with the bulk of these windbreaks being planted in the South Island. In-row spacings should be not less than 2 m apart for 'Tasman' and 'Veronese' and 1 m apart for 'Crow's Nest'.

Poplar windbreaks/timberbelts for pastoral farms

Poplar clones suitable for timberbelts include 'Tasman', 'Toa', 'Kawa', and 'Eridano'. The other clones, 'Veronese', 'Crow's Nest', 'Pakai', and *P. trichocarpa* 'PN 471', are suitable for windbreaks but less suitable for sawlog production because of their tendency to sprout large numbers of epicormic shoots following pruning.

All of these clones, except 'Crow's Nest', should be planted at not less than 4 m apart in single rows. 'Crow's Nest' has the same growth habit as Lombardy poplar but double the growth rate. It can be planted in staggered double rows or as a single row at 1–3 m spacings. Its timber production potential is unknown.

Ornamental poplars

Five ornamental poplar cultivars exist in New Zealand but all are of minor importance except the new rust-resistant, golden-foliaged, hybrid black poplar 'Manawatu Gold'. There is some potential for developing a range of poplars with differing foliage and bark colours, tree form and smaller size for urban parks and farm landscapes. Many landscape designers include balsam poplars such as *P. maximowiczii*, *P. trichocarpa*, *P. yunnanensis*, and *P.* ×*gileadensis* 'Candicans' in plantings because of their strong balsam scent in spring.

Growth and Yield

In their natural habitats most poplars are fast-growing trees. Heights of over 30 m and diameters over 90 cm are common, and *P. deltoides* in North America can grow to over 50 m in height and over 180 cm in diameter. It is the fastest growing commercial forest species in North America and individual trees growing on favourable sites have reached 13 m in height at age three and more than 30 m at age nine. *Populus deltoides* unimproved clones planted at 2700 stems/ha without irrigation have yielded about 140 m^3/ha total volume at age four.

In British Columbia, planted *P. trichocarpa* has averaged 16.8 m in height and 20 cm dbh (diameter at breast height) at 10 years, with some individual trees more than 21 m in height and 30 cm dbh. A plantation on deep alluvial soil in coastal Washington produced more than 500 m^3/ha in 24 years, with dominant trees reaching 35–37 m in height and 33–41 cm in dbh. Exceptional trees of *P. trichocarpa* have reached more than 60 m in height and up to 300 cm in diameter.

In New Zealand the largest recorded poplar, *P. deltoides* 'Frimley' planted in 1875 at Frimley Park, Hastings, was 47.7 m in height with a diameter of 2.8 m in 1986 (Flook, 1994). *Populus yunnanensis* planted in 1908 by Redwood Goulter, the first owner of Lake Timara sheep station in Blenheim, was recorded in 1970 as being 25 m in height with a dbh of 100 cm and a spread of 27 m.

Assessments of 39 mature and semi-mature stands by Forest Research showed that, with a clone properly matched to site and pruned on a similar schedule to that recommended for radiata pine, about 235 m^3/ha of total volume production could be expected at around 15 years for a crop established at a final spacing of 100 stems/ha on good sites. This reduced to about 75 m^3/ha for plantings on hill country. At a stocking rate of 200 stems/ha and a rotation of about 20 years, a total yield of 401 m^3/ha could be expected on good sites. These figures are preliminary estimates based on a MARVL* inventory of a range of different species and clones, although black poplars, particularly Italian hybrids, made up the majority of stands assessed (Table 3).

Table 3 - Poplar clones assessed in MARVL inventories

Poplar group	Clone	No. of stands assessed
Balsam	'Androscoggin'	4
Black	*P. deltoides* hybrid	4
	'Eugenei'	1
	'I-30'	2
	'I-78'	9
	'I-214'	7
	'I-488'	1
	'Rochester'	1
	'Robusta'	5
	Mixed *P. deltoides* × *P. nigra* clones	1
	'Yeogi 1'	2
Other	Mixed clones	2
Total		39

Table 4 summarises this inventory information, and shows the expected mean top height and total volume production for good, medium and poor sites at wide spacings (7 × 7 m, 200 stems/ha). Low fertility soils with pans or impeded drainage, or hill country away from riverberms in cold areas of both islands, are likely to be 'poor' sites but this can be ameliorated by choice of clone, cultivation, irrigation, and fertilisation.

In addition to planting on suitable sites, selection of the correct species, clone and spacing is essential for the success of poplar plantings. Failure to select the correct cultivar can result in growth rates reduced to half of those in Table 4.

Estimates of volume by log grade have also been produced by Forest Research, based on further analysis of the same 39 stands used to produce the height and volume functions. Total recoverable volume was allocated to one of four generalised log grades (Table 5).

* MARVL (method for assessment of recoverable volume by log grade) is a computer-based inventory system.

Table 4 - Approximate height and total volume growth for wide-spaced (7 × 7 m) poplars in New Zealand

Age (years)	Good site (riverberm)		Medium site (erosion control plantings)		Poor site (hill country)	
	Volume (m^3/ha)	Mean top height (m)	Volume (m^3/ha)	Mean top height (m)	Volume (m^3/ha)	Mean top height (m)
10	173	20	104	18	55	14
15	302	27	181	24	96	19
20	401	31	240	28	128	22
25	467	34	281	30	149	24
30	507	35	305	32	161	25

Table 5 - Poplar log grades

Log grade (cm)	Min. SED* size (cm)	Branch
Pruned sawlogs	30	na
Small branched and internodal sawlogs	20	< 6
Large branched sawlogs	20	> 6
Pulp	10	na

* SED = small end diameter
na = not available

Estimates of volume by log grade for a high-pruned stand on a good site at wide spacings (7 × 7 m, 200 stems/ha) are shown in Table 6. Total recoverable volume at age 20 is expected to be 370 m^3/ha, with more than 40% of this (163 m^3/ha) comprised of pruned logs, a further 30% (120 m^3/ha) of small branched sawlogs and internodal lengths, and the remainder being large branched sawlogs and pulp. The same regime on a poor site, however, is expected to yield only 11 m^3/ha of pruned logs, 43 m^3/ha of small branched and internodal sawlogs, 7 m^3/ha of large branched sawlogs, and 46 m^3/ha of pulp.

Data collection on log yields and wood quality is continuing. Timber milled from existing unpruned trees is currently fetching returns equivalent to that of box grade radiata pine on the New Zealand market. The return for clear-pruned logs in the future could be expected to exceed this price level as they will be suitable for more premium uses, such as veneers. On the Asian market, where poplar is an accepted species, prices for clear-pruned poplar are expected to move closer to those received for export radiata pine, depending on end use. Specialised markets already exist in Asia. Chile, for example, is currently exporting disposable chopsticks and icecream sticks, manufactured from pruned poplar, to Korea and China.

Because of the small size of the poplar resource in New Zealand and the wide variety of species and clones present, it is difficult to provide a realistic estimate of growth and yield for any one species or clone. Given that the existing resource of poplar grown for timber in New Zealand is small in size and narrow in genetic base, it is possible that provenances and clones not yet tested in New Zealand may prove more productive than those tried to date.

Table 6 - Approximate log grade allocation for high pruned (6 m), wide-spaced (7 × 7 m) poplars on a good site (riverberm) in New Zealand

Age	Total recoverable volume (m^3)	Log grade volume (m^3/ha)			
		Pruned logs	Small branched and internodal sawlogs	Large branched sawlogs	Pulp
10	150	50	43	7	50
15	274	130	74	13	57
20	370	163	120	21	67
25	433	179	153	26	75
30	471	189	173	30	80

Wood Properties, Processing and Uses

Contributed by Tony Haslett*, John Richardson* and Allan Wilkinson

Wood properties

Wood of poplar species has a fine texture and indistinct growth rings. The wood, which is usually odourless, is often favoured because of its even pale white colour, with heartwood usually being difficult to distinguish from the sapwood. The exception to this, and a potential processing problem, is the occurrence of 'blackheart' (also known as 'bacterial wetwood'), a zone of bacterial infection characterised by an abrupt change of colour (Fig. 29). The moisture content of blackheart can be up to 50% higher than that of normal wood which means that drying time is increased and the blackheart material is prone to collapse in drying. For these reasons, logs containing over 50% by volume of blackheart are probably not worth sawing if the objective is to obtain dry finishing grades of timber.

Blackheart formation is thought to be initiated by branch dieback or injury to the tree stem. Newer clones such as 'Kawa' and 'Eridano' are less susceptible than the older hybrid black poplars. Collaborative research (HortResearch and Forest Research) is in progress to identify the bacteria causing wetwood in both poplars and willows in New Zealand, to develop seedling screening techniques to increase resistance in new clones to these bacteria, and to survey the extent of blackheart within trees and between sites.

Tension wood, which shows as a woolly fibrous surface after sawing, is common. In drying it causes collapse and high longitudinal shrinkage, and warp and splitting of the dry lumber. Further research is required to determine the influence of site and in what varieties tension wood is most common.

The basic density of poplar wood is generally classified as low to medium depending on species or hybrid combination or clone. In New Zealand the most common hybrid poplars vary from 300–340 kg/m^3 (e.g., 'I 214', 'Eridano') through 340–370 kg/m^3 (e.g., 'I 78', 'Veronese') to 370–400 kg/m^3 (e.g.,'Kawa', 'Pakai', 'Androscoggin'). Recent investigations have indicated densities of 320-450 kg/m^3 for *P. trichocarpa* from Salinas, California, and there appears to be considerable potential for breeding and selecting higher density clones for sawn timber production.

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* Manufacturing Technologies, New Zealand Forest Research Institute Limited.

Fig. 29 - 'Blackheart', the zone of bacterial infection, also known as 'bacterial wetwood', is clearly evident in this *P. deltoides* × *P. nigra* 'I 214' log.

Fig. 30 - Furniture made from *P. deltoides* × *P. nigra* 'I 214'.

Fig. 31 - Dresser unit made from 'Kawa' timber grown and milled in Northland. The waka racing paddle is made mainly of Italian hybrid poplar wood.

Fig. 32 - Pole production stoolbed of 'Toa'.

Fig. 33 - 'Kawa' in Northland pruned to 8 m. When felled at 15 years of age, this tree was 25 m tall and had a volume of 1.3 m^3. Part of it was processed into the solid wood dresser unit shown in Fig. 31.

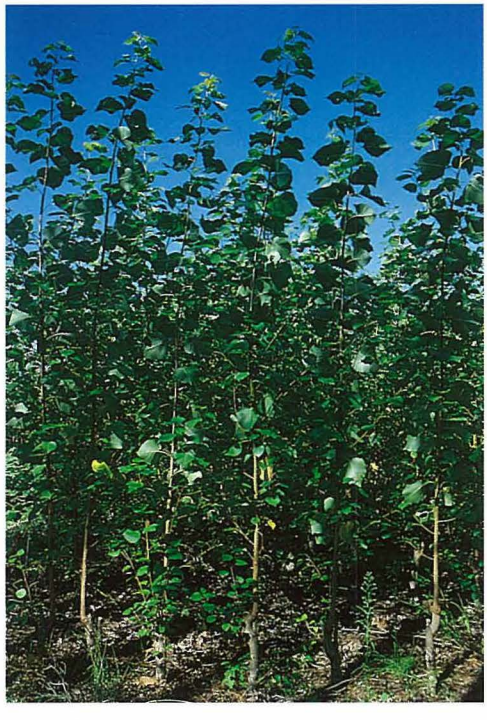

Fig. 34 - One-year-old regrowth of 'Kawa'.

Although there are considerable density differences amongst different poplar species and clones (Table 7), trees of a clone exhibit very little density variation. For example, 'Kawa', with a mean density of 365 kg/m^3, had an individual tree density range of only 9 kg/m^3 compared to a range of over 100 kg/m^3 for non-clonal radiata pine. All poplars tested to date in New Zealand have shown a trend for increased density with increased stem height, but radial trends are more variable. 'Veronese' and 'Kawa' showed no marked radial density change but, for three *P. deltoides* × *P. nigra* hybrids, density increased slightly (about 30 kg/m^3) over the first 15 growth rings. Comparisons have been made of basic wood density of breast height cores from trees of two clones, 'Veronese' and 'Eridano', grown from rooted stumps in a plantation at 5 × 4 m spacing on flat ground and from 3 m unrooted poles at 10 × 10 m spacing on sloping eroding hillsides. There were no significant differences in basic density between the sites. Variation in wood properties will be assessed for individual clones over a larger range of sites during the next four years.

Table 8 summarises the clearwood strength properties of several poplars. The low wood density of some poplars is associated with low clearwood strength properties. However, in-grade testing of 100 × 50 mm and 150 × 50 mm timber of *P. deltoides* and 'Androscoggin' has shown that, provided critical joints receive additional fixing, building grade poplar timber can be used in light frame construction using the same working stresses as for radiata pine No.1 framing. Low surface hardness tends to detract from the use of poplar for furniture.

Processing

Poplar logs contain slight to moderate growth stresses which can cause the logs to end-split as well as resulting in splitting and warping of the sawn timber. To minimise end splitting and staining, excessive storage periods should be avoided, and the logs should be handled with care and cross-cut to short lengths immediately prior to sawing. Where growth stress is a problem, specialised sawing patterns are recommended and these are discussed at length in FRI Bulletin No. 142.*

Timber recovery from sawing poplar logs is lower than from radiata pine, and the main timber defect is knots, so logs with excessive numbers of branches and bumps should not be sawn. Due to difficulties in timber drying, sawing crooked logs and logs with over 50% of their end section as pronounced blackheart should be avoided, as the resultant tension wood will cause excessive warp in drying. Internal decay is generally not as marked as that found in poplar overseas.

The whiteheart wood is easy to dry without degrade and 25 mm thick material can be kilned from green at 70°C in two to three days. However, due to its higher moisture content and tendency to collapse, timber containing blackheart must be air dried to 30% moisture content prior to final kilning at about 70°C. Tension wood can cause major warp problems so good fillet and bearer alignment and even ended stacks are essential.

Poplar wood has low natural durability so it is unsuitable for exterior uses without CCA preservative treatment. Although pressure treatment of dry timber with CCA salts gives variable penetration of the salts, CCA-treated poplar has been widely used for fence battens and gates. Boron diffusion treatment properties are acceptable and this process will provide protection against insect attack of timber used in a protected interior situation.

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* Haslett, A.N. 1988: "A guide to handling and grade-sawing (New Zealand) plantation-grown eucalypts". New Zealand Forest Research Institute Bulletin No. 142.

Table 7 - Physical properties of New Zealand-grown poplars

Species/clone	Age (years)	Density (kg/m³)		Shrinkage to 12% mc* (%)		Green mc** (%)	Blackheart (%)
		Basic	Air-dry	Tangential	Radial		
'Veronese'	15	345	415	4.9	1.8	146	21
'Kawa'	8	365	440	5.2	1.9	122	2
P. deltoides × *P. nigra*	42	385	465	6.0	2.1	118	55
'I-214'	30	305	-	-	-	163	0
'Eridano'	13 and 15	340	435	4.8	1.9	97	3
P. deltoides	>30	385	-	7.2	3.3	145	37
P. deltoides clones							
'24-2'	15	355	-	-	-	103	5
'28-6'	15	335	-	-	-	140	26
'47-2'	15	340	-	-	-	121	17
P. trichocarpa × *P. deltoides*							
'S909-12'	15	275	-	-	-	191	38
'S910-2'	15	310	-	-	-	161	35
'S910-4'	15	285	-	-	-	168	35
'69042-4'	15	290	-	-	-	152	30
Pinus radiata	25	410	475	4.0	2.0	160	

* Moisture content

** An overall figure for white and blackheart combined

Table 8 - Clearwood strength properties of poplars compared to medium-density radiata pine

Species/clone	Age (years) (MPa)	Modulus of rupture (MPa)		Modulus of elasticity (MPa)		Compression parallel		Hardness (kN) (kg/m³)		Basic density
		Green	12%	Green	12%	Green	12%	Green	12%	
'Veronese'	15	33.0	52.5	4.4	5.5	13.8	21.6	1.7	2.1	320
'Kawa'	8	35.2	56.9	4.3	5.4	15.0	24.2	2.0	2.3	338
P deltoides 'Frimley'		37.1	61.5	5.3	6.8	12.8	31.6	1.4	2.1	338
P. nigra 'Italica'		36.1	61.5	5.4	6.8	15.6	33.9	na	na	305
'Androscoggin'	18	39.1	61.2	5.7	7.2	na	na	na	na	363
Pinus radiata	25	38.1	85.8	5.5	8.2	15.4	36.7	2.3	3.6	415

na - not available

All the machining properties of poplar are inferior to those of radiata pine. In planing, poplar has more chipping and, after moulding or turning, a more fibrous surface requiring considerable sanding. Sawmillers and cabinet-makers utilising poplars have emphasised the critical importance of sharp tools and well maintained sanding equipment. Furniture manufacturers and cabinet-makers appreciate the light colour of poplar. No problems have been encountered in the application of surface coatings and poplar is highly regarded for its ability to take an even stain.

Pulping properties

Richardson and Jones (1997) have reported the results of the first chemi-mechanical pulping study of New Zealand-grown poplar. This study was undertaken because the New Zealand pulp and paper industry is giving serious consideration to the use of short-rotation, short-fibred hardwood species to enable the production of improved paper grades. The study examined the paper-making properties of chemi-mechanical pulps produced from the clone *P. deltoides* × *P. nigra* 'I 214' using a range of alkaline and alkaline peroxide liquor applications. Stone groundwood and pressure groundwood pulps were also produced and their properties compared with the chemi-mechanical pulps.

Cold soda pulps, produced with alkali applications of 3–8%, had excellent strength properties and a low energy demand relative to radiata pine mechanical pulps. Brightness and scattering coefficient, however, were relatively low. In contrast, alkaline peroxide mechanical pulping, stone groundwood and pressure groundwood, produced pulps with high bulk, moderate strength properties, and excellent optical properties.

Uses

In New Zealand, poplar wood has been used for farm gates and fence battens, truck and bridge decking, light frame construction, packaging, stock crates, stockyard rails, shoes, kitchen utensils, panelling, mouldings, doors, furniture (Figures 30 and 31), veneers, fibreboard (in a mix with *Pinus radiata*), and match production. The amount of poplar timber currently used in New Zealand is small because of the scattered distribution of the resource and the predominance of radiata pine as New Zealand's main timber species, but the availability and use of the poplar resource is increasing as more farmers, sawmillers and cabinet-makers become aware of poplar's potential.

Present Extent of Poplar Resources

No new major commercial plantations have been established since 1973 when there were some 3300 ha of poplars scattered in small plantations throughout the country. Some of this plantation resource has been milled experimentally with 1000 tonnes of pulp logs being exported in 1993 and 2000 tonnes being cut for local and export orders in 1995–96. Over the last two years there has been increasing interest in utilising the existing resources and starting small (1–30 ha) woodlot, riparian, and wide-spaced (10 × 10 m) plantings to create a new poplar resource of pruned logs for both New Zealand and Asian markets.

Most of the resource available is composed of:

- Old plantings of Lombardy poplar and *P. deltoides* 'Frimley', scattered throughout the North and South Islands.
- A few small woodlots of the Schreiner hybrids, 'Androscoggin', 'Oxford' and 'Rochester', and the hybrid black poplars, 'Robusta' and 'Eugenei', in old New Zealand Forest Service plantings and in river protection plantings (20–40 years old) in the South Island.

- Wide-spaced farm plantings and riverbank and stream bank plantings of the Italian hybrid black poplars (principally 'I 78' and 'I 214' planted from 1963–1973). At least one million trees were planted (based on nursery outputs).
- Wide-spaced trees and windbreaks of the hybrid black poplars 'Flevo' and 'Tasman', planted from 1974 to the present.

Future Role

Poplars will continue to play an important role in soil and water conservation in New Zealand, particularly for erosion control in hill country pasture and as riparian strips, and also as farm and horticultural shelter. The genus *Populus* also represents a largely untapped resource of potential species for production forestry in New Zealand. Deciduous hardwoods that grow as fast or faster than radiata pine, with contrasting fibre and wood characteristics to those of pine as well as to those of eucalypts and acacias, could provide diversity in an industry in which the small grower is becoming increasingly represented. This diversity could be attractive to the farmer, especially if healthy species producing high value products can be identified and grown.

There is potential in the North Island for combining poplars such as *P. trichocarpa* and white × aspen hybrid poplars (*P.* ×*canescens*, *P.* ×*tomentosa* and *P. alba* × *P. glandulosa*) with radiata pine in erosion control forestry. The poplars would be sited in riparian zones and large wet seepage areas amongst the radiata plantations, and could be logged concurrently with the radiata. Their rapid coppicing from cut stumps and sprouting from root systems would enable land stabilisation effects to continue while the radiata plantations became re-established. Poplars can also be established on valley floors considered too wet or flood-prone for radiata establishment or long-term stand stability.

In the South Island there is potential to develop a short-rotation fibre resource from riverbank plantations combined with tree willow protection plantings, along most of the major rivers of the Canterbury plains. Length of rotation and spacings would be determined by whether a role exists for veneer and sawlog production from these river plantings. The regional council in South Canterbury has already established and processed successful woodlots in river gravels on a trial basis.

To enhance the commercial prospects for poplar timber in New Zealand by providing greater genetic diversity and improved material, there is potential to properly introduce populations of selected species and undertake breeding programmes. Any such programme needs to take into account wood quality and suitability for different products. As well, the potential for breeding populations to colonise aggressively and become environmental weeds requires evaluation. Future cultivar releases for erosion control and forestry should be male only, to eliminate the possibility of new species and varieties spreading by seed.

NURSERY PRACTICE AND PROPAGATION TECHNIQUES

Not all poplars are readily propagated from hardwood cuttings. Those that are difficult include some *P. alba* and *P. deltoides* clones, *P. tremula*, *P. tremuloides*, and white × aspen poplar hybrids. *Populus lasiocarpa* and *P. wilsonii* are apparently impossible to propagate.

Production of Vegetative Materials

(a) First rotation–poles

Year 1

- Prepare 20–30 cm long cuttings with 10–20 mm top diameter from healthy one-year-old shoots obtained from coppice stools or one-year-old rooted cuttings in June–August. Ensure, if possible, that cuttings have at least two dormant buds at the top.
- Segregate any cuttings without buds to obtain more uniform stoolbed establishment.
- Store in closed plastic bags in a cool store until planting time or (if fully dormant) in plastic bags at freezing temperatures to prevent fungal problems often encountered when stored at 2–4°C.
- Insert vertically into cultivated soil to almost their full length at 0.5 × 2 m spacing. Boom spray the planted area immediately after planting with simazine, diuron, or linuron at rates up to 2 kg ai/ha, depending on soil type. Care is needed on free-draining sandy soils because of rapid leaching of herbicide into the rooting zone.
- Thin to one shoot per cutting in November or December. Maintain complete weed control. Irrigate as necessary.

Year 2

- Prune off side branches on the lower 2 m of each pole in February or March.
- Maintain weed control by mowing or spraying using spray shields.
- As soon as possible after pole harvesting, paint the cuts on the stool with an appropriate fungicidal wound dressing to prevent entry of silverleaf spores.
- Harvest poles from June to early August, preferably during fine weather.
- Store horizontally under sprinklers or in well-aerated soaking ponds. Some poplar species, particularly smooth-barked balsam poplars and *P. deltoides*, have bark that is intolerant of low oxygen levels and begins to die after 10–15 days held in stagnant non-aerated water. *Populus nigra* and *P. deltoides* × *P. nigra* clones are more tolerant and thus root more easily from vegetative material planted into poorly drained soils.
- Before spring growth commences, remove all trimmings from the stool-bed, apply a maintenance dressing of 250 kg/ha of superphosphate, and maintain weed control by spraying along the rows with combinations of knockdown and residual herbicides. Apply lime to the soil if the pH drops below 6.

(b) Second and subsequent rotations

Year 1

- Thin to the best 1–2 shoots per stool in December or after the threat of storm damage is over, cut back any damaged leaders to a strong bud, and remove any forks.

Year 2

- As for the first rotation.

Production of Rooted Trees

- Cuttings are prepared as for stool nurseries and planted in single rows at 0.25 × 1 m spacing. In the North Island on fertile soils this will produce 2–4 m tall trees in one season. If smaller trees are desired, plant at half these spacings and use smaller cuttings.
- Cuttings should be pruned to a single leader in November or December. Lower branches are usually pruned off to half stem height in late March.
- In May or June undercut trees at 30 cm depth with a tractor-drawn or winched U-shaped blade, fitted with either a wedge-shaped lifting shoe or several fingers on the trailing edge.
- Lift trees and trim lateral roots to 10 cm from the stem using secateurs. Store by heeling plants at least 25 cm deeper than the top of the original cutting into sawdust, milled bark, sand, or nursery soil. Do not let the roots become desiccated.

Supply of Planting Material and Further Information

Reduced demand for poplar material in the mid 1980s resulted in reduced output capability by soil conservation nurseries so planting material is currently in short supply. People contemplating planting poplars are advised to order well in advance of the planting season. Contact your local poplar and willow nursery or regional council. Regional council soil conservation staff should also be able to advise on the suitability of particular varieties for local situations, as well as planting techniques and costs. If selected planting stock is not obtainable locally, a new cultivar is required, or further information is sought, contact:

HortResearch
Private Bag 11030
Palmerston North

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APPENDIX 1 - Classification and distribution of *Populus* species

Botanically the poplars are generally divided into two subgenera, *Balsamiflua* and *Populus*, and further subdivided into sections and subsections, depending on the particular opinion of the taxonomist. In the near future, research on DNA and other biochemical profiles should assist in clarifying the inter-relationships of species and subgenera.

The large complex of Asian/Himalayan poplars is poorly described and understood, and current taxonomy requires considerable international revision.

The following classification is as given by Eckenwalder (1996 and 1997a) and modified for the new section *Abaso*, described by Eckenwalder (1996, 1977a, 1977b) with the exceptions of *P. cathayana*, *P. koreana*, *P. maximowiczii* (grouped under *P. suaveolens* by Eckenwalder), and *P. wilsonii*, which are known by these names in arboreta in New Zealand.

Species marked in bold are represented in New Zealand by one clone (***P. ciliata***), to several dozen clones (***P. deltoides***), per species.

Section	Species and Authority	Origin
TURANGA		
(Subgenus *Balsamiflua*)	*euphratica* Oliv.	Eurasia, North Africa
	pruinosa Schrenk	Turkestan to south-west Siberia
	ilicifolia (Engl.) Rouleau	Kenya
POPULUS		
(Subgenus *Populus*)		
Subsection *Trepidae*	*adenopoda* Maxim.	Eurasia,
	davidiana Dode = *P. tremula* L.	North-east Asia, China
	gamblei Dode	India
	rotundifolia Griff.	North-west Himalayas
	tremula L.	Europe, Asia, North Africa
	grandidentata Mich×.	North America
	tremuloides Mich×.	North America
Subsection *Albidae*	***alba*** L.	Western Europe, Eurasia
	alba var. ***subintegerrima*** Lange (syn. var. ***hickeliana***)	Spain, Morocco
	guzmanantlensis A.Vazquez & Cuevas	Mexico
	monticola Loudon	Mexico
	simaroa Rzed	Mexico
ABASO*		
(Subgenus *Populus*)		
	fremontii S.Wats. subsp. *fremontii*	South-west USA, north-west Mexico
	fremontii subsp. *mesetae*	Mexico
	mexicana Wesm. subsp. *mexicana*	Mexico
	mexicana subsp. *dimorpha*	Mexico

Section	Species and Authority	Origin
AIGEIROS **(Subgenus *Populus*)**		
	deltoides R.S.Marsh subsp. ***deltoides***	Eastern USA
	deltoides subsp. ***monilifera***	Northern and central USA
	deltoides subsp. *wislizenii*	Central and south-west USA
	nigra L.	Western Europe
	nigra var. ***thevestina***	Central Eurasia, Middle East
TACAMAHACA **(Subgenus *Populus*)**		
	angustifolia James	Mexico and USA to the Canadian border
	balsamifera L.	North central and
	syn. *trichocarpa* subsp. *tacamahaca*	north-east USA
	trichocarpa Hook. subsp. ***trichocarpa***	Western USA and Canada
	ciliata Schur	India
	jacquemontiana Dode	India
	cathayana Rehder	Central and north-east China
	koreana Rehder	Korea, China
	laurifolia Ledeb.	Northern China to Russia
	maximowiczii Henry	China, Korea, Japan
	pseudosimonii Kitay	North-east China
	purdomii Rehder	China
	simonii Carr.	Northern China, Mongolia
	suaveolens Loudon	Northern China to Russia
	szechuanica C.K.Schneid.	China, Himalayas
	ussuriensis Kom.	North-east China
	yunnanensis Dode	South-west China
LEUCOIDES **(Subgenus *Populus*)**		
	heterophylla L.	Eastern and south-east USA
	lasiocarpa Oliv	Asia
	wilsonii C.K.Schneid.	Asia

APPENDIX 2 - Poplar clones and cultivars in New Zealand - with parentage

Clone, cultivar or hybrid	Parentage	Comments
'Andover'	*P. nigra* × *P. trichocarpa*	American Schreiner hybrid
'Androscoggin'	*P. maximowiczii* × *P. trichocarpa*	American Schreiner hybrid
'Argyle'	*P. deltoides* × *P nigra* 'Italica'	
×*berolinensis*	*P. laurifolia* × *P. nigra* 'Italica'	
×*canadensis*	*P. deltoides* × *P nigra*	syn. ×*euramericana*
'Candicans'	*P. balsamifera* × *P. deltoides* = *P.* ×*gileadensis*	
'Candicans Aurora'		Variegated mutant form of 'Candicans'
'Crow's Nest'	(*P. deltoides* × *P. nigra*) × *P. nigra*	
'Eridano'	*P. deltoides* × *P. maximowiczii*	
'Eugenei'	*P. deltoides* × *P. nigra*	
'Flevo'	*P. deltoides* × *P. nigra*	
'Frimley'	*P. deltoides*	
'Frye'	*P. nigra* × *P. laurifolia*	American Schreiner hybrid
'Generosa'	*P. deltoides* × *P. trichocarpa*	
'Gileadensis'(syn. 'Candicans') = *P.* x*jackii* 'Gileadensis'	*P. balsamifera* × *P. deltoides*	Balm of Gilead
'Hiltingbury Weeping'	*P. tremula* × *P. tremuloides*	
'I 30', 'I 78', 'I 154', 'I 214', 'I 455', 'I 488'	*P. deltoides* × *P. nigra*	'Italian hybrids'
'Kawa'	*P. deltoides* × *P. yunnanensis*	
'Laevigata'	*P. deltoides* × *P. nigra*	
'Luisa Avanzo'	*P. deltoides* × *P. nigra*	
'Maine'	*P.* 'Balm of Gilead' × *P.* ×*berolinensis*	American Schreiner hybrid
'Marilandica'	*P. deltoides* × *P. nigra*	
'Manawatu Gold'	*P. deltoides* × *P.* ×*euramericana*	
'Oxford'	*P. maximowiczii* × *P.* ×*berolinensis*	American Schreiner hybrid
'Pakai'	*P. deltoides* × *P. trichocarpa*	
'PN 471'	*P. trichocarpa*	
'Pyramidalis'	*P. alba* var. *pyramidalis*	(syn. 'Bolleana')
'Regenerata'	*P. deltoides* × *P. nigra*	
'Robusta'	*P. deltoides* × *P. nigra*	

Clone, cultivar or hybrid	Parentage	Comments
'Rochester'	*P. maximowiczii* × *P. nigra*	American Schreiner hybrid
'Roxbury'	*P. nigra* × *P. trichocarpa*	American Schreiner hybrid
'Rumford'	*P. nigra* × *P. laurifolia*	American Schreiner hybrid
'Sempervirens'	*P. nigra* 'Italica'	Semi-evergreen mutant
'Serotina'	*P. deltoides* × *P. nigra*	
'Silver poplar'	*P. alba*	
'Strathglass'	*P. nigra* × *P. laurifolia*	American Schreiner hybrid
'S909-12', 'S910-2', 'S910-4', '69042-4'	*P. trichocarpa* × *P. deltoides*	
'Tasman'	*P. deltoides* × *P. nigra*	
'Toa'	(*P. deltoides* × *P. nigra*) × *P. yunnanensis*	
'Yeogi 1'	*P. alba* × *P. glandulosa*	
'Yunnan'	*P. yunnanensis*	
'Veronese'	*P. deltoides* × *P. nigra*	