Trends in plantation management in New Zealand – past, present and future

John Moore

Abstract

New Zealand's radiata pine plantation industry has been underpinned by advances in silvicultural practices that have resulted in productivity gains and a greater certainty in outcomes. Significant advances have been made in tree improvement, stock production in nurseries, establishment practices, weed control and tending operations. Implementing the collective benefits of each of these components has made the development of New Zealand's radiata pine plantation industry a success story for global forestry. While the achievements of over a century of research, development and operational practice have built a strong legacy, there are many challenges and opportunities for future generations of silviculturalists and forest managers to address. These include climate change, increasing scrutiny of forestry practices and the rapid pace of technological change. This paper reviews some of the key developments in radiata pine silviculture and describes future challenges and opportunities.

The commercial forestry sector today

The commercial forestry sector in New Zealand is almost entirely based on radiata pine (*Pinus radiata*) (MPI, 2020). The development of a commercial forestry sector, which is a significant contributor to New Zealand's economy, from a species that was not of any commercial significance in its native range is a major success story for international forestry. It is no accident that radiata pine has become the cornerstone of the New Zealand forest industry. Its potential for use in widespread afforestation was recognised more than a century ago by the 1913 Royal Commission on Forestry (Anon, 1913; Goulding, 2013).

While the first radiata pine trees and stands planted in New Zealand were from unimproved seed and generally exhibited poor form, due to a combination of stem sinuosity and large branching (Burdon et al., 2017), almost a century of silvicultural and tree improvement research has resulted in significant improvements in productivity and quality. This research has generated new knowledge on how to manage this species, along with models and systems to support forest management (Goulding, 1994; Maclaren, 1995). Concurrently, there has been a strong research focus on determining the suitability of radiata pine for a range of different wood products, including appearance and structural lumber, panel products, engineered wood products and pulp and paper. The versatility of radiata pine has enabled it to be used in a wide range of applications (Cown, 1999; Kininmonth & Whitehouse, 1991).

This paper provides an overview of the development of radiata pine silviculture in New Zealand over the past century, but it is by no means an exhaustive coverage of the topic. Publications such as the *Radiata Pine*

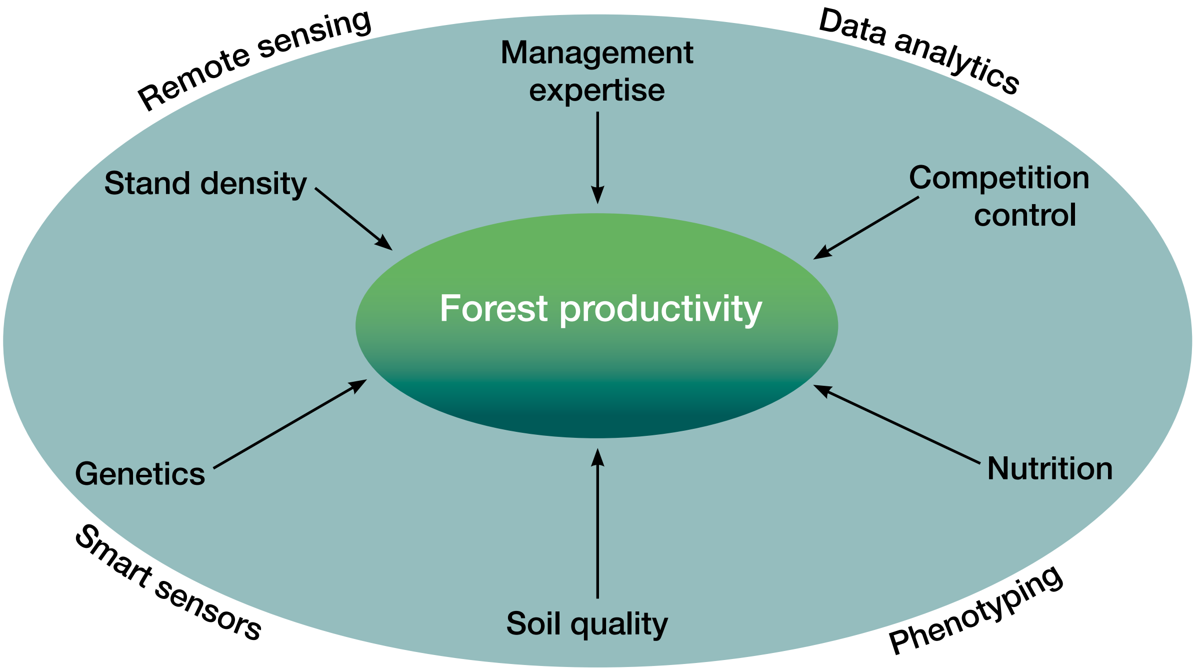

Figure 1: Key drivers of forest productivity (adapted from Fox, 2000)

Grower's Manual (Maclaren, 1995) and *The Sustainable Management of Pinus radiata Plantations* (Mead, 2013) contain more detailed information on the development of radiata pine silviculture up until now. The second half of the paper introduces some of the future challenges facing plantation silviculture, along with advances that could provide new opportunities.

Silviculture and its place in plantation management

Silviculture is the art and science of producing and tending a forest (Ashton & Kelty, 2017). It has traditionally focused on controlling forest establishment, composition, structure and growth. Given that biological productivity, along with prices, is a key driver on the financial performance of commercial forestry, much of the focus on radiata pine silviculture has been on increasing productivity through identifying and overcoming limiting factors.

Silvicultural practices (such as site preparation, planting genetically improved seedlings, control of competing vegetation, fertiliser application and manipulation of stand density) can be employed by forest managers to improve forest productivity (Fox, 2000) (Figure 1). Much of the focus of silvicultural research over the past century has been on each of these areas, along with developing the management expertise, tools and equipment necessary for the cost-effective implementation of solutions. The application of these practices has resulted in a substantial increase in plantation productivity, particularly on coastal sand sites with naturally low nutrient capital (Figure 2).

Key advances in radiata pine silviculture in the past century

Seedling production and nursery practices

Many of the first radiata pine plantations were established through direct seeding, but the low success rate of this practice resulted in it being phased out by the end of the 1920s. Plantation establishment practices quickly shifted to the production of seedlings in nurseries. The survival of these seedlings after planting out in the forest was typically around 60%, which necessitated higher planting densities (up to 3,000 seedlings/ha) to achieve acceptable final crop stocking levels. An intensive focus on improving nursery practices from the 1950s onwards resulted in out-planting survival rates well above 90%. This dramatically reduced plantation establishment costs through reducing initial planting densities and the need for blanking programmes.

Radiata pine stock is also produced via vegetative cuttings, either as bare-rooted stock or in containers. Current research efforts are focusing on improving the performance of these production systems. This includes techniques to:

- Improve the rooting of cuttings
- Investigating new systems for producing better containerised stock
- Trying to reduce the amount of fertiliser and fungicide used in the production of tree stocks without compromising quality and performance after out-planting.

Tree improvement

In little over a century radiata pine has gone from a 'wild type' to a domesticated species. Genetic improvement of radiata pine in New Zealand started in the 1950s when the first selection of trees with outstanding phenotypic performance ('plus trees') was made (Burdon, 2008; Carson, 1996). The longstanding goal of New Zealand's radiata pine tree breeding programme has been the production of large, fast-grown and well-formed logs. This gave rise to the growth and form (GF) rating system (Jayawickrama & Carson, 2000), which was later replaced by the GF Plus rating system developed by the Radiata Pine Breeding Company (www.rpbc.co.nz). The GF Plus system includes seedlot ratings for (diameter) growth, wood density, stem straightness, branch habit and improved resistance to Dothistroma needle blight.

Silviculturalists want to know how much additional value can be gained from deploying improved genetic material. They also want to be able incorporate genetic gain into growth and yield prediction systems that are used for regime analysis, scheduling tending operations and developing the yield tables that are used as inputs into forest estate models. Analysis of data from a national series of large plot genetic gain trials that were established between 1978 and 1994 showed that relative to a stand grown from an unimproved seedlot (GF Plus 9.9), a stand grown from a highly improved seedlot (GF Plus 25) had 25% more volume at age 30 years and would yield 33% greater stumpage value (Kimberley et al., 2015).

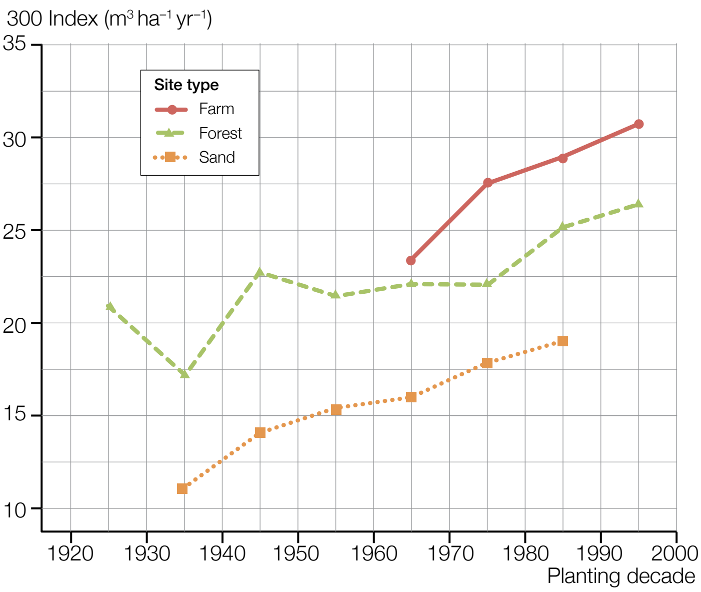

Figure 2: Change in radiata pine stand productivity over time (based on unpublished analysis from Mark Kimberley, Scion)

The other key development in radiata pine tree improvement has been varietal forestry, also known as clonal forestry. This is the commercial production and deployment of well-tested clones or varieties as distinct from simply using vegetative propagation techniques to bulk up improved families in traditional seedling-based forestry (Carson et al., 2015). There are several purported advantages of clonal forestry, including increased genetic gain relative to family forestry within the same generation. However, there are also several key perceived risks, which are mostly linked to concerns around the impact of reduced genetic diversity (Wu, 2019).

For clonal forestry, mosaics of small monoclonal blocks have been proposed as the best deployment option (DeBell & Harrington, 1993), and considered the most effective and efficient approach for operational-scale establishment of short-rotation plantations. The benefits of monoculture include greater uniformity in stem size and wood characteristics, which are important for operational considerations. Genetic diversity can be managed at the landscape level, with theoretical studies indicating that deploying between five and 30 unrelated clones across an estate provides similar risk mitigation to traditional family forestry. Kaingaroa Timberlands is currently the main practitioner of clonal forestry and they have increased deployment of production clones from 120,000 plants in 2008 to over 1.5 million in 2015.

Site preparation

There have been considerable changes in site preparation practices in the past 50–60 years, particularly with a greater awareness of the need to maintain nutrient pools, soil structure and to overcome impediments constraining root form and growth. Mechanical site preparation is used to ameliorate soil physical limitations at a site that may otherwise impede tree growth and to facilitate ease of planting on cutover sites. It is also crucial for achieving good survival after planting on frost-prone sites (Washbourn, 1978).

Earlier practices of root-raking and burning have given way to more precise forms of site preparation that have resulted in improved survival and early growth of radiata pine. Ripping was the first widely adopted method of site preparation for forestry in New Zealand that aimed to improve soil-site limitations. Initially, it was used only on landing sites, but by the mid-1970s it started to be used as a general site preparation technique (Chavasse & Brunsden, 1976). Ripping remained the most common type of mechanical soil cultivation in New Zealand through the 1990s, but then decreased as line-raking and spot-mounding became more popular (Coker & Jones, 2009). While most mechanical site preparation occurs on flat-to-rolling terrain, excavators capable of operating on steeper terrain mean that there is the ability to expand the treated area.

Thinning and pruning

There has been a large shift in thinning and pruning practices since the first large-scale plantations

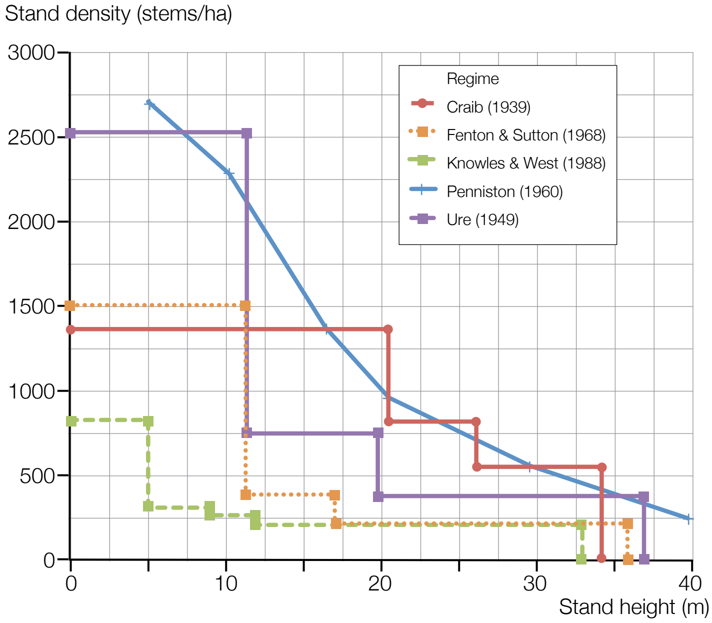

Figure 3: Thinning schedules for notable radiata pine silvicultural regimes

were established. Many of these early plantations were not thinned due to labour shortages and a lack of markets for logs from thinning operations (Sutton, 1976). Instead, self-thinning occurred, often accelerated by the sirex wood wasp (*Sirex noctilio*). This experience highlighted the importance of careful thinning to avoid stands being in an over-stocked state.

Some of the early thinning regimes were developed to manage the natural regeneration that occurred after harvest or a fire (Ure, 1949). These regimes involved a mixture of pre-commercial (waste) thinning and commercial (production) thinning to capture mortality before the next intervention (Figure 3). The regime was also applied to planted stands, with planting densities of 2,500 trees/ha adopted originally to counter poor survival and tree form.

Concerns by some over the challenges of implementing commercial thinning and the impact on stand value led to the development of the direct sawlog regime (Fenton, 1972; Fenton & Sutton, 1968). This involved a combination of heavy and early thinning, coupled with pruning to produce large pruned logs as rapidly as possible. The rationale for this regime was the predicted increase in global demand for high-quality finishing timber, low prices for knotty grades of radiata pine and the lack of silvicultural control of branch size. The direct sawlog regime with pruning was widely adopted in many forests throughout New Zealand, with the result that until relatively recently approximately 60% of New Zealand's radiata pine estate was grown under this regime (MPI, 2020).

The most recent change in practices has been the cessation of pruning, particularly by larger forest growers, and a return to unpruned regimes with a corresponding increase in stand densities. This has been driven by several factors, including:

- An increase in the cost of pruning

- A relatively small price differential between pruned logs and their unpruned equivalent
- The reduction in total yield that occurs when thinning to relatively low stand densities to grow large diameter pruned logs.

Modelling and end-of-rotation assessment of silvicultural trials show substantially higher returns from higher-stocked unpruned stands compared with lower-stocked pruned stands (Dash et al., 2019; Watt et al., 2017).

Future opportunities and challenges

It has been claimed that we mostly know everything there is to know about radiata pine silviculture and future efforts will only provide incremental gains. However, it is important to remember that past success is not a guarantee of future success. There are several potential disrupters that could have a significant impact on radiata pine forestry and these will require us to reconsider our silvicultural practices. There are also new technological advances that offer the potential to change these practices. Many of these advances will have far-reaching implications across many areas of society and are likely to be adopted and adapted for use by the forestry sector.

Regulation of the use of chemicals

Plantation forestry is highly dependent on chemical weed control for successful establishment and good early growth. There has been considerable scrutiny on the use of herbicides in forestry. Between 2007 and 2015, the widely used active ingredients terbuthylazine and hexazinone were placed on the Forest Stewardship Council's 'highly hazardous' pesticides list and could only be used in FSC-certified forests under a derogation (Rolando et al., 2016). These two active ingredients are no longer on FSC's 'highly hazardous' pesticides list, but picloram now is.

There is also increasing pressure on the use of glyphosate due to perceived concerns about its effect on human health. Research into alternative chemical and non-chemical control methods has highlighted how effective the current active ingredients are at controlling the range of weed species that are most problematic for plantation forestry in New Zealand (Rolando et al., 2016).

Figure 4: Mechanised planting in Kaingaroa Forest using the M-Planter. Photo courtesy of Ben Dixon, Timberlands

Mechanisation and automation

A key aspect of successful silviculture is the ability to execute. Currently, key silvicultural activities such as planting, thinning to waste and pruning are carried out using manual labour (Baker, 2018). Nursery operations are also heavily reliant on manual labour. Like many other primary industries, the forest industry has experienced labour shortages, which has impacted the ability to carry out key silvicultural activities.

There is the potential to overcome the challenges with labour availability and to increase productivity through mechanisation. An example of this is mechanised planting (see Figure 4) which is already being trialled operationally. While production thinning is far less common than waste thinning in New Zealand, these operations are mostly mechanised, and there is an opportunity to adapt some of this technology for use in waste thinning operations.

One of the key challenges will be carrying out mechanised operations on steeper terrain; mechanised production thinning operations are mostly done on flat-to-rolling terrain. There have been several prototypes developed for mechanised pruning devices and some pilot trials undertaken, but to date no operational trials have been undertaken. Two critical success factors for mechanised pruning will be quality and cost, the latter a key driver of the economics of pruned regimes.

Automation is the logical follow-on from mechanisation, particularly for situations where there are safety risks or where labour issues are most acute (Parker et al., 2016). To date, most of the focus of automation has been in harvesting, which includes the development of autonomous systems (see Figure 5) and the remote operation of existing systems. However, there is also potential for automation in nurseries, particularly those producing containerised stock. Naturally, greater introduction of automation will have an impact on those workers who currently undertake these manual tasks (Bayne & Parker, 2012), but will potentially create new employment opportunities centred around the design, manufacture and servicing of these automated systems.

Biotechnology

There are many developments in the field of biotechnology that can assist radiata pine silviculture, mostly through aiding tree improvement programmes. Somatic embryogenesis is already being used in varietal (clonal) forestry (Carson et al., 2015), while genomic selection is in the process of being developed (Li et al., 2015). This is expected to increase the accuracy of genetic evaluation and to enable these assessments to be made on much younger trees. As a result, the generation interval would be shortened, leading to more genetic gain per unit time.

Another biotechnology that has gained considerable attention is gene editing, which offers the potential to produce a step change in productivity, biosecurity and speed of innovation, especially for sectors such as forestry with slow breeding cycles (Fritsche et al., 2018). While gene editing has already been demonstrated for several crops that are relevant to other New Zealand primary industries, it is still to be implemented for conifer species in use in New Zealand forestry.

The subject of gene editing is a source of ongoing debate in New Zealand. Currently, gene editing is regulated the same as genetically modified organisms and can only be done under controlled conditions for research purposes. New Zealand's major trading partners are currently evaluating the regulatory status of these technologies and have not made definitive decisions (Fritsche et al., 2018). There is also uncertainty about whether gene editing technologies where no foreign DNA is introduced into trees would be accepted by certification bodies such as FSC and the Programme for the Endorsement of Forest Certification (PEFC).

Climate change

Climate change is potentially a significant disrupter to forestry in many parts of the world, including New Zealand. While there is uncertainty about the magnitude of future climate change and its impacts, modelling studies have indicated that while rising CO_2 levels may result in increasing productivity, rising temperatures are expected to result in an increase in the number of days of very high and extreme fire danger (Watt et al., 2019).

There could also be increased risk of wind damage and impacts from insect pests due to increased populations and host susceptibility. Silvicultural regimes will need to adapt to increase the resilience of forests to future climate change. This will include changes to breeding to identify genotypes better adapted to future conditions (Matallana-Ramirez et al., 2021), and reducing stand density and rotation age to reduce inter-tree competition and the length of time stands are exposed to risk (Shephard et al., 2021).

Biomass and bioenergy

Climate change also presents opportunities for forestry. The economic impacts of carbon credits on forestry land eligible for registration in the Emissions Trading Scheme are well known (Evison, 2008). With the price of carbon (NZUs) rapidly increasing, there has been an increase in carbon forestry in New Zealand. The focus of silviculture for these forests is on maximising the rate of biomass accumulation and then protecting the accumulated capital from losses due to wind, fire, insects and diseases.

Figure 5: Prototype autonomous harvesting system developed by Scion and the University of Canterbury. Photo courtesy of Richard Parker, Scion

Owners of pre-1990 forests are not eligible to receive carbon credits, but increasing prices for NZUs may provide opportunities to grow biomass energy crops that would provide the feedstock for products that displace fossil fuels such as coal and diesel. None of this is new and there was research done on this subject in the late 1970s and early 1980s in response to the oil shock (Madgwick, 1981). If prices for bioenergy feedstocks increase, then growing short-rotation biomass forests could become economically more attractive.

Data-driven management

Silviculturalists use data and models to aid decision-making. In the past decade there has been a rapid increase in the availability of data to support forest management (Dash et al., 2016; De Gouw et al., 2020). These include remotely sensed data such as LiDAR and satellite imagery. In parallel, there have been rapid developments in computer software and hardware that enable these larger and more complex datasets to be analysed and turned into usable information that can support forest management. An example is the application of machine learning to quantify the variation in productivity at the forest estate scale and the drivers of this variation (Bombrun et al., 2020).

This knowledge enables silvicultural regimes to be better matched to site characteristics within the forest estate (i.e. moving towards precision forestry). Machine learning can also be used to 'mine' large datasets such as inventory data or permanent sample plot data to quantify factors that affect yields, stand dynamics, etc (Moore & Lin, 2019). Another example is the use of deep learning to identify and classify features in remotely sensed images (see Figure 6). The information generated can be used to plan silvicultural operations and to provide more comprehensive quality assurance checks once operations have been carried out. This could include site preparation, post-planting survival, health and vigour, and thinning.

Conclusions

More than a century of research and operational practice has created New Zealand's radiata pine plantation estate and the industry it supports. Developments in radiata pine silviculture have improved the genetic worth of the trees that are planted, the quality of stock produced in nurseries and their early growth. This, along with the development of tending schedules, has improved the performance of radiata pine plantations. The challenge for future silviculturalists is to build on this legacy and to take full advantage of the new opportunities that are presenting themselves in order to address the future challenges that our industry will face. It is important to remember that what has made us successful in the past is not guaranteed to make us successful going forward.

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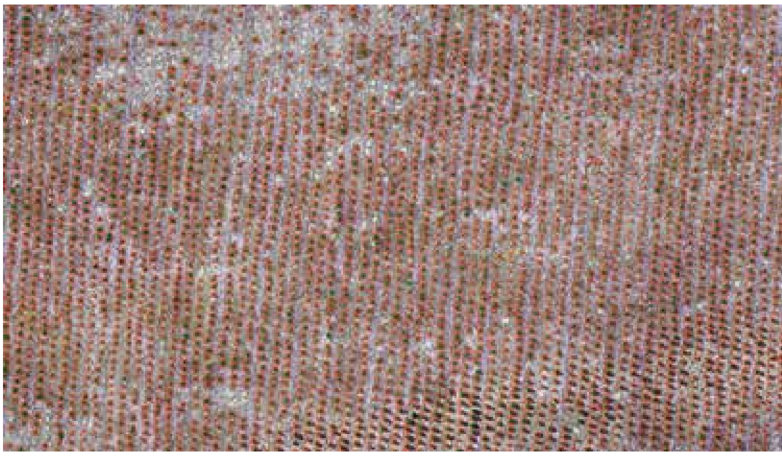

Figure 6: Example of automated detection of young radiata pine trees in Kaingaroa Forest using deep learning. Photo courtesy of Lien Pham, Timberlands

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John Moore is Research and Development Manager at Timberlands in Rotorua. Email: john.moore@tll.co.nz