1 Overview

This book is about how to grow *Pinus radiata* (radiata pine) forest plantations. Radiata pine is a versatile, fast-growing, medium-density softwood, very suitable for a wide range of end-uses. Its silviculture is highly developed, being built on a firm foundation of over a century of research, observation and practice. It is often considered a model for growers of other plantation species. This book explores current knowledge and experience with radiata pine forest plantation management and examines its long-term sustainability.

Forest plantations are stands of trees established by planting or artificial seeding. Silviculture is the art and science of controlling the establishment, growth, health and quality of forest stands to sustainably meet the needs of owners and society. For radiata pine forest plantations, commercial objectives for the production of wood, fibre and fuel generally dominate, but the forester should always take into account wider societal values. Forest plantations can enhance landscapes, reduce erosion, improve water quality, sequester and store carbon, harbour biodiversity and produce a range of ecosystem services that provide other direct and indirect benefits. Plantations can also have adverse impacts, and have sometimes gained a negative image when these have been ignored. The forest manager needs to adapt forest plantation management to ensure that the wider benefits of plantations are maintained and that negative features are minimized. Society today expects foresters to manage plantations to balance social, cultural, environmental and economic values.

Silviculture is an applied science, built on basic science and ecology, and it is also an art. Shepherd (1986) interpreted the art of silviculture as the imaginative skill of the practitioner in interpreting scientific knowledge for a particular situation. However, art is also the conscious use of skill, taste and creative imagination in the practical production of beauty. Thus, silviculturalists should aim to create beauty in the landscape or an individual stand while ensuring that the plantation achieves its other objectives. The silviculture of radiata pine is not static. Biotechnology, ecophysiology and computer applications are helping to refine management practices, and managers must also respond to emerging challenges such as climate change and changing perceptions of sustainability.

GENERAL APPROACH

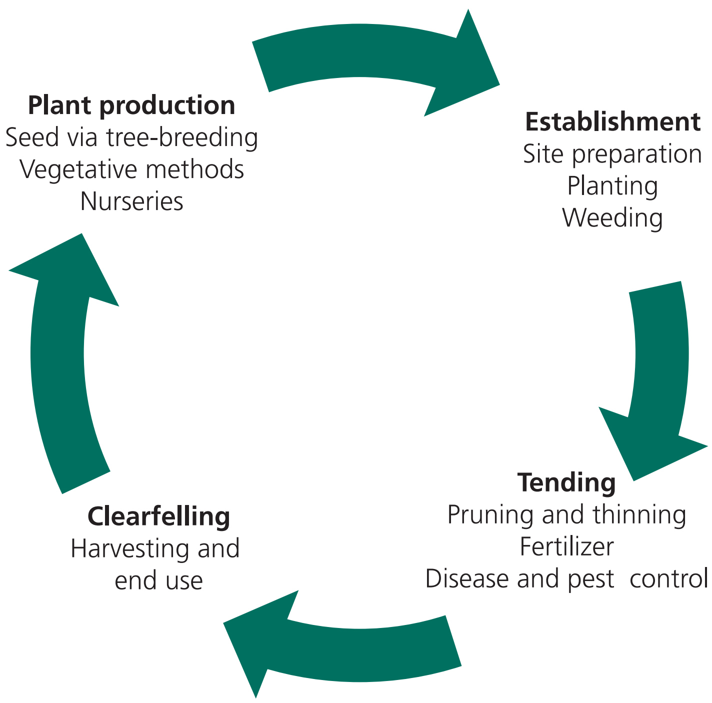
Radiata pine management must integrate the biological aspects of growing trees with socio-economics, management objectives, practical considerations and other constraints and opportunities. Although stands of radiata pine may appear simple, they are quite complex ecosystems – they contain large, long-lived trees that change considerably over time and interact in changing ways with the environment and other organisms. A plantation forest is even more complex, being made up of stands of differing sizes and ages, sometimes adjoining one another and often on differing sites. For a plantation to be sustainable, its biological requirements are paramount, because the trees must survive and the ecosystem must be stable. However, silvicultural decisions are easier and clearer when they are related to management objectives. Economic, environmental, cultural and social factors are also important when setting the principal plantation management objectives. Powerful tools, including economic analysis, are available to assist decision-making (see Chapter 3).

While different chapters of this book deal with different aspects of silviculture, for example establishment and thinning, we are actually dealing with a continuum in the life of a stand (Figure 1.1). After a stand is harvested, the cycle begins anew, but the removal of mature trees causes dramatic changes to the microclimate. The new planting site may differ from the previous rotation because of harvesting impacts and changing weed and pest spectra. Such changes will influence silvicultural practices. The cyclic continuum shown in Figure 1.1 is an example of a systems approach; the individual operations should be viewed as part of an integrated system rather than as subjects in their own right. One way of ensuring this integration is to define the desired state that will achieve the management objectives. It is also important to use an adaptive management approach in which the plantations are monitored and management is altered as needed.

This book describes the underlying biological mechanisms or processes that occur in trees and stands, thus enabling the plantation manager to determine appropriate management responses in differing situations. However, as this is not a physiological text, that aspect is covered only lightly.

The book places considerable emphasis on principles, as this enables knowledge to be applied to different situations. Technology is constantly changing: the weed-control techniques used today are quite different from those of only 30 years ago and no doubt will continue to change, but the principles behind weed control are likely to endure. The book illustrates these principles through examples that show how various forest managers have approached their specific situations and requirements.

FIGURE 1.1
The plantation cycle, with major operations related to the planting stock production, establishment, stand tending and clearfelling of the crop



HISTORICAL PERSPECTIVE

Pinus radiata D. Don, without doubt the best-known expatriate of the North American conifers, is the world's most extensively planted exotic softwood. The specific name, radiata, comes from its radiating cone scales. In early literature the species was often called *P. insignis* Doug., as it was separately described a little later by Douglas (Bannister, 1954; Lavery and Mead, 1998). The almost universal common name for the species and the timber is radiata pine (or pino radiata in Spanish), but it is still referred to as Monterey pine in the United States of America and some other English-speaking countries, or as *pino insigne* or *pino de Monterrey* in some Spanish-speaking areas. Insignis (or *insigne* in Spanish) can be translated as "remarkable", a term that the species lives up to.

Radiata pine was first formally described by David Don, Professor of Botany at Kings College, London, to the Linnean Society on 2 June 1835, from specimens collected in 1829 or 1830 by Dr Coulter (Don, 1836; Bannister, 1954). However, the species was apparently first collected and taken to Europe in 1787 by the La Pérouse expedition, and there are much earlier reports of the species in its native habitat and its use as timber (Bannister, 1954; Contesse, 1987; Libby, 1997). Radiata pine at Monterey was noted in Spanish records, perhaps as early as 1542, and was used in the Carmel Mission in 1769 (Contesse, 1987). In 1833, the Scot, David Douglas (of Douglas fir fame), apparently was responsible for the earliest successful introduction of the species to England, from seed collected in 1830. This appears to have been the first planting of radiata pine outside its native habitat.

FIGURE 1.2
The Mt Peel radiata pine in Canterbury, New Zealand, planted in 1859 as a three-year-old seedling

Note: The tree is 3.1 m in diameter and almost 50 m tall; photograph taken in 2010.

The introduction of radiata pine to Australia may have been as early as the 1840s, although the first record of seed was in 1857 for the Melbourne and Sydney botanic gardens.[1] It is also recorded as being in cultivation in Hobart in the same year. From 1859, seedlings from this collection were distributed widely in Victoria and later in other states. Two 3-year-old plants from Sydney were planted in 1859 by J.B.A. Acland at Mt. Peel in South Canterbury, New Zealand; this is the first recorded planting of radiata pine in that country (Figure 1.2), although there are unconfirmed suggestions of earlier plantings in Canterbury and Auckland. The earliest confirmed milling of radiata pine was by Duncan Rutherford at Culverdon, Canterbury, in 1893, the timber being used for farm buildings. During the 1860s there were further introductions to both Australia and New Zealand, including a few larger importations of seed direct from California to New Zealand between

1 This discussion on the introduction of radiata pine to countries is based on Contesse, 1987; Libby, 1997; Lavery and Mead, 1998; Burdon and Miller, 1992; Shepherd, 1990; Wu *et al.*, 2007; Johnson *et al.*, 2008.

the late 1860s and the early 1880s. It appears that most of the latter importations came from the Año Nuevo area near San Fransisco (Burdon, 2001).

The first commercial plantation of radiata pine in Australia was in 1876 at Bundaleer in South Australia. In the same year the species was also planted on coastal sand-dunes near Bunbury in Western Australia, but that planting was a failure. The first plantations in New South Wales and Victoria were established in 1878 and 1880, respectively. Even though the New South Wales stands were milled in 1908, the first commercial radiata pine plantation in New South Wales was planted in 1912. The first recorded use of radiata pine wood in Australia – for apple crates – was in 1902 at Wirrabara in South Australia. The following year the South Australian Woods and Forests Department established its own sawmill.

In New Zealand the potential of radiata pine was also quickly recognized, and by the mid 1870s it was being planted extensively for shelterbelts and woodlots, particularly in Canterbury. In 1881 there were reported to be 3 284 hectares (ha) of radiata pine plantations in Canterbury. The plantings made up to the 1880s were presumably the seed source for the major plantings that took place in New Zealand in the 1920s and early 1930s.

A few specimens of radiata pine were introduced unintentionally to Chile in 1886 or perhaps a few years earlier, but the first plantation of 10 ha was planted near Concepción in 1893 (Contesse, 1987). In the early 1900s the Government of Chile hired a German forester, Federico Albert, who recommended planting radiata pine and eucalypts to control severe soil erosion; this led to the beginnings of a plantation programme in 1910, although major plantings of radiata pine did not begin until about 1935. Following the implementation of government subsidies to private growers in 1974, there was a large increase in new radiata pine plantations.

In Uruguay, radiata pine was introduced in 1871 and was planted in the 1940s and 1950s, but most of those plantations were abandoned as the species proved unsuitable. In Ecuador, radiata pine was introduced in 1905, with the first recorded plot planted in 1925 at an altitude of 3 350 m (Miller, 1974; Garrison and Pita, 1992). Radiata pine was planted between 3 000 m and 3 800 m from the 1960s, with a total of 20 000 ha established by 1990.

Radiata pine was perhaps introduced to South Africa in about 1850, although the records are poor. The first plantation near Cape Town dates from 1885 (Donald, 1993). Interestingly, the first recorded diseases of radiata pine were recorded there in 1893 (Lundquist, 1987).

In Spain, the first recorded planting of radiata pine was in 1840 in a botanical garden near Lekeitio (Goldazarena, Romón and López, 2012). The species was not planted widely until the 1950s.

Finally, as recently as 1990, radiata pine was introduced to Sichuan Province, China, as a reforestation species (Hui-quan *et al.*, 2003).

The planting of radiata pine as an exotic gave the species a new lease of life. Before that, it was a relict species in its natural habitat, covering about 10 000 ha within 5 km of the coast; it was able to survive against more long-lived species such as Douglas fir because of its resilience to fire and the climatic niche. Today, the area of radiata pine with a natural understorey (Figure 1.3) in California is about 5 300 ha, and there are another 4 500 ha in developed areas with varying canopy cover (Zander Associates, 2002). However, estimates of the current area of radiata pine vary widely, partly because of this urbanization. For example, Rogers (2004) estimated the current area of natural forest to be between 4 300 and 7 700 ha, of which only 1 353 ha were fully protected, while Burdon (2001) suggested an intermediate figure. There are 130 ha of radiata pine remaining on Cedros Island and only 220 trees on Gaudalupe Island (Rogers, 2004). In California, the species is considered an amenity tree rather than a timber species (McDonald and Laacke, 1990).

Radiata pine belongs to the closed-cone pine group (subsection Attenuatae) that also includes *P. muricata* and *P. attenuata*. Five provenances are recognized, with three taxonomic varieties. The three mainland provenances (Año Nuevo, Monterey and Cambria, which are between latitudes 35.5°N and 37°N) belong to var. radiata. Most plantations are derived from the Año Nuevo and Monterey seed sources. The var. binata comes from Guadalupe Island (latitude 29°N) and var. cedrosensis from Cedros Island (latitude 28°N). Both these varieties have paired needles and tend to have

FIGURE 1.3
Natural radiata pine stand at Monterey, California

persistent thin, smooth bark. More information on the natural stands and their ecology can be found in McDonald and Laacke (1990).

THE FOUR PHASES OF RADIATA PINE PLANTATION DEVELOPMENT

The history of radiata pine – its discovery, introduction, domestication and development – is a fascinating story. It has been suggested that the development of radiata pine into the pre-eminent exotic plantation conifer is the forestry equivalent of the development of rice, wheat and maize during the Green Revolution (Bentley, 1997). Table 1.1 shows a timeline for key silvicultural and other technical developments. We can also divide this timeline into phases (Figure 1.4).

The "discovery" phase lasted from the eighteenth century through to the mid 1870s in New Zealand and Australia and even longer in other countries. In this phase, people started to become aware of the potential and limitations of radiata pine. There were early prophets, such as Baron Von Mueller in Australia but, at first, most people thought the species a curiosity (Box 1.1). By the end of this phase, however, its virtue of rapid growth, coupled with reasonably wide site tolerance, was starting to be recognized.

In the second, "acceptance", phase, perceptions evolved to the point where radiata pine was accepted as a prime candidate as a plantation species. While this could be seen as a natural progression, given its performance, for many people it required a major shift in thinking. The people promoting radiata pine had come from Europe, where they were accustomed to hardwoods like oaks and European beech and slower-growing conifers such as Baltic pine. Many such people grew up equating slow growth with high wood quality. It was therefore a considerable leap of faith to accept fast-growing radiata pine, a species unknown and unproven in its native country, as a prime candidate for timber supply. Europe is only now beginning to accept radiata pine timber for other than low-value uses.

Several conditions made the acceptance of radiata pine easier in the Southern Hemisphere. In parts of recently colonized countries, settlers needed to plant trees for

FIGURE 1.4
Phases in the development of radiata pine plantation forestry

TABLE 1.1
Timeline for the domestication of radiata pine and the development of silviculture

Year	Event	Country*	People or group*
1786–87	First seed collected	France	La Pérouse expedition
1833	First nursery plants	UK	D. Douglas (collected 1830)
1839	First rooted cuttings	Europe	Nurserymen
1840	Introduced to Spain	Spain	Carlos Adán de Yarza
<1850	First seed imported to Southern Hemisphere	SA	
1857	First confirmed seed import	Aus.	Botanical Gardens
1859	First confirmed planting in NZ	NZ	J.B.A. Acland, Mt Peel
1866	First commercial recommendation	Aus.	F. von Mueller
1870-80s	Shelter and first plantations	NZ/Aus.	
1880s	Introduced Chile	Chile	A. Junge
1913	Large-scale use recommended	NZ	Royal Commission
1920-30	High pruning used	SA[a]	
1925-35	First planting boom	NZ	State and private
1926	Wood properties	NZ	A.R. Entrican
1929	First newsprint used	NZ[b]	
1928-30	Biological control of Sirex	NZ[c]	Cawthron Institute/FRI
1939	First fertilizer trial results	Aus.	W.V. Ludbrook
1950s	Serious breeding begins	NZ/Aus./SA	Research institutes
1955	First aerial application of phosphate	NZ[d]	M.J. Conway
1957	First seed orchards	Aus./NZ	
1960s	Mill studies	NZ/SA	G.S. Brown and others
1965	First computer growth model	NZ/Aus.	J.W. Shirley
1968	Economic evaluation	NZ	R. Fenton & W.R.J. Sutton
1968	Nutrient cycling	NZ[e]	G.M. Will
1970s	Weedicides	NZ/Aus.	FRI, Aus. states
1970s	Intensive site preparation	NZ/Aus.	FRI, Aus. states
1970s	Intensive fertilizer research	NZ/Aus.	FRI, Aus. states, CSIRO
1970s	Improved nursery techniques	NZ/Aus.	FRI, Aus. states
1970s	Index selection in breeding	NZ	FRI, M. Wilcox
1975	First tissue culture plantlets	NZ	FRI, K.J. Horgan
1977	3/2 power law evaluated	NZ data[f]	
1979-82	Radiata Pine Task-force	NZ	FRI; led by W.R.J. Sutton
1980	Grade index – pruned logs	NZ	J.C. Park
1980-2005	Silvopastoral studies	NZ/Aus./ Chile/Spain	FRI, Aus. states, Lincoln University, INFOR Chile
1985	Somatic embryos	NZ[g]	FRI
1997	Test-tube grown wood fibres	NZ[h]	FRI, D. Smith.
1998	Transgenic plants	NZ[i]	FRI
2002	Agrobacteria – mediated gene transfer	NZ/Chile	
2004	Marker-aided selection explored	Aus./NZj	CSRIO
2005	Transgenic insect resistance	NZ[k]	FRI
2005	300 index of growth	NZ[l]	FRI

Note: Aus. = Australia; CSIRO = Commonwealth Scientific and Industrial Research Organisation (Australia); FRI = NZ Forest Research Institute; NZ = New Zealand; SA = South Africa; UK = United Kingdom of Great Britain and Northern Ireland.

Sources: a = Hinze and van Larr (1986); b = Kininmonth (1997); c = Miller and Clark (1935); d = Conway (1962); e = Will (1968); f = Drew and Flewelling (1977); g = Smith, Sing and Wilton (1985); h = Anon. (1997); i = Walter *et al.* (1998); j = Devey *et al.* (2004) for older trees; k = Grace *et al.* (2005);l = Kimberley *et al.*(2005)

BOX 1.1

Early recognition of radiata pine's commercial potential

As early as 1866, Baron Ferdinand Von Mueller (Director of the Melbourne Botanic Gardens) suggested that *Pinus radiata* be used as a commercial plantation species. However, it was not until 1876 that the species was first planted in South Australia for this purpose.

In New Zealand, the wide-scale planting of radiata pine began in the 1870s, especially in the Canterbury region. In an invited paper to the Agricultural Conference in 1898, Sir John Hall (who later served as a prime minister of New Zealand), after describing the failures and advantages of many tree species with which he had experimented, stated:

"... the one tree which is conspicuous for rapidity of growth and abundance of foliage, and which by its strength and constitution is enabling it to resist frost and drought and to thrive in the poorest soil, is the *Pinus insignis** ... it is an abundant seeder, and is easily grown from seed ... it is difficult to believe that for such timber, many useful purposes will not be found".

* An early name for *Pinus radiata* – see main text.

timber or shelter. This was particularly true in Canterbury, New Zealand, where the first large-scale plantings appeared. Many native species in those recently colonized countries were thought unsuitable for plantations because of their slow growth or difficulties in their use as timber, and temperate Australia lacked fast-growing native softwoods. In New Zealand, a 1913 Royal Commission found that if fast-growing plantations were not established, there could be a wood shortage by the 1960s because of extensive clearing for agriculture and the slow growth of the native conifers. In Chile, radiata pine was used extensively to afforest degraded agricultural land and to replace wood coming from native forests (Contesse, 1987).

Perhaps another reason for the eventual acceptance of radiata pine was that leaders promoting it were not always trained forestry people; quite often they were farmers and enthusiasts (Box 1.1), people who were willing to experiment and to believe their eyes, not what they had been taught. For instance, T.W. Adams planted 240 species on his farm in mid Canterbury, but in the 1913 Royal Commission on forestry he backed radiata pine. Before that Royal Commission, the New Zealand government was mostly still planting traditional European trees, even though other growers had already shifted to radiata pine. Important research into wood properties and experience in end-use during the acceptance phase was also integral to the species' ultimate acceptance in the market place.

During the acceptance phase there were a number of early silvicultural studies (Table 1.1). In Australasia, studies were conducted on radiata pine in its natural habitat[2]; growth, and factors affecting growth[3]; establishment[4]; spacing, thinning and pruning[5]; and nutrition.[6] The South Australians led the way in general forest management in

2 Habitat studies of Lindsay (1932) and Fielding (1953).
3 Growth aspects (Gray, 1931, 1943, 1944; Poole, 1933; Syme, 1933; Moorhouse, 1935; Jacobs, 1937; MacDougal, 1938; Adams, 1940; Fielding, 1940; Fielding and Millett, 1941; Millett, 1944a,b; Stoate, 1945).
4 Establishment studies of Carter (1933), Field (1934) and Jacobs (1939) – the latter two on cuttings.
5 Thinning and spacing (O'Conner, 1935; Craib, 1939, 1947; Lane Poole, 1943; 1944; Jolly, 1950); pruning (Hall, 1937; Roche and Hocking, 1937; Jacobs, 1938).
6 Tree nutrition (Cockayne, 1914; Kessell, 1927; Walker, 1931; Stephens, 1933; Kessell and Staote, 1936; 1938; Askew, 1937; Ludbrook, 1937; 1942a,b; Smith and Bayliss, 1942; Smith, 1943; Adams, 1946; Stoate, 1950).

this period, but some important ideas were also developed in South Africa. O'Connor (1935) introduced the idea of free-growing and suppression zones and then, shortly afterwards, I.J. Craib suggested some (what were then) very radical ideas on thinning (Craib, 1939, 1947). After the Second World War, John Ure in New Zealand proposed a schedule for naturally regenerated stands that included the idea of thinning to waste, as well as two pruning lifts to 6.1 m (Ure, 1949). During this period there were also early genetic (Sherry, 1947) and nutritional (Laughton, 1937) studies in South Africa. The biological control of the sirex wood wasp was tried in New Zealand in the 1930s (Miller and Clark, 1935).

From the early 1950s, the acceptance phase was followed by a "development" phase – a period of intense activity that came with the realization that radiata pine was a "winner" (Figure 1.4). A concerted effort was made to develop all aspects of silviculture, use and marketing (Table 1.1), and there was a second wave of planting around the world.

New Zealand and Australia led this development phase. A smaller research programme was undertaken in South Africa, and from the 1980s research expanded rapidly in Chile, although some studies were also undertaken there from the 1960s (J.A. Prado, personal communication, 2012). In Spain, most research on radiata pine has been recent. In New Zealand the effort was concentrated largely in the Forest Research Institute at Rotorua. In Australia it was spread between CSIRO and state government research groups, with cooperation facilitated by the Australian Forestry Council and its associated research working groups. In all countries, however, some individual field foresters and academics made important contributions.

The New Zealand experience is particularly instructive. After the Second World War a deliberate effort was made to expand forestry research, and new scientists were recruited. The focus was largely on radiata pine and the efforts were led by visionaries (Sutton, 1984; Kininmonth, 1997). Most aspects of silviculture and wood science came under scrutiny. By the 1960s there were teams of researchers in tree breeding, nurseries, establishment, the economics of silviculture, mensuration, soils and tree nutrition, pathology and entomology, and tree physiology. The researchers came from diverse backgrounds but significantly included a number who had their initial training and experience as foresters. Major advances were made in most fields, some of which were complemented by research going on elsewhere. The vision at this time was to develop a new silviculture that would lead to greater productivity and profitability. All the signals were that this was important to the industry, the government and society.

In essence what happened during the development phase, especially in New Zealand and Australia, was that radiata pine began to become domesticated. Before this, silviculture was based around seed from wild sources (i.e. unimproved) and the degree of management was largely limited to getting the trees to grow. Often, management objectives were poorly defined. But the development phase saw:

- intensive breeding programmes commenced;
- nursery techniques substantially improved;
- intensive field establishment methods developed and accepted;
- fertilizers introduced to correct serious deficiencies and also to improve growth in apparently healthy stands;
- disease control systems introduced;
- thinning and pruning schedules physically and economically evaluated and developed.

Other activities that affect silviculture were also undergoing improvement. These included mensuration and management models, hydrological aspects, harvesting systems and improvements in wood technology.

In the last decade we have passed beyond this development phase. There is now a major focus on ensuring the sustainability of pine radiata plantations – biologically, economically and socially. Research is ongoing into radiata pine silviculture, management and harvesting and end-uses, sometimes based on new technologies, in an effort to increase productivity and competitiveness (Table 1.1). At the same time, the planting surge that occurred in the latter part of the twentieth century has abated and it is unclear if there will be any further significant expansion of the radiata pine estate. The current period could be described as a "consolidation" phase.

If the new areas of research lead to a major change in the quality and growth rate of radiata pine, coupled with refined management and perhaps increased planting, radiata pine could be described as having a fully domesticated status. This has occurred with many food crops but has yet to be seen in forestry.

This book is largely based around these great leaps – the discovery, acceptance, development and consolidation phases – that have helped to revolutionize plantation forestry throughout the world.

DISTRIBUTION OF RADIATA PINE PLANTATIONS

Today there are over four million ha of planted pine radiata worldwide (Table 1.2, which also shows the main uses, by country), with the largest plantations in Chile and New Zealand (about 1.5 million ha each) and Australia (0.77 million ha). Between them, these three Southern Hemisphere countries account for over 90 percent of the world's radiata pine plantations. The species is also planted on a moderate scale in Spain (0.29 million ha) and South Africa (57 000 ha), and at a small scale in several other countries. The expansion of radiata pine forests has been rapid in the last half-century, there being only about 650 000 ha worldwide in the mid 1950s (based on Scott, 1960). In recent years, the area of radiata pine worldwide has remained static (Table 1.2), driven largely by poor returns (Manley and Maclaren, 2009).

New Zealand

Over 90 percent of plantations in New Zealand are privately owned, although growers generally do not own the land. The majority of radiata pine plantations are in the Central North Island wood-supply region, which accounts for 31 percent of total

TABLE 1.2
Estimated radiata pine plantation areas and the average annual change in area over the last five years, together with major uses by country

Country	Estimated area ('000 ha)	New area or loss ('000 ha/yr)	Main uses
Australia	773* (2010)	1.5*	Sawlogs, pulplogs, reconstituted, posts and poles, energy, shelter
Chile	1 478* (2009)	11.5*	Pulplogs, sawlogs, veneer, energy, erosion control
Ecuador	20* (1990)	ND	Erosion control, sawlogs, fungi; agroforestry
New Zealand	1 545* (2011)	-11*	log export, sawlogs, pulplogs, reconstituted, posts and poles, energy, shelter, erosion control
Italy	6** (2005)	0*	
Spain	287*** (2006)	ND	Sawlogs, mixed plantations, agroforestry
South Africa	57* (2008)	-2*	Sawlogs, veneer logs, posts and poles
Argentina	5.5* (2011)	0	
Other	35		
Total	4207	-1	

* Uses in-country data up to 2011; ** FAO (2006); *** MMAMRM (2006); estimate includes 61 000 ha of mixed species.

Note: The year of estimate is given in brackets. ND = no data

TABLE 1.3
Percentage of stands for radiata pine by tending schedules and age class for the whole of New Zealand and for the Central North Island Region (CNI) in 2011

Tending schedule	1–5 yrs	11–15 yrs	21–25 yrs	Central North Island Region, 1–5 yrs
Minimum*, no production thinning	61	38	27	51
Intensive**, no production thinning	31	47	54	29
Minimum* + production thinning	3	3	2	7
Intensive** + production thinning	5	12	17	12
% production thinned	8	15	19	19
% intensively tended**	36	59	71	41

* Minimum tending schedules will not be high pruned but may be thinned.

** Intensive tending schedules will be pruned to ≥4m and thinned.

Note: Percentages may not add up to 100 due to rounding.

Source: MAF, 2011

plantings, compared with 25 percent in the entire South Island (MAF, 2011). Most of this Central North Island resource is in the hands of ten large growers, who manage 80 percent of the plantation area. The total volume of radiata pine harvested in New Zealand doubled in the last 20 years, to 25 million m^3 in 2011. A large proportion (approximately 48 percent) of this harvest is exported in log or chip form or as processed products, primarily to Asia. About 45 percent of radiata pine products are used within New Zealand. In 2010, the forest industry produced 3.6 million m^3 of sawn timber, 1.5 million m^3 of panel products (43 percent as fibreboard) and 1.5 million tonnes of dry pulp. In recent years, older sawmills have struggled to remain profitable, and there has been a downturn in the pulp and paper industry. The Central North Island region processes about half of all logs in the country. Radiata pine is also used for posts and poles, energy, shelter and erosion control. Most of the industries are not fully vertically integrated – that is, they do not own the land and the forests that supply their industrial plants.

Four generalized radiata pine management practices are applied in New Zealand (Table 1.3). Minimum tending schedules, without high pruning, are often used on steeper country or low-quality sites, while intensive schedules are employed on easier and more fertile sites. Both the minimum and intensive tending schedules include thinning, but production thinning is relatively unusual. Table 1.3 provides data by selected age classes based on what has occurred or is planned in the case of stands in the 1–5 year age class. It is apparent that managers are moving away from intensive high pruning schedules and overall there will be less production thinning. In the Central North Island region, the area of plantation subject to production thinning has halved in the last 15 years (MAF, 2011).

Chile

In Chile, radiata pine forests are located largely between Valparaíso (Region V) and Puerto Montt (Region X), with the greatest concentrations in regions VII, VIII, IX and XIV. Region VIII (Bíobío) has 44 percent of the total radiata pine plantation estate and is the centre of the main pulp and paper industries. High rates of radiata pine planting in Chile began in the mid 1970s, but in recent years Region XIV (Los Rios) near Valdivia has been the focus of new planting and now contains about 10 percent of the resource. Most is owned by large, vertically integrated companies. In 2009, the total harvested volume was 35 million m^3, of which 56 percent was used as sawlogs, 35 percent was used for pulp and 8 percent was used for panel products (INFOR, 2010).

Unlike in New Zealand, less than 2 percent of the harvest, by volume, was exported unprocessed as logs or chips. A large part of Chilean manufactured production, however, is exported.

Most of the resource is managed for maximum volume production and includes production thinnings (Mead, 2010a). High pruning is often used to obtain clear veneer logs. Some stands are grown with less intensive management for pulp logs.

Australia

Radiata pine plantations in the states of New South Wales, Victoria, South Australia, Tasmania and Western Australia are concentrated around a number of wood-supply regions (Gavran and Parsons, 2011). The area of new plantings expanded rapidly between the 1960s and the 1990s, often led by state governments, after which the rate of expansion slowed (Table 1.2). Almost half the total area of radiata pine plantations is in the Murray Basin and Green Triangle wood-supply regions of Victoria and South Australia. The wood-supply regions of the Central Tablelands of New South Wales, Central Gippsland of Victoria, Western Australia and Tasmania each has between 7 and 11 percent of the resource area, for a total of 36 percent of the Australian resource. In recent years, the state governments of Victoria and Tasmania have sold their plantations and large parts of their estates are now owned or managed by companies.

Australia's total annual softwood log supply is 10.3 million m^3, most of which is radiata pine. The cut is expected to remain fairly stable in the medium term. The Green Triangle region (mainly in eastern South Australia) and the Murray Basin area each supply about 20 percent of these logs, while Western Australia, the Central Tablelands of New South Wales and Tasmania supply 7 percent each. The logs are used primarily to make structural lumber and pulp, with lesser quantities going to panel and treated roundwood. The industry is generally not vertically integrated, although there are exceptions.

Radiata pine stands are commonly grown with multiple production thinnings but are seldom pruned (see Chapter 9).

Spain

Of Spain's 287 000 ha of radiata pine, most is in the Basque region. Of this, 226 000 ha are in pure stands (MMAMRM, 2006). The annual production deriving from these trees is 1.5 million m^3 of sawlogs, amounting to 20 percent of the Spanish conifer cut.

RADIATA PINE IN THE GLOBAL CONTEXT

According to Evans (2009a), there are 271 million ha of planted forests worldwide, of which 141 million ha can be described as plantations. Almost 80 percent of plantations are grown primarily for wood production. One-quarter of planted forests employ introduced species, although in South America and Oceania the percentage is much higher (97 and 77 percent, respectively) (FAO, 2006).

While the 4.2 million ha of radiata pine plantations worldwide is a relatively small part of the total planted forest estate, radiata pine is the most productive and widely planted introduced conifer (Table 1.4; note, however, that some countries have considerably larger areas of native conifer plantations). Not shown in Table 1.4 are very large areas of various introduced broadleaf and palm species, such as a range of eucalypt species in South and Southeast Asia (4.0 million ha) and Brazil and Chile (3.7 million ha), rubber (10 million ha), coconut (11 million ha) and oil palm (6 million ha). In Brazil, hybrid eucalypts can have extremely fast growth rates of up to 70 m^3 per ha per year.

Table 1.4 shows that radiata pine mean annual increments (MAIs) range from 12 to 34 m^3 per ha per year for merchantable volume, but these country averages do not indicate upper limits to the growth rates of the species. In the New Zealand permanent sample plot data set, the single greatest MAI for total net volume was 52 m^3 per ha per year at age 24 (Shula, 1989). This was considered similar to the Australian experience. In a mapping study of radiata pine growth rates in New Zealand for trees planted after 1975 using the 300 index (total stem volume MAI for trees pruned to 6 m and having a final crop stocking of 300 stems per ha at age 30), the MAI ranged from 7 to 47 m^3 per ha per year with a mean, weighted by area, of 27 m^3 per ha per year (Palmer *et al.*, 2010). In this same study, site index (height at age 20) ranged from 13.5 m to 46.3 m, with a weighted mean of 30 m. On a fertile farm site in New Zealand, the periodic mean annual increment (PMAI) for radiata pine (between the ages of 11 and 21) was 54 m^3 per ha per year (Maclaren and Knowles, 1999) while Beets *et al.* (2011) reported a maximum PMAI (between the ages of 9 and 13 years) of 73 m^3 per ha per year, although the average was 47 m^3 per ha per year. Thus, the upper limit of MAI for radiata pine is about 50 m^3 per ha per year, although current annual increments and PMAIs can be higher.

Radiata pine also provides a very small proportion of the total industrial wood harvested worldwide. The estimated 60 million m^3 of logs harvested annually is only 3.3

TABLE 1.4
Growth rates, typical rotation lengths and areas of selected species used in large-scale plantations in selected countries

Species	Mean annual increment* (m^3/ha/yr)	Rotation (yrs)	Countries included	Total area (million ha)
*Pinus radiata***	14–34	18–28	Chile	4.2**
	16–21	25–30	Australia	
	17–20	25–32	New Zealand	
	12–16	28–35	South Africa	
	12–16	20–40	Italy	
	14–22	18–35	Spain**	
P. elliottii	12–18	25–35	Argentina/South Africa	3.1
	7–8	20–30	USA	
P. patula	12–18	35–35	South Africa	0.4
P. pinaster	5–14	40–70	France/Australia	1.0
P. sylvestris	2–5	63–87	Europe	9.0
P. taeda	14–17	21–29	Argentina/South Africa	11.3
	9–10	20–30	USA	
Acacia mangium	20–32	6–12	Southeast Asia	2.1
Cryptomeria japonica	8	40	Japan	5.0
Cunninghamia lanceolata	3–14	15–30	China	15.4
Eucalyptus globulus	16–25	10–27	Australia	0.4
E. grandis	21–27	21–22	Argentina/Australia/ South Africa	0.5
E. nitens	15–24	12–40	Australia	0.3
	22–28	7–9	South Africa	
Larix decidua	4–13	90–129	Europe	2.0
Picea abies	3–8	66–86	Europe	5.5
Picea sitchensis	2–8	43–67	Europe	0.8
Pseudotsuga menzesii	9–13	49–81	Europe/New Zealand/Chile	0.6
Tectona grandis	5–11	34–58	South and Southeast Asia/Sudan/Brazil	5.9

* Typical minimum and maximum values – extremes outside these ranges do occur.

** Area based on Table 1.2. Radiata pine growth rates taken from FAO, 2006, and for Spain from Fernández and Sarmiento, 2004, and Rodríguez *et al.*, 2002a. The upper growth rate for New Zealand is conservative (see text).

Source: adapted from FAO, 2006, although note that not all countries are in that report percent of the total world production from natural and plantation forests. However, for the countries that have large areas of radiata pine, it is a very important wood resource and the basis of significant industries.

As a plantation species, radiata pine has numerous economic and social benefits, although it is restricted to a definite ecological niche and has end-use limitations. As the following chapters will show, it is a valuable and versatile timber species, which is managed with a high degree of sophistication.